Plotting Position for Low Flow Frequency Analysis at Jempol River Streamflow Station

IOP Conf. Series: Earth and Environmental Science 1140 (2023) 012021 doi:10.1088/1755-1315/1140/1/012021

Plotting Position for Low Flow Frequency Analysis at Jempol River Streamflow Station

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Abstract. Low flow frequency analysis is an important technique for calculating the probability of river flow availability during crucial low flow seasons, such as drought. It is also useful to predict the low flow information of a river in volume and frequency for future planning and construction of water resource projects since the low flow has a significant impact on water quality, water supply, and river sustainability conditions. Therefore, this study was performed to determine the low flow frequency analysis of the Jempol River streamflow station using Weibull and Gringorten plotting position formulas. The average recurrence interval (ARI) of 2-, 5-, 10-, 25-, 50-, and 100-year were determined based on 18 years of historical streamflow data. The study illustrates the annual minimum flow magnitude of 1-, 4-, 7-, and 30-day durations for the study area. It shows that the Gringorten formula tends to give higher estimation values up to 18% compared to the Weibull formula when the flow duration increase. Therefore, the outcome of this study could be used in the future for any project related to the low flow information of Jempol River.

1. Introduction

During monsoon seasons, certain areas in Malaysia, especially in the East Coast regions, experience flooding. However, the regions face drought events during the transitional period. This phenomenon could lead to severe disasters, and preventative measure is required to prevent these circumstances. According to [1], the drought season in most districts of Peninsular Malaysia usually occurs between June and August. The water intake from the river is critically dependent on the sufficiency of flow under drought conditions.

River flow during dry periods or seasons is generally called low flow. Flow statistics can be used to indicate the magnitude of the flow of a specific river location. The magnitude of low flow for the specified period will determine the amount of water available for consumers. In addition, low flow characteristics for continuous-record streamflow stations can be defined by using low flow frequency curves obtained from annual minimum flows. Low flow events are generally characterised by the average discharge calculated over a given period rather than by instantaneous flows. Therefore, the purpose of frequency analysis of an annual series is to obtain the relationship between the magnitude of the event and its probability of exceedance.

The exceedance probability of an event can be obtained using an empirical formula such as California, Hazen, Weibull, Chegodayev, Blom, and Gringorten, which are called plotting positions. As stated by [2], taking the calculated data of recurrence interval (T) for each event in the sequence, the variation of flow magnitude is plotted against the corresponding T on a semi-log paper or log-log paper. By utilising the extrapolation of this plot, the flow magnitude of a specific interval or duration for any average recurrence interval or ARI can be projected. As river flow information is very important for local authorities or agencies to regulate water supply and quality management, the results of flow statistical findings are commonly used as a benchmark or standard when establishing wastewater treatment plant effluent limits and acceptable pollutant loads to meet water quality guidelines [3].

Numerous studies have been carried out to estimate floods (high flows) of Malaysian rivers [4,5,6,7]. However, limited studies have been carried out on the estimation of low flow for rivers in Malaysia. Forecasting the low flow of a river in magnitude, as well as frequency, is essential for the planning and design of water resource systems as low flow significantly affects water supply, water quality, and river ecological condition. As a result, it is now acknowledged that there is a need to provide long-term baseline monitoring and analysis of low flow to support integrated river basin management.

The study of low flow characteristics in Malaysia is still at an early stage compared to other developed countries such as the United States, which is more advanced with appropriate equipment and applications to carry out the low flow analysis. Since the study of low flow characteristics is relatively important, efforts to develop an understanding of low flow in Malaysia should be taken significantly to ensure that local authorities have adequate information about the low flow condition.

A problem usually encountered in the design of water resources projects is determining the reliability of the water supply. Frequent low flow periods, especially during the drier months, have also created severe water quality problems in river basins and caused undue stresses to the fauna and flora communities in the riparian waters. Additionally, according to [8], about twenty-eight (28) water treatment plants in Pahang state recorded low levels due to drought, which had affected the ability of the water treatment plants to receive water from the Pahang River.

Low flow is a critical element to meet demands, often competing uses and requirements since most states are experiencing population growth, resource depletion, and the over extraction of water. The economic loss during low flow periods can be much bigger than during floods [9]. Furthermore, the most adverse conditions for water pollution control in rivers occur during drought seasons. Low flow is vital to predict the demand for water needed during critical low flow periods because people will know when to be prepared. Information on the magnitude and frequency of low flow events is needed to plan water supply systems, wastewater discharges, reservoirs, and irrigation schemes, as well as preserve water quality for flora and fauna [10]. Adequate information on low flow characteristics will probably be useful for other researchers and local authorities in the future planning of river basins.

The current study analyses and discusses the results of statistical distribution for different durations and ARIs, which ranged between 1 and 30 days and between 1- and 100-year ARI, respectively, for Jempol River streamflow station using Weibull and Gringorten plotting formulas.

2. Methodology

In Malaysia, the estimation of low flow frequency for gauged sites is analysed using Hydrological Procedure No. 12 [11]. The results of the analysis can be used to design water intakes, reservoirs, irrigation systems, water supply systems, hydroelectric power generation schemes, and water quality management. In low flow frequency analysis, the aim is to develop a frequency curve for low flows of a specified duration. The frequency curve is derived by fitting a theoretical frequency distribution of low flows using either graphical or analytical means.

The recorded stream flow data from Jempol River station, operated by the Department of Irrigation and Drainage (DID) Malaysia, were used in this study to compute flow statistics. All data were taken every 15 minutes between 1990 and 2020. For missing data consideration, only annual series data with not more than 20 per cent of missing data were included for further analysis. Therefore, only 18 years of daily flow data were used for the analysis of the current study for detailed statistical analysis purposes. Theoretically, a low flow statistic can be analysed using daily mean flow data to determine the magnitude and frequency of low flow events.

Flow data were collected at an ongoing streamflow gauging station at Jempol River station. The data used to compute flow statistics was based on the recorded flow data operated by DID. All data were taken from 1990 to 2020. However, there were missing data due to flood events or equipment errors. From this streamflow data, the low flow analysis was performed based on the daily mean flow by calculating the average data to determine the magnitude and frequency of low flow events.

2.1. Description of the study area

Jempol River is the first tributary of the Pahang River, which is in the district of Maran. The study was carried out at Jempol River streamflow station (ID No. 3626401) in Rancangan Felda Jengka. This station was opened by DID in January 1979. It has a flow contributed area of 279 km^2 with 28 km of river length. The coordinate for the station is 3° 38’ 39’’ N, 102° 40’ 6’’ E, as shown in figure 1.

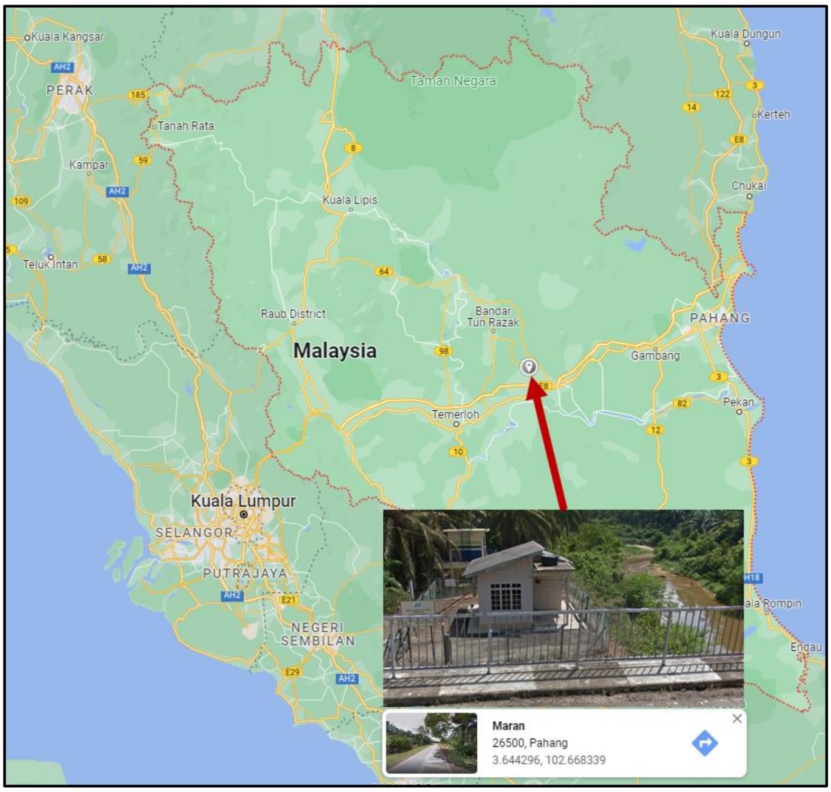

Figure 1. Location of Jempol River streamflow station

2.2. Statistical analysis

Generally, hydrological data can be analysed using a statistical method based on frequency analysis such as statistical distribution. Frequency analysis is related to the magnitude of extreme events (flood or low flow) to their frequency of occurrence using the probability of distribution.

For this study, all streamflow data were analysed using Weibull and Gringorten plotting position formulas to develop low flow frequency curves. The collected streamflow data was required to obtain the calculation of the annual minimum flow through the moving average method for durations of 1 day, 4 days, 7 days, and 30 days. There were missing data that should be of concern due to flood events or equipment errors. The percentage of missing data for each year was set at less than 20 per cent, especially during dry months. The flow data were arranged in an increasing order of magnitude and a ‘rank’ or i value was assigned for each flow, beginning with 1, and increasing sequentially. In the next step, the N flows were tabulated in ascending order and a rank i was assigned to them. Then, the recurrence intervals were calculated using the following plotting position formulas:

Weibull formula as equation (1):

$$T = \frac{N + 1}{i} \tag{1}$$

Gringorten formula as equation (2):

$$T = \frac{N + 0.12}{i - 0.44} \tag{2}$$

Where

- T = plotting position of an annual low flow, in the year of ARI
- N = length of records in years
- i = rank of the annual low flow in the series

Both plotting position formulas are recommended by [11] for the calculation of the frequency analysis of individual stations. In order to produce a low flow curve, the flow values for the time period of interest were first ranked by magnitude. Then, a graph was plotted with years against flow values, and it reflected the flow characteristics of a river throughout the range of discharge.

3. Result and discussion

Low flow frequency analysis, as defined in this study, is the annual minimum daily of flow values averaged over designated periods. Series of annual minimum for 1-, 4-, 7- and 30-day low flow trends from 1990 to 2020 were selected in the study, as shown in figure 2(a), (b), (c) and (d). It can be observed from the figure that all series show the lowest flow in 2016 and the highest flow in 2002 for 30-day period, 2003 for 1- and 4-day periods, and 2004 for 7-day period. For example, for 1-day low flow period, the lowest flow was 0.103 m^3/s in 2016 and the highest flow was 6.424 m^3/s in 2003. Meanwhile, for 30-day period, the highest flow rate was 7.728 m^3/s in 2002, while the lowest flow rate was 0.437 m^3/s in 2016. It shows that the minimum flow during this period was significantly higher compared to other periods (short duration) of low flow.

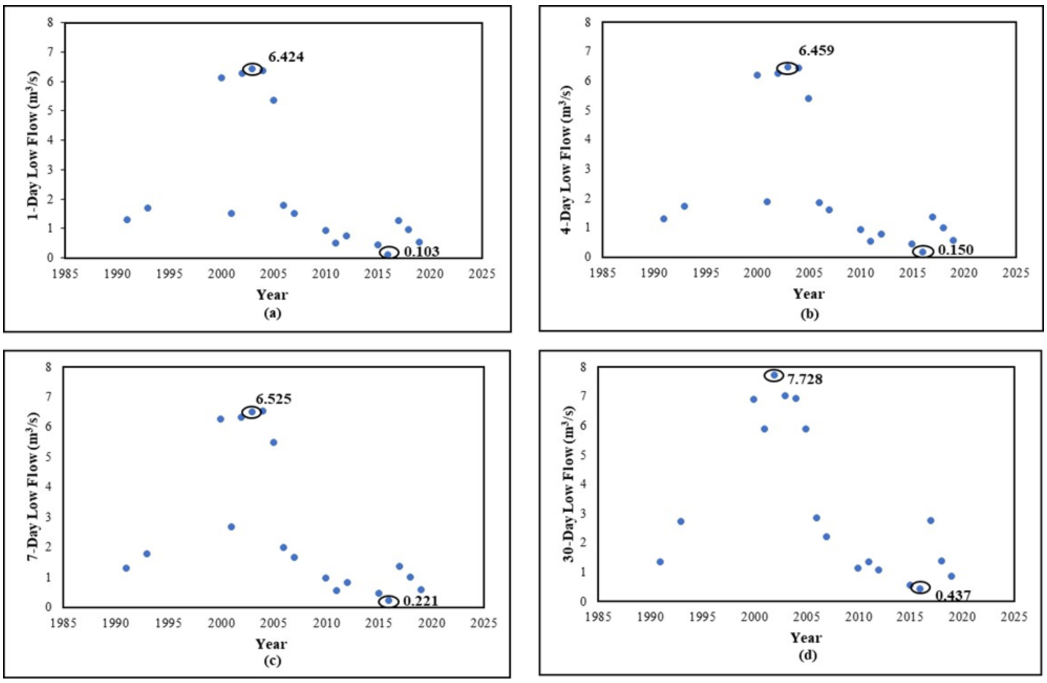

Figure 2. Series of annual minimum (a) 1-day, (b) 4-day, (c) 7-day, and (d) 30-day low flow

3.1. The annual 1-, 4-, 7- and 30-day low flow frequency curves

Low flow characteristics can be defined by continuous-record streamflow stations using low flow frequency curves obtained from the previous data on annual minimum flows. From the graph in figure 2, the results for the river gauging data were analysed to find out the trend of low flow frequencies from 1990 until 2020 in the Jempol River. According to [11], the Weibull formula is suitable for a record length of less than 20 years, while the Gringorten formula is fit for a record length greater than 20 years. However, the estimation of low flow discharges in this study used both formulas for the Jempol River to confirm the performance of both formulas. The trend can be seen in the plotted graph, which used both plotting formulas in figures 3 and 4. Basically, for design purposes, based on the selected return period, low flow information can be obtained from these curves.

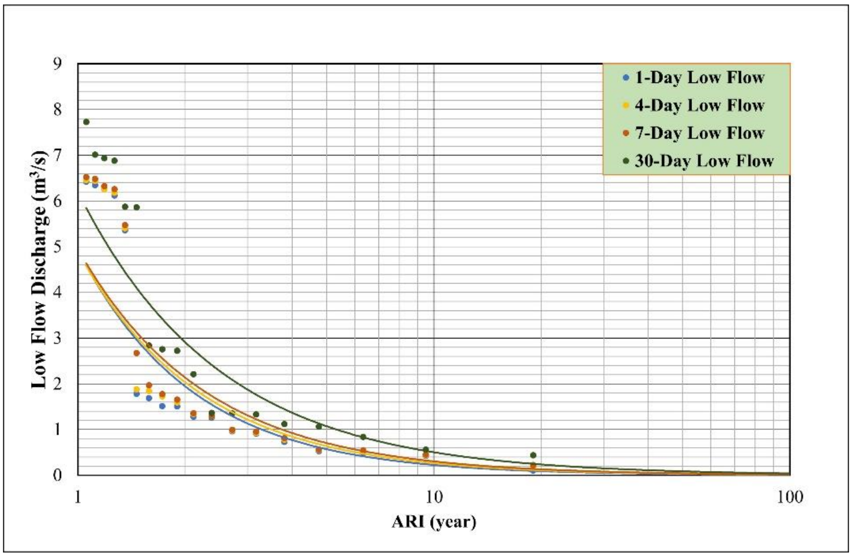

Figure 3. Weibull frequency curves

Figure 3 shows the frequency curves derived individually from durations of 1-, 4-, 7- and 30-day. The curves are represented using the Weibull plotting position formula. The results showed that the 1-day low flow curve was the lowest, while 30-day low flow curve was the highest compared to other durations.

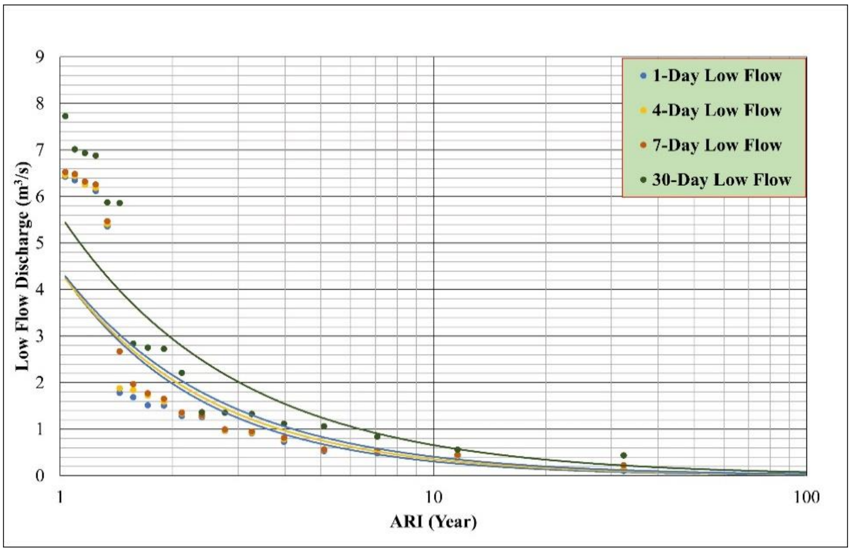

Figure 4. Gringorten frequency curves

Figure 4 shows the frequency curves derived by constraining the Gringorten plotting position. The advantage of this plotting low flow duration-frequency curve is that the low flow value of any given ARI can be estimated. The data from these curves could offer important information about future water quality and quantity management, especially in the river basin. For example, the longer durations of low flow with over 30 days are important for water supply applications. Meanwhile for short durations of low flow between 1 to 10 days are applicable for water quality problems.

Table 1. The magnitude of low flow for different durations and ARIs

Average Recurrence Interval (year)	Low Flow (m^3/s)							
	Weibull Formula				Gringorten Formula			
	1-Day	4-Day	7-Day	30-Day	1-Day	4-Day	7-Day	30-Day
2	1.948	2.035	2.139	2.914	1.976	2.062	2.162	2.938
5	0.571	0.637	0.705	1.073	0.685	0.760	0.837	1.253
10	0.225	0.264	0.305	0.504	0.307	0.357	0.409	0.658
25	0.066	0.083	0.100	0.186	0.107	0.132	0.158	0.281
50	0.026	0.034	0.043	0.087	0.048	0.062	0.077	0.147
100	0.010	0.014	0.019	0.041	0.021	0.029	0.038	0.077

The magnitude of low flow with ARI of 2-, 5-, 10-, 25-, 50-, and 100-year were calculated using the graphical method for 1-, 4-, 7-, and 30-day duration, as tabulated in table 1. It is noticed that the estimated discharges show small differences in the results obtained by both formulas. From the observation for all ARIs, the estimated values show an increase from the 1 to 30-day duration. It also reveals that the Gringorten formula tends to give higher estimation values compared to the Weibull formula when the flow duration increase.

4. Conclusion

In conclusion, the selected methods to analyse the frequency of low flow for the Jempol River were successfully discussed. The study represents the methodology and analysis of low flow frequency for gauged streamflow stations. Based on the results, the prediction magnitude of low flow for different series durations in the Jempol River streamflow station were successful using Weibull and Gringorten plotting position formulas. The results from both formulas clearly show significant differences up to 18 per cent in terms of plotting formulas to obtain the different values of ARI and flow duration.

In addition, the use of the Weibull plotting position is more appropriate because the record length in this study was less than 20 years. Thus, the graph was plotted with years against flow values to reflect the flow characteristics of a river throughout the range of discharge. The method described in this study could be developed and applied for a wide range of practical problems where it is necessary to maintain consistency between different durations but related frequency curves. Finally, low flow information is important for humans and the ecosystem. For humans, a shortage of streamflow will lead to insufficient water supply, while it can lead to insufficient environmental flows to sustain aquatic life for the ecosystem.

5. References

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Acknowledgments
Authors would like to acknowledge the financial support provided by the Universiti Malaysia Pahang through the Fundamental Research Grant No. RDU220320. This study is also supported by the Department of Irrigation and Drainage (DID) Malaysia for the streamflow data.