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Low Flow Frequency Analysis at Triang River Streamflow Station

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Abstract. Low flow analysis is essential for determining the communities' water supply. As water supply is a necessity for human daily survival, it is crucial to recognize that the availability of water can have a significant impact on local livelihoods and the sustainability of local populations. Triang River is a tributary of the Pahang River in Peninsular Malaysia. The existence of the Triang Water Intake and Treatment Plant along the Triang River stream serves to determine the low flow magnitudes and frequency curves for the Triang River streamflow station using the Weibull, Gringorten, and Cunnane plotting position formulas. Based on 20 years of historical data, this study analyzed the annual minimum streamflow data for 1-, 4-, 7-, and 30-day durations as well as the average recurrence intervals (ARIs) of 2-, 5-, 10-, 20-, 50-, and 100-year streamflow data. These three plotting position formulas were successfully used to estimate the low flow magnitudes for the various durations and different ARIs. The findings can serve as a guide for developing future water resource projects that take into account the Triang River's low flow data.

1. Introduction

Numerous hydrological systems are significantly impacted by climate change, which raises the risk of regional water hazards including floods and droughts [1]. Water resources in different countries may be impacted by regional and local variations in climate and weather [2]. For instance, a severe drought brought on by the 1997–1998 El Nino event caused water deficit across several Malaysian regions. This occurrence shows that Malaysia's water strategy is insufficient and must be revised to take changing weather patterns into account. Furthermore, the effects of climate change have prompted frequent water shortages. The effects of climate change on river flows can range from droughts and low flow to flooding caused by excess water [3].

Low flow, as used in hydrology, is the amount of water moving through a stream during a prolonged period of dry weather [4]. It is a regular occurrence and stands as a crucial part to the flow pattern of any river. The use of flow data enables the estimation of the amount of flow at a specific river position.

Pahang is a state located on the East Coast of Peninsular Malaysia that experiences heavy precipitation of rainfall during the monsoon season from November up until February [5]. After that, February is said to be the driest month of the year while May is the hottest. Within these months, extreme weather conditions may occur and can lead to a drastic change in the rivers [6].

Hence, preventative analysis and inspection is done to combat the potential of long droughts due to climate conditions. When issues concerning water supply and demand arise, evaluation of low flow data might illustrate potential water availability in streams. When the source of water originates from an uncontrolled ecological river, the availability of water is dependent on the low flow properties. Therefore, the present analysis will assist other researchers in selecting the ideal time to conduct water quality sampling.

1.1 Literature review

Plotting position is an empirical distribution that is premised on a random sample taken from a probability distribution and it is obtained by plotting the exceedance probability of the sample distribution against the sample value [7]. There are seven plotting positions (Hazen, Weibull, Blom, Cunnane, California, Gringorten, and Chegodajev) that can be used in determining the probabilities of exceedance [8]. Plotting positions also permit a visual examination of the appropriateness of the probability distribution that is determined by frequency analysis of the provided data. Conversely, the method of graphic representation that involves plotting position has been utilized in numerous subfields of hydrology and the planning of water resources [9].

Among the distribution functions frequently referred to in the literature in connection with low flows are different forms of Weibull, Gumbel, Pearson Type III, and Log-normal distributions. Many studies have examined the most suitable probability distributions for fitting the sequences of annual minimum flows in different regions and for the minima of deferent averaging intervals and evaluated methods in the estimation of distribution parameters [10]. A study conducted by [11] in 2000 combined historical discharge data with theoretical frequency distributions, such as Log-normal, Weibull, and Extreme Value Type 1 distributions with the Gringorten plotting position.

To date, more than ten plotting position formulas have appeared in the literature. [12] and [13] published a comprehensive review of the existing plotting formula and postulated that a plotting formula should be unbiased and have the smallest mean square error among all estimates. Their review further revealed that the Weibull formula is more flexible and provides more accurate results, but it requires more assumptions and expertise to use. On the other hand, the Gringorten formula is simpler and easier to use, but it has limited accuracy and is not as flexible as Weibull [14].

The discussion thus far suggests that each of these plotting position formulas has its own advantages and disadvantages and that the choice of formula will depend on the characteristics of the data and the goals of the analysis. This study used the Weibull, Gringorten, and Cunnane plotting formulas to examine and explain the statistical distribution results of low flow analysis for different durations and ARIs, which spanned from 1 to 30 days and between 1 and 100 years, respectively, for the Triang River streamflow station. A comparison of low flow magnitudes between the results of this study and Hydrological Procedure No. 12 (Revised and Updated 2015) (HP No. 12) by [15] would also be investigated.

2. Methodology

In Peninsular Malaysia, HP No. 12 is commonly utilized to calculate low flow magnitudes. Hydrological Procedures are a technical guideline design published by the Department of Irrigation and Drainage (DID) Malaysia to assist stakeholders towards achieving sustainable water resources management in Malaysia. It is an updated and revised version of Hydrological Procedure No. 12, "Magnitude and Frequency of Low Flows in Peninsular Malaysia," which was first published in 1976 and later updated and revised in 1985 by [16]. Designing water intakes, reservoirs, irrigation systems, water supply systems, hydroelectric power generation plans, and water quality management can be done using the findings of this study. The goal of low flow frequency analysis is to create a frequency curve for low flows that last a certain duration. The frequency curve is created by mathematical or graphical methods of fitting a theoretical frequency distribution of low flows.

In this analysis, streamflow data with 15-minute intervals was collected from 1990 until 2020 at the Triang River station managed by DID. When missing data was taken into consideration, the analysis only comprised annual minimum series data with no more than 20% missing data. Therefore, only 19 years' worth of daily flow data was relevant for the subsequent analysis. Theoretically, the size and frequency of low flow episodes can be determined by examining a low flow statistic using daily mean flow data.

2.1. Description of the study area

This study was conducted at the Triang River streamflow station within the Bera district of Pahang. It is a connected tributary of the Pahang River that spans across 40 km in length with a catchment area of 2000 km^2. Figure 1 depicts a water treatment facility and a water intake along the Triang River, which demonstrates the existence of a water supply and demand balance in the study area and the surrounding neighborhood. *Sg. Triang di Jam. Keretapi* (ID No. 3224433) is the station designation given by DID to the streamflow station of the Triang River. The streamflow station's latitude and longitude are 3° 14' 30'' North and 102° 24' 45'' East, respectively.

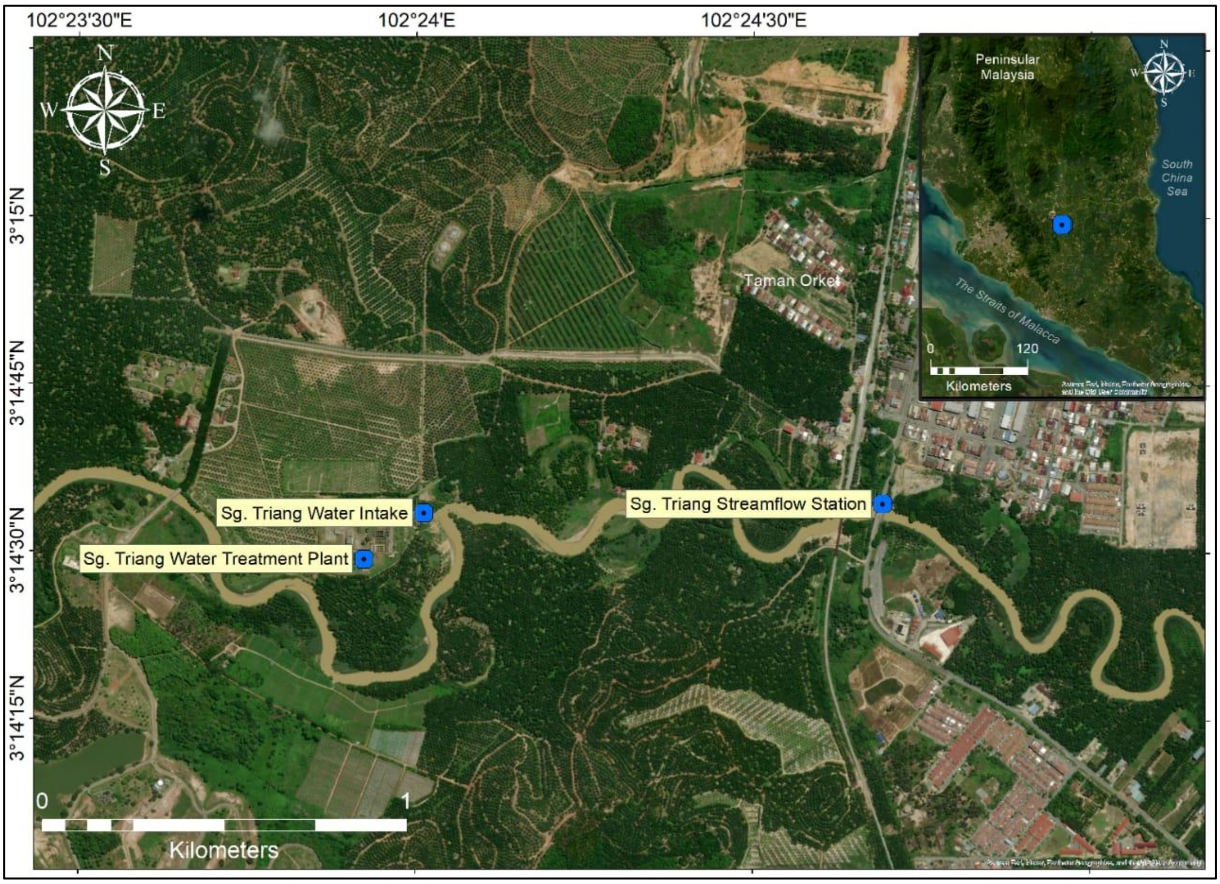

Figure 1. Location map of the study area.

2.2. Plotting position

Generally, simple empirical techniques, such as plotting position approaches, imply a relationship between the low flow discharge and its Average Recurrence Intervals (ARIs). The Weibull, Gringorten, and Cunanne plotting position formulas were used to analyze all streamflow data for this study in order to produce low flow frequency curves. The streamflow measurements were necessary to calculate the annual minimum flow using the moving average method for the durations of 1 day, 4 days, 7 days, or 30 days.

It should be noted that several missing data might raise prominent concerns due to equipment errors or natural disasters like floods. Therefore, the percentage of missing data for each year must be less than 20%, particularly in dry months. The flow data was sorted in the ascending order of magnitude and a "rank" or i value—starting at 1 and increasing sequentially—was assigned for each flow. The *N* flows were later recorded in ascending order and given a rank *i*. Then, using equation (1), the following plotting position formulas were used to calculate the recurrence intervals:

Weibull formula:

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

Gringorten formula as equation (2):

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

Cunnane formula as equation (3):

(3)

Where;

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

These plotting position formulas in equations (1) and (2) were recommended by [16] for the frequency analysis of low flow frequency. Meanwhile, the plotting position in equation (3) served as another appropriate formula to be used as it provides accurate results and is less sensitive to outliers and skewness than other methods [9]. Then, a graph reflecting the flow characteristics of a river across the range of discharge was plotted with low flow discharge against ARI in year.

2.3. Comparison with Hydrological Procedure No. 12

For the ARIs of 2 to 50 years, HP No. 12 provides low flow frequency estimates for the time periods of 1 day to 30 days. Low flow estimations are based on denser data networks with a longer record period and the use of regional frequency analysis via the L-moment approach for choosing and parameterizing probability distributions. HP No. 12 divides Peninsular Malaysia into nine regions, each having its own growth factors to apply in the calculation of low flow magnitudes. The procedure also published the formula to estimate low flow discharge for 1-, 4-, 7-, and 30-day.

3. Results and discussion

Annual minimum daily flow values for 19 years were used in this study. Figures 2(a), (b), (c), and (d) show the annual minimum data for 1-day, 4-day, 7-day, and 30-day, respectively. It can be seen that the largest flow for all series occurs in the year 2000 and the lowest flow varies depending on the period. For instance, for a 1-day low flow, the lowest flow was 0.498 m^3/s in 1994 and the maximum flow was 18.269 m^3/s in 2000. The lowest minimum flow rate for a 30-day period was 3.68 m^3/s in 2018 while the highest minimum flow rate for that period was 18.269 m^3/s in 2000. This demonstrates that the minimum flow during this period is noticeably higher than during a short duration low flow period.

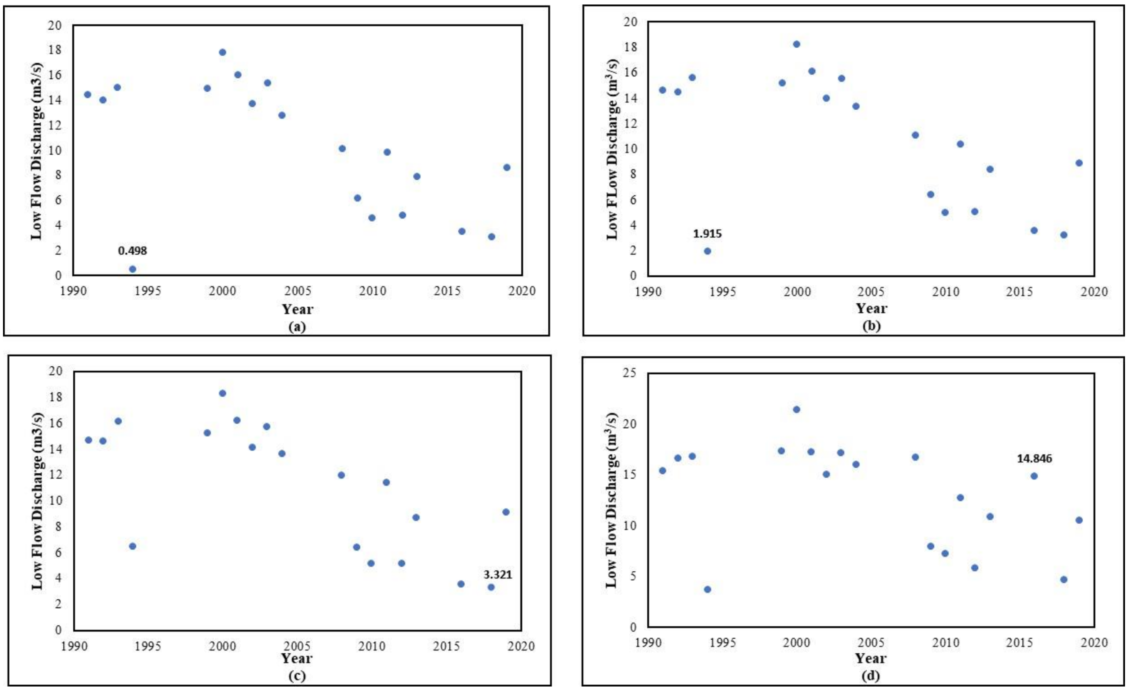

Figure 2. Series of annual minimum (a) 1-day, (b) 4-day, (c) 7-day, and (d) 30-day low flow.

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

Low flow frequency curves derived from the historical data of annual minimum flows can be used to determine the low flow magnitudes of continuous-record streamflow stations for different ARIs. All findings from the river gauging data were examined using the graph to discover the pattern of low flow frequencies for 19 years. The trend in the drawn graph can be seen in figures 3, 4, and 5. Essentially, these curves can be used to generate low flow information for design purposes based on the chosen ARI.

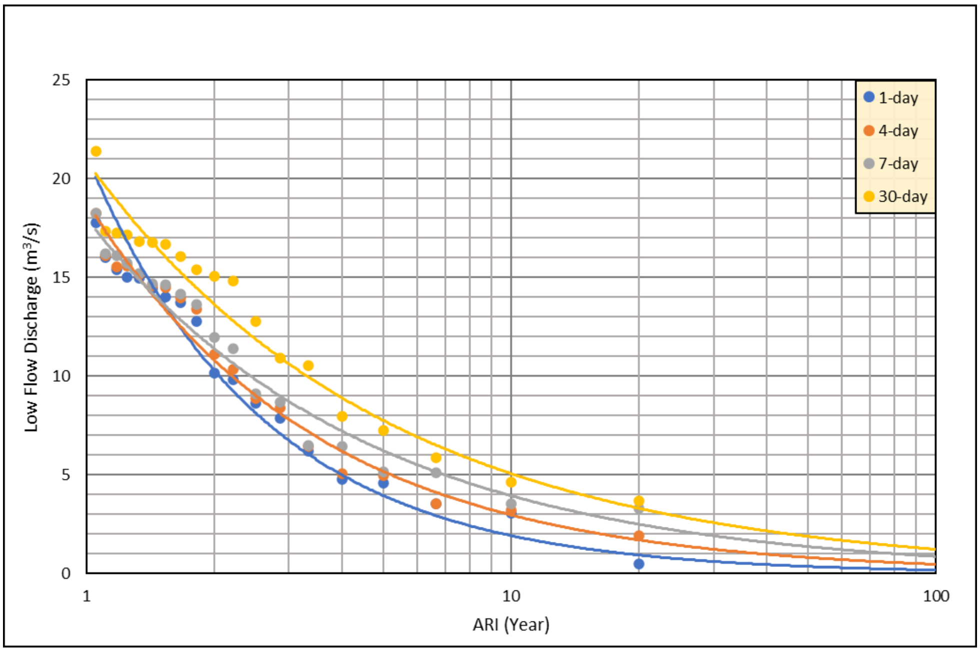

Figure 3. Weibull frequency curves.

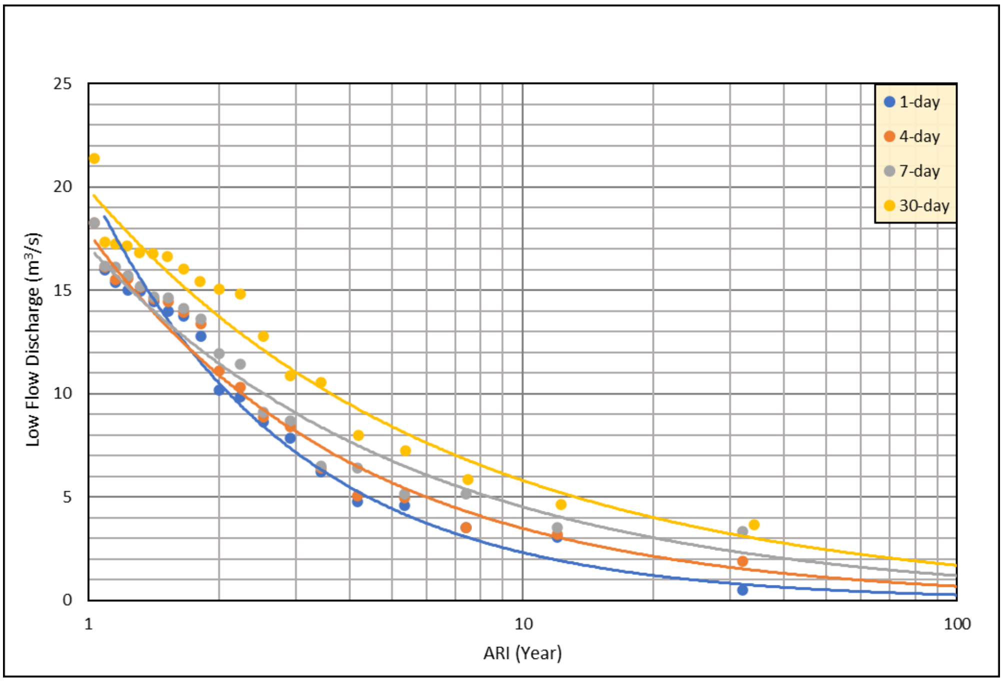

Figure 4. Gringorten frequency curves.

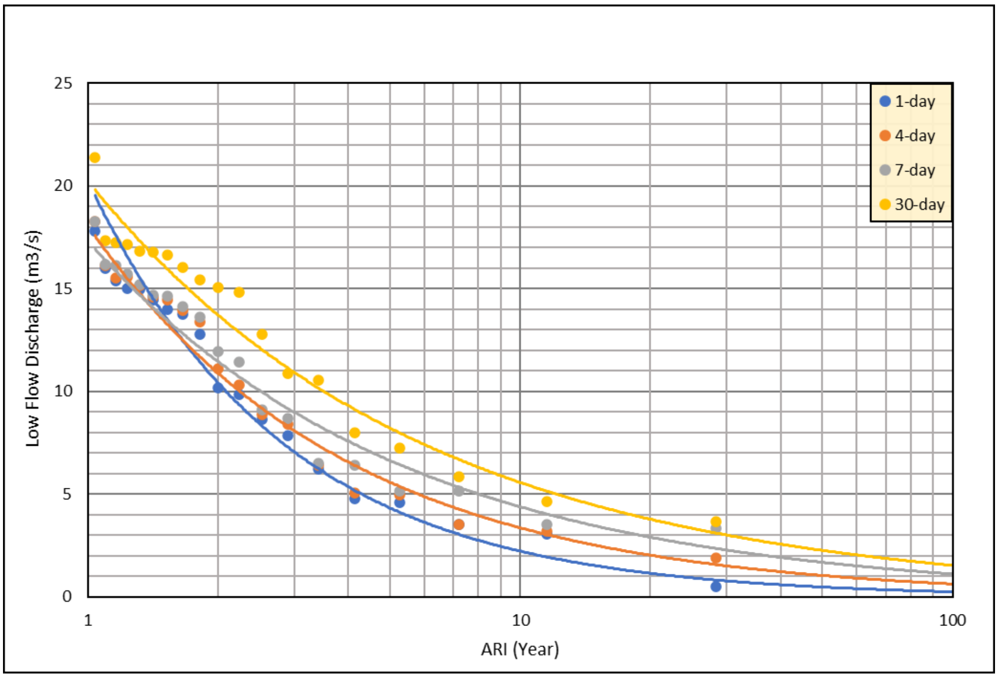

Figure 5. Cunnane frequency curves.

The frequency curves for various 1-, 4-, 7-, and 30-day durations are shown in figures 3, 4, and 5. The Weibull, Gringorten, and Cunnane plotting position formulas were used to represent the curves. The data revealed that the 1-day low flow curve had the lowest value in comparison to other durations. Conversely, the 30-day low flow curve had the highest average. The information from these curves can be useful for predicting future water quality and quantity, particularly for managing water supplies.

Table 1. Low flow discharge magnitude for different durations and ARIs.

Average Recurrence Interval (year)	Low Flow Discharge (m^3/s)											
	Weibull Formula				Gringorten Formula				Cunnane Formula			
	1-Day	4-Day	7-Day	30-Day	1-Day	4-Day	7-Day	30-Day	1-Day	4-Day	7-Day	30-Day
2	10.293	10.818	11.403	13.641	10.528	10.912	11.471	13.739	10.447	10.905	11.463	13.736
5	3.958	5.183	6.234	7.758	4.503	5.761	6.817	8.415	4.439	5.700	6.750	8.352
10	1.921	2.971	3.948	5.062	2.368	3.554	4.598	5.808	2.324	3.489	4.522	5.732
20	0.932	1.703	2.500	3.303	1.246	2.192	3.102	4.008	1.216	2.136	3.029	3.934
50	0.358	0.816	1.367	1.878	0.533	1.158	1.843	2.455	0.517	1.117	1.784	2.392
100	0.174	0.468	0.866	1.225	0.280	0.714	1.243	1.694	0.270	0.683	1.195	1.642

The magnitude of low flow with the ARIs of 2-, 5-, 10-, 20-, 50-, and 100-year was calculated using the graphical method for 1-, 4-, 7-, and 30-day duration. Based on the results in table 1, the estimated discharges displayed slight variations in the magnitudes of the three formulas. When the ARI and flow duration increase, the Weibull formula frequently provides lower estimation values than the Gringorten and Cunnane formulas.

Table 2. Low flow discharge magnitude for different durations and ARIs calculated from HP No. 12.

Average Recurrence Interval (year)	Low Flow Discharge (m^3/s)			
	Hydrological Procedure No. 4			
	1-Day	4-Day	7-Day	30-Day
2	9.712	10.455	11.034	13.951
5	6.137	6.606	6.973	8.815
10	4.528	4.875	5.145	6.505
20	3.297	3.549	3.746	4.736
50	2.006	2.159	2.279	2.881

Table 2 displays the low flow discharge's magnitude as determined by the HP No. 12 formula. Only the discharge calculation up to a 50-year ARI is available for HP No. 12. When the ARI grows larger, the discharges decrease; when the durations increase, the discharges increase.

3.2. Comparison of low flow magnitude

This study compared the outcomes computed using the plotting formula and HP No. 12. Small percentage differences were found between 2- and 5-year ARI, ranging from 1.5% to 27.7% for Cunnane, 1.5% to 26.6% for Gringorten, and 2.2% to 35.5% for Weibull.

Furthermore, the proportion of difference for short durations (1-day) increased as the ARI grew greater (50-year ARI). For Weibull, the number was 82.1%, whereas it was almost 74% for Cunnane and Gringorten. As a result, none of the three plotting formulas could be used to estimate low flow discharge for ARIs equal to and greater than 20-year ARI and 1-day duration because the percentage of differences exceeded 50%. In contrast, the percentage differences for other durations and ARIs were considerable.

The use of the most recent streamflow data in this study, as opposed to HP No. 12, had an influence over the findings. In contrast to HP No. 12, which used regional growth factor, this analysis used a specific station in low flow discharge estimation. These factors have some impacts when comparing the outcomes.

4. Conclusion

The present study serves as an example of low flow frequency analysis for the gauged streamflow station. The findings demonstrate that the Weibull, Gringorten, and Cunnane plotting position formulas were successfully used to estimate the low flow magnitudes across various durations at the Triang River streamflow station. While the Weibull formula had significant differences than the Gringorten and Cunnane formulas in terms of low duration such as 1-day in higher ARI, results from the Gringorten and Cunnane formulas clearly showed slight significant differences up to only 4% in terms of plotting formula to obtain the different values of ARI and flow duration.

Further comparison of the results with HP No. 12 revealed that none of the three plotting equations can be used to predict low flow discharge for ARIs equal to and bigger than 20 years and 1-day intervals. On the other hand, low ARIs can utilize the 4-, 7-, and 30-day periods. This is because the analysis used updated streamflow data, which was also impacted by the HP No. 12 implied region growth factor. Therefore, low flow magnitudes can still be estimated using these three plotting position formulas.

Conversely, a graph reflecting the flow characteristics of a river along its discharge range was produced with low flow discharge versus ARI values. The approach outlined in this study can be refined and used to solve a wide variety of real-world issues when maintaining the consistency between varying durations; yet, linked frequency curves are essential. Finally, understanding low flow is crucial for both people and the ecology. A lack of water in rivers will cause insufficient water supply for humans; however, it may result in insufficient environmental changes for aquatic species in the ecosystem.

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