

# Assessment of probability distributions and minimum storage draft-rate analysis in the equatorial region

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**Abstract.** Streamflow information is critical to the management and development of water resources strategies. The reliability of water supply from rivers depends on their low flow characteristics. This study is essential to understand the concept of low flow, drought characteristics, and the predictive significance of river storage-draft rates in managing sustainable water catchment. Low flow frequency analysis was derived using the Weibull plotting position and four specific frequency distributions. Maximum likelihood was used to parameterise, while Kolmogorov-Smirnov tests are used to evaluate their fit to the dataset. The best probability distribution is then selected based on individual probabilistic analysis and the flow duration curve for the study threshold level ( $Q_{90}$  percentiles) with the pooling procedure derived to quantify the drought characteristics. The mass curve is used to quantify the minimum storage draft-rate required to maintain the 50% mean annual flow for a recurrence interval of 10 years. The streamflow trend can estimate future water availability to maintain and sustain ecosystem functions. Moreover, streamflow trend analysis can also be used to predict any change in river flows for making water withdrawal decisions, which indirectly can improve drought management response. The results indicated the hydrological droughts have generally become more frequent and critical in the availability of rivers to sustain water demand during low flows. These results can help in emphasising the natural flow of water to provide a water supply for continuous use during low flow.

## 25 **1 Introduction**

Droughts are long-term natural disaster phenomena resulting from less than average precipitation causing significant damages to a wide variety of sectors and affecting large regions. The rapid development of the world now shows an increase in populations, and climate change lends to increase drought occurrences (Bakanoğullari and Yeşilköy, 2014; Tigkas et al., 2012). Droughts have considerable economic, societal, and environmental impacts. Drought can typically be classified into four types depending on different kinds of drought impacts in different areas: meteorological, hydrological, agricultural and socio-

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economic (Hasan et al., 2019; Tri et al., 2019). Any types of drought are dynamic and defined by various characteristics such as frequency, severity, duration, and magnitude. The main factor involved in hydrological drought is climate change and anthropogenic activities of surface water resources. The assessment of hydrological drought provides a better representation of the hydrological cycle's water surface. Hydrological drought also allows the incorporation of spatial details that impact internal storage and soil, vegetation and terrain characteristics. This study mainly focuses on hydrological drought. The related hydrological aspects, including low water levels and decreased groundwater recharge, are more directly affected by the hydrological drought impacts.

Extreme drought can cause significant water cycle imbalances that alter the processes of precipitation and evaporation, the circulation of atmospheric water vapour and the availability of soil moisture, resulting in a low volume of water in streams, rivers and reservoirs. The equilibrium between both the water is taken out for supply and that substituted by surface runoff must be maintained. A big issue is when there is a dry season, and there is no estimated water excess. Under such conditions, water shortages can happen even though the dry season is not that dry. Drought is most frequently the consequence of climate change and human activities in the area or regions. Human activities and poor management are also complicated and exacerbated by the consequences of water scarcity and drought. In certain regions, water consumption increases the severity of water scarcity and triggers water shortage events in regions that are relatively well endorsed with water resources (Wada et al., 2013).

The hydrological drought design system is somewhat complicated and susceptible to catchment characteristics or climate, and a combination of the two variables (Loon et al., 2015; Mohammed and Scholz, 2018; Zhai and Tao, 2017). Precipitation and temperature are two main factors among different environmental factors that mainly determine the climate model and antecedent situation for hydrological drought events (Joetzjer et al., 2013). Water availability in many areas is becoming less predictable due to climate change. More significant periods of drought and higher temperature are projected to affect the rainfall distribution, river flow used for water availability causing deleterious effects on water supply. Watershed also performs a significant part in the propagation of drought and affects procedures such as pooling, lagging, and lengthening (Fleig et al., 2006; Sarailidis et al., 2019). Some research further explored the specific functions of climate control and watershed influence in regulating features of hydrological drought, and the findings are hugely based on spatial scales (Austin and Nelms, 2017; Barker et al., 2016; Liu et al., 2012; Zarafshani et al., 2016; Zhu et al., 2018). Generally, the hydrological drought duration and the quantity of the deficit are more climate-related than watershed control. However, watershed features such as geology, region, slope, and groundwater regime perform a significant part in regulating hydrological drought duration and quantity deficit for the regional scale where the climate is presumed to be relatively constant (Gianfagna et al., 2015; Laaha and Blöschl, 2006, 2007; Liu et al., 2016). The influences on hydrological drought are not restricted to the external variables such as climatic and watershed variables and should not be disregarded for anthropogenic activities in the form of land-use modification,

reservoir control, irrigation, and water extraction or withdrawal (Hatzigiannakis et al., 2016; Richter and Thomas, 2007; Sun et al., 2018; Toriman et al., 2013).

A hydrological drought is a natural event with streamflow deficits in duration and volume (Kubiak-Wójcicka and Bąk, 2018). It is believed that not every low flow event can be considered a hydrological drought, and that one hydrological drought can consist of several low flows (Teegavarapu et al., 2019). It is not advisable to equate hydrological drought with low flow or other related hazards. Low flow is a term that is often used, referring to low flow discharge. Low flow is often defined by minimum annual series which do not reflect a hydrological drought in all years. Fleig et al. (2006) were distinguish between hydrological drought and low flow characteristics. For some specific purpose, the main feature of drought is said to be the water deficit. Low flows are usually observed during a drought, but they only feature one aspect of the drought, namely the magnitude of drought. Low flow analysis is described as analyses that attempt to understand the short-term physical development of flows at a point along a river. The minimal annual n-day average discharge is the most widely used low flow index.

In the events that the low flow of the river is sufficient to meet the water demand, storage may be utilised to increase the guaranteed water supply. The hydrological aspects which must be considered are the amount of storage necessary to sustain a given draft rate and the associated risk of insufficient storage to meet this draft rate. The relationship between inflow, storage and draw-off is complex. The significant sources of error are associated with frequency analysis. Error in frequency analysis is due to the fitting the type of extreme value distribution to low flow series and uncertainties associated with assigning recurrences interval for cumulative probabilities to the events in series. Drainage basin stores are surface of significant quantities of water that may regulate the rate at which input feeds through to the output. Channel storage is the volume of water contained within banks of the river will operate as a water store between its initial input and ultimate output (Griffiths and Clausen, 1997).

Commonly, water storage in river basins is influenced by their morphology and physical characteristics such as basin- and channel-characteristics. The basin characteristics include size, shape, slope, stream density, land use and coverage, infiltration, soil types, geological and topographical conditions of the basin (Robin Burgers et al., 2014). In contrast, channel characteristics are the size and shape of cross-section, length, roughness, tributary and pondage conditions (Costa et al., 2003). Although the physics of water storage depletion processes are generally well understood, quantitative storage behaviour patterns modelling is rarely feasible due to a lack of knowledge of storage properties such as geometry, porosity and hydraulic conductivity, and the lack of data on evapotranspiration rates, inter-storage transfer and storage loss. It is fair to idealise the physical situation in these situations, even at the basin scale. All storages except for the storage of channels are regarded as separate, independent components of different types. They are assumed to contribute a net inflow to the stream, and it is assumed that streamflow response depends on the time elapsed rather than the actual input time. Besides, because storage is of concern as opposed to

dynamic effects, storage inflow is routed using mass equation conservation through a single reach representing the channel of the stream.

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High demand for water that can accommodate the daily water consumption of the population, as well as the lack of rain, has caused disruptions of water supply in Selangor (Khalid, 2018; Kwan et al., 2013; Ngang et al., 2017). Water shortages associated with the incident of El Nino / Southern Oscillation (ENSO) impacted parts of Malaysia, including Selangor (Sanusi et al., 2015; Shaaban et al., 2003; Zainal et al., 2017). Consequently, the characteristics of hydrological drought must be identified, and the effects of hydrological drought quantitatively evaluated. Studies conducted by Iqbal et al. (2016), Azadi et al. (2018), and Tigkas et al. (2012) have highlighted the issue of hydrological drought and its impact on agricultural, socio-economic and streamflow in the watershed (Azadi et al., 2018; Iqbal et al., 2016; Tigkas et al., 2012). The hydrological drought was referred to as the most critical aspect of drought with significantly reduced streamflow and lower water storage in the river system (Hasan et al., 2019). Because of this, in order to ensure that water supply requirements are met, the storage rate for each river should be known to ensure that the minimum storage during low flow and drought in the coming years will be able to accommodate consumers' water demand.

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The primary purpose of this study are: (1) to arbitrate the trend analysis of streamflow for 40 years; (2) to determine the best-fitted distribution of probability for each station for low flow frequency analysis; (3) to evaluate the hydrological drought characteristics, including severity, duration and magnitude; (4) to determine the minimum storage draft rates in 7 catchments in Selangor region in Malaysia. This study is essential to understand the concept of low flow, drought characteristics, and the predictive significance of river storage-draft rates in managing sustainable water catchment. The results are useful for developing measures to maintain flow variability and can be used to develop policies for risk management. Thus, this study consists of four types of analyses, which is: (1) a non-parametric trend analysis on annual mean, minimum, and maximum flows using the Kendall and Sen's slope test; (2) a low flow frequency analysis on annual minimum flow using the best fitted of distributions; (3) an analysis of drought characteristics determined using a fixed drought threshold at the 90<sup>th</sup> flow percentile; and (4) the determination of minimum storage draft rates necessary to ensure sufficient of water supply during low flow periods.

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An assessing of hydrological drought in this study is related to streamflow deficit measured from particular reference discharge. The method attempts to develop a general stochastic model of hydrological drought and uses the data on the low flow below reference discharge. Low flow frequency analysis is the purpose of assessing the probability of drought occurring (Cancelliere and Salas, 2010). In analysing droughts for water supply management, information on the low flow frequency analysis is crucial (Koteia et al., 2016). In Smakhtin's study, he analysed the existing method of estimating low flow time series, including extreme low flow analysis, baseflow separation, duration curve, and streamflow recessions (Smakhtin, 2001). Prolonged hydrological drought will result in phenomena of low flow events. A hydrological drought of severity – duration – frequency

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(SDF) curve was developed using a threshold level method developed by Sung and Chung (2014). Hydrological drought events occur when a water deficit occurs within a specified period when the streamflow is less than threshold levels, and the drought ends when the streamflow is above the threshold level in a series of times (Fleig et al., 2006).

## 135 **2 Methodology**

Streamflow data were obtained from the Department of Irrigation and Drainage Malaysia, which covers approximately 40 years (1978 to 2017) of records for all streamflow gauging stations. Precautions were taken to ensure reasonable low flow regimes are captured. The daily observed streamflow data had consistent statistical properties and analysis of streamflow for determining the threshold level values to drought analysis. The low flow indicator applied to the available time series is the minimum low flow for weekly or 7-day low flow. For calendar years, the annual indicators were taken out. The low flow index chosen in our study is the mean annual minimum flow on a 7-day average (MAM7) basis. For this study, two indicators are chosen, which characterise low flow differently: Q95 and MAM7. Both parameters are less sensitive to measurement errors than the minimum discharge. Lastly, the minimum storage draft rate required for Selangor was determined using a mass curve analysis.

### 145 **2.1 Site description**

The scope of this study covers the entire streamflow station in the Selangor state. Selangor covers an area of 8,104 km<sup>2</sup> and is located on Peninsular Malaysia's west coast. Selangor's water supply system not only covers the state of Selangor but also supplies water to the Kuala Lumpur and Putrajaya areas (Sakke et al., 2016). Langat-, Klang-, and Selangor-River basin are the main river basins in Selangor. There are also three other river basins in Selangor which are Buloh-, Bernam-, and Tengi-  
150 River basin. Table 1 shows the locations and characteristics of all streamflow gauging stations involved in this study.

Figure 1 shows the seven streamflow gauging stations involved in this study with four streamflow gauging stations located at Langat River basin at Dengkil, Kajang, Semenyih, and Lui. There is also streamflow gauging station at Rantau Panjang for the Selangor River basin, Tanjung Malim, and JAM SKC for the Bernam River basin, respectively (Department of Irrigation and  
155 Drainage Malaysia, 2011). The headwater of the Langat river basin starts from the northeast of the basin, flows to the southwest, and joins with the Semenyih River. The Langat and Semenyih dams, Selangor and Tinggi dams are located at the upper reaches of the Langat River and Selangor River basins, respectively, (Elfithri et al., 2018) to regulate the quantities of streamflow to the treatment plants.

### **2.2 Climate characteristics**

160 Selangor state is characterised by its geographical position, which lies near the equator climate that is warm and humid over the year (Lassen et al., 2004). The average annual temperature varies between 27-30 °C, and the average annual relative

humidity is between 70-90% (Lee et al., 2013). The equatorial climatic regions are influenced by two monsoons, which are the southwest Indian monsoon and the northeast Asian monsoon contribute two rainy seasons with a significant amount of storm events resulting in a mean annual rainfall of about 2500 mm (Mamun et al., 2010). Even though Selangor is located in the humid region, it occasionally encounters drought periods. Dry spells, low rainfall, and increased soil impermeability due to population growth are the leading causes of low flow events. The low flow usually refers to a stream regime that indicates the average annual streamflow variability associated with the regional climate's annual cycle. A stream's regime can display one or more low flow events depending on the climate. Two rainy and two dry seasons represent the equatorial climate, and the two streamflow regimes have two corresponding periods of high flow and low flow.

### 170 2.3 Trend analysis

Trend analysis covers both detection and attribution for hydrological drought (Zou et al., 2018). Trends in streamflow have consequences for hydraulic models that are often based on the notion of stationarity that many researchers are now debating because of climate change effects within not only local but also regional climate patterns, or perhaps basin and regional scale (Zeng et al., 2015). Despite significant improvements in statistical hydrology for trend evaluations in recent years, researchers are paying more attention to trend analysis in order to understand better hydro-climatic variables such as precipitation (Nam et al., 2015), temperature (Marx et al., 2018), and streamflow in the context of prevailing uncertainties and changes in climate (Bormann and Pinter, 2017).

The function of trend analysis defines the situation of one variable versus the other and determines if a shift occurs within specified limits. Either positive or negative is displayed in the orientation of the shift. Mann-Kendall and Sen's T-tests are the most commonly used non-parametric trend analysis methods (Hisdal et al., 2001). The consistency of the performance of the analysis has a crucial significance in the trend analysis studies, particularly on the discharges of any stream. Mann-Kendall test is chosen due to its capability of identifying if there is a trend in a time series. The Mann-Kendall test is also based on rank order and straightforward to calculate. On the other hand, most studies are using Sen's slope estimation technique that presents the shift quantity (Assefa and Moges, 2018). Sen's slope is a non-parametric method for determining any trend's slope. It utilises data from a time series that is similarly distributed. The difference in slope is calculated per changed time for each data point.

In the streamflow time series data, the trend was analysed using the Mann-Kendall test to evaluate the significance of monotonic trends. The test is as follows; Assuming  $X_1, X_2, \dots, X_n$  is a series of data over a time period, the null hypothesis ( $H_0$ ) is tested, and the data comes from a series with identically distributed and independent variables. Over time, the data of the  $H_1$ , the alternative hypothesis, follows a monotonic trend. Under  $H_0$ , the Mann-Kendall test statistic is given by Eq. (1):

$$S = \sum_{i=j}^{n-1} \sum_{j=i+1}^n \text{sgn}(x_j - x_i), \quad (1)$$

where  $x_j$  and  $x_i$  are the data values in years  $j$  and  $i$ , respectively, with  $j > i$ ;  $n$  is the total number of years;  $sgn()$  is the signum function. The alternative hypothesis  $H_1$  of a two-sided test is that the distribution of  $x_i$  and  $x_j$  are not identical for all  $i, j \leq n$  with  $i \neq j$ . Therefore, the probability associated with  $S$  and the sample size,  $n$ , is determined to measure the trend significance statistically. Normalised test statistics  $Z$  are expressed as follows by Eq. (2):

$$Z = \begin{cases} \frac{S-1}{\sqrt{VAR(S)}} & (S > 0) \\ 0 & (S = 0) \\ \frac{S-1}{\sqrt{VAR(S)}} & (S < 0) \end{cases}, \quad (2)$$

The null hypothesis of no trend is rejected at 99% significance if  $|Z| > 2.575$ ; the null hypothesis of no trend is rejected at 95% significance if  $|Z| > 1.96$ , and the null hypothesis of no trend is rejected at 95% significance if  $|Z| > 1.645$ . In the test statistic,  $S$  calculates the sum of the difference between data points and the associations between samples to show the presence or absence of a trend. When the value of  $Z$  is positive, it gives a positive trend and a negative trend when  $Z$  gives a negative value. In this study, the level of significance of 0.05 or 95% ( $P$ -value = 0.05) was used. If their  $P$ -value was equal to or less than 0.05 ( $P$ -value  $\leq 0.05$ ), the trend tests were considered significant, as shown by Eq. (3) (Coch and Mediero, 2016):

$$Trend = \begin{cases} + & (Z > 0) \\ 0 & (Z = 0) \\ - & (Z < 0) \end{cases}, \quad (3)$$

The Mann-Kendall test is associated with the calculation of Sen's slope. Some patterns may not be considered as being statistically significant while they may be of practical interest, and if there are any shifts in streamflow, statistical tests may not detect them at a sufficient level of significance. Then a linear trend analysis is also conducted, and the trend magnitude is determined by the Sen's slope method. If a trend is identified in a time series, the slope can be determined using the slope estimator ( $\beta$ ) in Sen's slope test. The estimator  $\beta$  is the median of all slopes between data pairs for the entire data set. A positive  $\beta$  shows an increasing trend, and a negative  $\beta$  a decreasing trend as given by Eq. (4):

$$\beta = \text{Median} \frac{y_j - y_i}{x_j - x_i}, \quad (4)$$

with  $n$  the number of data;  $i, j$  are indices with  $i = 1, 2, \dots, (n-1)$  and  $j = 2, 3, \dots, n$ .

## 2.4 Probability distribution of low flow frequency analysis

There are several types of frequency distribution functions that have been successfully applied to hydrologic data. The probabilistic behaviour was analysed using four probability distribution functions (PDFs), widely used in extreme value analysis (Joshi and St-Hilaire, 2013; Zaidman et al., 2003). Then, probability distribution functions were fitted with their parameters estimated using the method of maximum likelihood estimation (Assefa and Moges, 2018). Goodness-of-fit was

220 determined by the Kolmogorov–Smirnov test. Here, a 95% confidence level was accepted to reject or accept a non-rejects a hypothesis, based on  $D$ -value.

The graphical illustration of probability plot is described as the  $i^{\text{th}}$ -order statistic of the sample,  $y(i)$ , as a function of a plotting position, which is simply a measure of the non-exceedance probability related to the  $i^{\text{th}}$ -order statistic from the assumed  
225 standardised distribution (Sharma and Panu, 2015). The  $r^{\text{th}}$ -order statistic is acquired by way of rating the observed sample from the smallest ( $i = 1$ ) to the greatest ( $i = n$ ) value, then  $y(i)$  equals the  $i^{\text{th}}$  largest value. According to Koteia et al. (2016), the plotting position of low flow,  $P$  can be obtained using the Weibull formula given by Eq. (5) (Koteia et al., 2016):

$$P = \frac{m}{(N+1)}, \quad (5)$$

where,  $P$  = The probability of low flow;  $m$  = the ranking, from highest to lowest, of mean annual minimum flow; and  $N$  = the  
230 total number of the mean annual minimum flow.

The selection of probability is according to the shape parameter. This is because the shape parameter can be represented as the skewness parameter. Table 2 shows the probability density functions for each distribution. For this study, the method of maximum likelihood is used for parameter estimation. The likelihood function is defined as Eq. (6):

$$l(\theta | x_1, x_2, \dots, x_N) = \prod_{i=1}^n f(x_i; \theta_1, \theta_2, \dots, \theta_N), \quad (6)$$

235 Once the parameters are estimated, the selected distributions will be tested for the assumption that the observed data is actually from the fitted distribution of probability. The Kolmogorov-Smirnov (KS) test has been used to determines the largest discrepancy between the theoretical ( $F_n(x_i)$ ) and empirical ( $F_0(x_i)$ ) cumulative distribution functions. The KS test obtains a  $D$ -statistic; the maximum vertical is given by Eq. (7):

$$D = \max |F_n(x_i) - F_0(x_i)|, \quad (7)$$

240 Where  $r$  is the rank of the observation  $i$  in ascending order, the smaller  $D$ -values imply a better fit of the streamflow series to the selected probability distribution. If  $D$  was higher than the critical value ( $\alpha = 0.05$ ), the distribution was rejected.

#### 2.4.1 Estimation of low flow based on the return period

After the probability calculations,  $P$  and subsequent returns period the low flow,  $T$ , the low flow rate variation will be plotted against the return period,  $T$  on the semi-log graph. With this graph, the specific magnitude of a specified period can be  
245 determined (Erfen et al., 2015; Gottschalk et al., 2013). The return period in a univariate setting is described in Eq. (8):

$$T = 1/(1 - P), \quad (8)$$

Where,  $T$  = the return period (year);  $P$  = the non-exceedance probability.



## 2.5 Flow duration curve (FDC)

Flow Duration Curve (FDC) describes the ratio of a specified percentage of time with discharge is equal to or surpassed (Crocker et al., 2003; Mohamoud, 2008; Vogel and Fennessey, 1994), which reflects the relationship between streamflow magnitude and length of time that relates to the average percentage of time a specific flow is exceeded (Sung and Chung, 2014). The FDC was developed by arranging streamflow values in decreasing magnitude order and assigning rank numbers to each streamflow value with the most substantial flow ranked as one and the smallest  $n$ , where  $n$  is the complete record quantity and calculating the percentage of time a given flow was equal to or exceeded (probability of excess) using the relationship in Eq. (9) (Awass, 2009; Koteia et al., 2016; Yahiaoui, 2019):

$$P = [r/(n + 1)] \times 100, \quad (9)$$

Where,  $P$  = the percentage of time a given flow is equalled or exceeded;  $n$  = the total number of records;  $r$  = the rank of the flow magnitude. Kannan et al. (2018) indicated the flow duration curve could be divided into five zones, representing high flows (0-10%), humid conditions (10-40%), medium-range flows (40-60%), dry conditions (60-90%), and low flows (90-100%).

While FDCs have a long history in hydrology, they are often criticised because their interpretation historically depends on the specific period in records. A period-of-record of FDC (POR FDC) represents the probability of streamflow exceedance over a long period. This definition can be beneficial as long as the period of record was used to create the FDC is long enough to provide a limiting streamflow distribution, or whether the period of record corresponds to particular planning or design life. Nevertheless, in many nations, records are shorter than this prescribed time for a large part of the gauged catchments. Regardless of the following limitations, engineers still prefer to use FDC compared to POR FDC. For individual years, they considered FDCs and viewed certain annual FDCs like a sequence of maximum or minimum annual flow. Engineers also want to estimate daily streamflow quantiles for hydrological design and planning. FDCs' annual concept requires FDCs to grant confidence intervals and return dates. FDCs can be built to generalise hydrological frequency analysis using average recurrence intervals.

### 2.5.1 Threshold level method

The low flow value was obtained from the flow duration curve at 90<sup>th</sup> percentiles. The magnitude of drought characteristics was determined by the threshold value and value difference between the time series. As the daily data series are used, the existence of minor drought events and mutually dependable drought events can be detected (Van Loon and Van Lanen, 2013). According to the study by Sakke et al. (2017), to eliminate the minor drought events, the events that occur for less than 15 days will be excluded while the mutually dependable events were also eliminated by the pooling procedure (Sakke et al., 2017). In this paper, the 7-day moving average was applied as a pooling procedure to obtain smooth data. Through these methods,

280 the mutually dependent drought events will combine into individual and independent drought events (Fleig et al., 2006). The minor drought events will be eliminated or combined with individual drought events automatically (Yahiaoui et al., 2009).

## 2.6 Minimum storage-draft rate method

285 The water supply or inflow is depending on low flow characteristics in the stream. When the inflow rate is less than the outflow (demand) rate, the maximum amount of water drawn from storage is the cumulative difference between supply and demand volumes of dry seasons. In channel storage, the function of both outflow and inflow discharge can be considered under two categories as prism and wedge storage. The water surface flow in the channel is not only unparallel to channel bottom but also varies with time. The storage, which is the maximum cumulative deficiency in any dry season, is obtained from the maximum difference in the ordinate between the mass curve of water supply and demand. Thus, the storage required can be expressed as in Eq. (10):

$$290 \quad S = \text{Maximum of } (\Sigma V_D - \Sigma V_S), \quad (10)$$

Where,  $V_D$  = Demand Volume;  $V_S$  = Supply volume.

The minimum storage draft rate was determined by using the mass curve of low flow at a monthly interval (Bharali, 2015). Although specific evaluation of storage requirements is essential for design, reconnaissance planning can frequently be facilitated by using draft-storage curves based on low flow frequency analysis. Alrayess et al. (2017) determined the capacity of river storage by the mass curve method. The mass curve has many useful applications in the design of storage capacities, such as to determine the reservoir storage capacity and flood routing (Gao et al., 2017). The procedure for the mass curve method has the following steps; first, construct a mass curve of the historical streamflow (monthly streamflow); determine the slope of the cumulative draft line for the graphical scales; next, superimpose the cumulative draft line on the mass curve; lastly, 300 measure the largest intercept between the cumulative draft line and the mass curve.

The estimation of the storage draft rate in this study will determine the minimum storage of a river to sustain the water supply during low flows and droughts. The mass curve of the monthly low flow rate is used in this analysis to obtain the minimum storage rate of the river. The mass curve analysis of low flow for the duration of January to December plotted against duration 305 for recurrence interval of 10-year. The cumulative draw off corresponds to a constant draft rate of 50% of the mean annual flow and connected by a straight line. The slope of the line represents the average rate of flow that can be maintained between time. Thus, the slope of the straight line joining the starting point and the last points of the mass curve represents the average of discharge- over the whole period of plotted records.

### 3 Results

310 The streamflow data from the seven streamflow gauging stations will be analysed in three aspects, which are mean annual low flow and the probability of occurrence, drought characteristics using the threshold level and the estimation of storage draft rate of the river. Statistical characteristics were calculated from the observed 40 years daily streamflow time series: the mean, minimum, and maximum of 14,610 values data; standard deviation, skewness, and kurtosis for each station (Table 3).

#### 3.1 Trend analysis

315 Annual series trend analysis presents the overall view of the shift in systems of streamflow (Assefa and Moges, 2018). The Mann-Kendall test and Sen's slope results are displayed in Table 4. The results of this analysis indicated that five selected stations (S01, S02, S04, S05, and S07) are increasing trends of streamflow. Two of the stations, S03 and S06, have indicated a decreasing trend with the negative change of streamflow.

320 In the S03 and S06 stations, there could be several factors for decreasing streamflow. Some of this involves modifications in the catchment of physical characteristics such as changes in land cover in river basins (Hisdal et al., 2001). Another five stations indicated an increase in trends of streamflow due to climate change for the increasing temperature and soil water evaporation (Siwar et al., 2013; Taye et al., 2011). The trend analysis was conducted using the non-parametric Mann-Kendall test. A positive slope demonstrates an upward trend, while a negative slope indicates a downward trend. Another benefit for  
325 this method is that it offers a significance indicator dependent on the slope hypothesis test and also delivers the degree of alteration magnitude. The total difference can be obtained by multiplying the slope by the number of years during the time under observation.

#### 3.2 Low flow frequency analysis

Frequency analysis has focused on fitting a theoretical probability distribution function to the observed data and providing low  
330 flow estimates for any given return period. For each station, annual minimum streamflow was plotted using all the distributions. The goodness of fit was performed using Kolmogorov-Smirnov. All the PDFs were ranked for streamflow at each station. Ranks, according to these three goodness of fit, showed a significant variation. In the case of annual minimum streamflow, various distributions were found the best fit for different stations, namely, Gamma, Gumbel, Lognormal 2P and Pearson type-3. Figure 2 shows the example probability of mean annual minimum flow for station 1. The estimated parameters were  
335 determined and shown in table 5.

The primary purpose of this study is to determine the best-fitted distribution of probability for each station for low flow frequency analysis. Such projections could provide valuable input for policy and decision-making purposes. The information about the return period of extreme can be used in determining the risk management by extreme events such as hydrological

340 drought, while the geographical station location and the surrounding environmental factors for the variation of streamflow. Table 6 shows the best-fit results of the K-S test and P-value results with their ranking.

The primary aim of the probability distribution fitting is to represent the low flow probability most accurately. Among all the stations, it was found that among all distributions, the Lognormal 2P yielded the most cases of best-fit distributions, while the  
345 Gumbel and Gamma yielded the second and third amount of best-fits respectively. Comparatively, it is proposed that 2P Lognormal distributions predict low flow discharges for all the rivers under analysis, which can be used in water quality and quantity management at gauged and ungauged areas. When the best fit probability distribution of the low flow series of the D-day has been determined, the low flow discharge of the D-day can be estimated according to any given return period. It should be noted that the research is station dependent on this analysis. The low flow-duration-frequency curves were therefore  
350 obtained at the base of gauging station. The low flow-duration-frequency curves are powerful tools for many applications, but particularly for engineering practice. An engineer may get any discharge of the low flow-duration-frequency curves from any low flow model. The fraction of non-zero flows in this river basin is always 100 per cent allowing one to measure up to 100-year return cycle D-day low flow discharges. Table 7 shows the return period of low flow at all streamflow stations.

355 A catchment with a slow or quick response to rainfall intensity that usually has prolonged or rapid recession actions depends entirely on the catchment's physical characteristics. Low flow in catchments that respond quickly is lower than in those that respond slowly. Low flow in catchments that respond slowly is more persistent than in catchments that respond quickly. These differences demonstrate the significant effect on low flow events of hydrological processes and storages.

360 The existence of extreme values in the streamflow data may be determined using the Box plot method. The Box plot method is based on creating a so-called Box graph. This graph is the best possibility for geometrical visualisation of the distribution of random variables in some groups. These groups are created ordering the streamflow data between the extreme values, minimum and maximum. Each group has an equal number of data, and in mathematical statistic, this is called a quartile. The skewness describes the form of distribution of the random variables and measures both direction and degree of asymmetry of  
365 the distribution of the random variables.

Figure 3 displays the low flow relationship with the watershed area represented by the boxplot graph. The boxplot is a standardised way of displaying the distribution of low flow per watershed catchment area based on the five-number summary. The boxplot graph displays the full range of variation, which is from minimum to maximum data set in each station. The  
370 largest range for low flow per area is in S06 while the smallest range is in S01. The boxplot graph provides information about the shape of a data set. S01, S02, and S04 are skewed right, S03, S05, and S06 are symmetric shape data, and S07 is skewed left. From the discussions above, it is clear that the natural elements that affect a variety of factors of the river's low flow regime consist of distribution and hydraulic components, climate, and topography.

### 3.3 Hydrological drought characteristics analysis

375 The threshold level value per Q percentile obtained from the flow duration curve is shown in Table 8. In this study, only  $Q_{90}$   
was used as a threshold level in the determination of drought events. Several days and percentage where the streamflow rate  
was below the average level are recorded to show the severity of droughts events at each station. The growing perception of  
hydrological drought improvement on a global scale has some necessary implications for water management. It is recognised,  
for example, that the duration and the volume of the deficit of the drought are associated (Fleig et al., 2006). Figure 4 to 7  
380 shows the drought characteristics below the threshold level ( $Q_{90}$ ), with removing minor drought for each station in the Selangor  
region.

Station S01 has 39 episodes of drought events in 40 years. This station also recorded 1593 days of drought, with a total deficit  
of 10,299.97  $m^3/s$ . The lowest deficit was recorded in 1994 at 41.53  $m^3/s$ , while the highest deficit was recorded in 1986 at  
385 666.58  $m^3/s$ . The average amount of water deficit is 264.10  $m^3/s$ . This river has been affected by water rationing that happened  
in Selangor in early 2014 for 3 to 4 months. The most prolonged period of individual drought was recorded in 2014 at 112  
days from March 05 to June 24. The shortest period of a single drought was marked three times in 2004 and 2005 by 15 days.  
Station S02 was part of the Langat river basin and has had 29 episodes of drought events in 40 years. The total duration of the  
drought events was recorded at 1,261 days from 14,610 days of total observation of only 8.63% of the entire record period and  
390 below the threshold level  $Q_{90} = 2.99 m^3/s$ . The overall deficit for this station is 2,340  $m^3/s$ , with an average of 80.70  $m^3/s$ . The  
lowest deficit was in 1993 at 34.44  $m^3/s$ , while the highest deficit was recorded in 1986 with 179.73  $m^3/s$ . The overall total  
deficit is 1.57% of the total water flow.

The threshold level of S03 is 1.47  $m^3/s$  at an average level with 12 episodes of drought events. The total number of the  
occurrence of the drought was 1,577 days, which was 10.79% of the overall record of observation. S03 has the record value  
of the total number and episode of the least drought event among all stations. However, S03 also records a long period of the  
drought of individual events. The longest single drought took place in 1998, with 241 days commencing on February 24 and  
ending on October 22. S03 also recorded the lowest deficit amount amongst all stations with 1,660  $m^3/s$  during the period of  
drought. This total is 2.2% of the total water flow through this station, which is 75,562  $m^3/s$ . The highest deficit was recorded  
400 in 1998 with a total of 226  $m^3/s$  over 241 days. The lowest deficit was recorded in the dry season in 1997, with only 21.57  $m^3/s$   
within 20 days. Station S04 has 28 episodes of drought occur in 40 years of records. The most prolonged period of individual  
and annual drought was recorded in 2004 by 306 days. The shortest period was at 15 days in 1999. The number of drought  
events exceeding the number of years of drought was due to repeated events occurring 18 times with a maximum of four (4)  
replications in one (1) year. The total number of days of the occurrence of this drought is 1,460 days, which is 9.99% of the  
405 total daily flow data. The overall deficit of 28 drought events was 673.54  $m^3/s$ . The lowest total deficit was recorded in 1983

as much as 7 m<sup>3</sup>/s, while the highest deficit was recorded in 2004 with 131.27 m<sup>3</sup>/s. The average amount of total deficit was 24.06 m<sup>3</sup>/s.

410 Station S05 has been categorised as the most critical station with the highest number of days of droughts events. The longest annual drought event was recorded in 1998 with 217 days, and for individual drought events, this occurred in 1999 with a period of 111 days. Using the threshold level at Q90 = 21.52 m<sup>3</sup>/s, 1,236 days (10%) of the total are below the threshold level categorised as drought. Repeat drought events recorded in 1978, 1979, 1986, 1987, 1990, 1998, 2000 and 2002. The drought episode was seen most repetitive in 1998 with four (4) repetitions a year. The total magnitude deficit of the entire river water stream during the occurrence is 18,695.45 m<sup>3</sup>/s. The value of the minimum storage rate at 67.36 m<sup>3</sup>/s exceeds the amount of  
415 low flow rate at 35.61 m<sup>3</sup>/s that will occur at the return period of 50-year. Station S06 shows the drought episodes are seen in succession from 2011 to 2017 and 2016 record the highest drought events with four (4) replay events. The year 2014 records the most extended individual drought episode of 177 days, and the longest annual drought comes in 2013 with 372 days. S06 recorded a total deficit of 3,847 m<sup>3</sup>/s. The year 2012 recorded the highest deficit of 496.13 m<sup>3</sup>/s while 1989 recorded the lowest deficit with only 54.19 m<sup>3</sup>/s. The average deficit is 113.16 m<sup>3</sup>/s, with 34 episodes of drought event in 40 years.

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S07 had the highest drought events with the number of years of drought recorded as 39 years with repeated drought events in 1978, 1983, 1985, 1987, 1990, 1991, 1992, 1998, 1999, 2001, 2002, 2005 and 2016. The most prolonged drought period was recorded in 2005 with a period of only 99 days, while the shortest period was in 1971, 1987, 2000, and 2016 with a period of 15 days. The most prolonged period of individual drought events with 205 days occurred in the same year in 2005. The total  
425 drought days at this station was 1,614 days, which was 11.05% of the total days. S07 recorded a deficit of 21,740 m<sup>3</sup>/s during the drought episode, and this percentage is the highest percentage recorded compared to other streamflow stations. This stream records a high deficit amount with fewer drought days. The highest deficit reached 1,445 m<sup>3</sup>/s recorded in the drought events in 1990, while the lowest deficit was in 1983 with a total of 161.32 m<sup>3</sup>/s.

430 From the results, S01 exhibits the highest number of drought events, which is 39 episodes, with the mean deficit is 264.10 m<sup>3</sup>/s. This station is located downstream of the Langat basin. It indicates the downstream watershed catchment has more drought episodes compared to the upstream catchment. Magnitudes differ significantly between catchments since there were also varied specific hydrological characteristics, such as station spatial distribution, precipitation and temperature magnitudes, and frequency of extreme events like drought.

435

### 3.4 Estimation of minimum storage draft-rate

Figure 8 shows the flow mass curve for the determination of the minimum storage-draft rate of each station that needs to be maintained at a draft rate of 50% of the mean annual flow during low flows to sustain the water supply.

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The minimum storage required for maintaining a draft rate required for S01 is 21.51 m<sup>3</sup>/s in October, S02 is 13.37 m<sup>3</sup>/s in December, S03 is 4.79 in December. The minimum storage required for S04 is 2.32 m<sup>3</sup>/s in October for 40 years' duration period; S05 is 15.00 m<sup>3</sup>/s in September. While, the minimum storage required to maintain the draft rate for S06 is 10.90 m<sup>3</sup>/s in October, and lastly, for S07 is 6.17 m<sup>3</sup>/s in September.

## 445 4 Discussion

The results of the analysis demonstrate the spatial and temporal variability of the hydrological drought using streamflow data. This section discusses the advantages and limitations of the implications of these findings.

### 4.1 Streamflow trend

For the annual average streamflow at the gauging stations, five stations indicated an upward trend, and two stations indicated a downward trend for 40 years' data. The interpretations of trend analysis for relatively partial streamflow records may only reflect a short-term condition and may not be representative of an actual long-term change in the streamflow data. This issue is valid for relatively short-term records that begin or end in a historically low flow condition. One of the influential aims of the time series trend is to define the nature characteristic represented by the sequence of observations and predicted future values of the time series variable. The analysis of observed data for changes and trends of streamflow data can be used to assess the impact of climate change. The streamflow trend can estimate future water availability to maintain and sustain ecosystem functions. Moreover, streamflow trend analysis can also be used to predict any change in river flows for making water withdrawal decisions, which indirectly can improve drought management response.

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### 4.2 Hydrological drought

The hydrological drought effects will happen slowly but last longer. Hydrological drought can lead to consequences for water supply, agriculture, water quality, and electricity production, which leads to both economic and ecological loss. Low flow statistics are often used in characterising hydrological drought. There are several ways to define low flows. Low flow rates are generally smaller than the median flow of a river. Different low flows can be used to investigate different ecosystem functions of a river and can be used to indicate when a river is in a drought situation.

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This study used a hydrological drought index called threshold level methods to identify drought characteristics. This method uses fixed or moving thresholds to identify at what flow a river is considered to be in a drought and easily determine its

duration, severity, and frequency. Commonly, the thresholds level is taken from flow duration curves (FDC) of streamflow data. Flow duration curves show the interaction of frequency and magnitude in streamflow using a graphical method. FDC can be developed for different periods such as daily, monthly, and annually based on objectives study. Multiple low flow indices can be obtained from FDC, such as Flows with 70-99% exceedance,  $Q_{20}/Q_{90}$ ,  $Q_{50}/Q_{90}$ ,  $Q_{90}/Q_{50}$ , 7 days 10-year flow, and 7 days 2-year flow that describes low flow regime of a river (Blum et al., 2016). Calculating frequency and return period of mean annual minimum  $n$ -discharge are a standard index. It uses the mean minimum flow of a certain amount of days ( $n$ ) ranging from 1-30 for every year of record (Sarailidis et al., 2019). The limitation of FDC is they do not provide any information about the intensity and duration of low flow events in streamflow time series.

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When the streamflow falls under a certain threshold level from a streamflow hydrograph, a series of hydrological drought events can be derived. Therefore, it is possible to obtain the drought characteristics, including duration of drought, deficit volume and interval of drought. The value of the threshold level is subjective, but it is necessary as it influences the number of events, the period of drought, and the volume of a deficit. Thresholds may be flow minima that are either ecologically substantiated or are derived from the water resources management requirements, reservoir operation, and navigation (Sarailidis et al., 2019). Threshold levels between the 70<sup>th</sup> percentile and 95<sup>th</sup> percentile flow from the flow duration curve (FDC) are recommended for perennial streams such as the Selangor river catchment (Heudorfer and Stahl, 2017). The 90<sup>th</sup> percentile flow is used in this study to characterise hydrological droughts from streamflow series.

485 Several indices could be used to provide a more accurate representation of hydrological drought. Which indices one chooses to use is going to affect the result directly. One of the problems in the use of an annual  $Q_{90}$  threshold is the drought events may not be entirely accurate. It is important to note that the  $Q_{90}$  threshold merely identifies low flows accounted for catchments regular flow. Therefore, the  $Q_{90}$  threshold does not necessarily imply a situation where functions in nature are affected. The threshold level can reflect a specific requirement, such as for water supply or minimum environmental flow, or a normal low flow condition of the river can be represented. For a bigger picture and understanding of the broad spectrum of hydrological drought, more indices need to be put together in an index. Different methods will allow different characteristics of hydrological droughts. The threshold level method should be used for more detailed deficits and in-depth study. Complex indices would be most useful to verify results in regional studies.

490

## 5 Conclusion

495 Low flow analysis is an essential and widely studied design and management of hydrology and water resources. Varying and complex natural processes may produce low flows in a river on a catchment scale. The flow duration curve is one of the primarily used tools for assessing low flow and the river regime. This method was selected because it is one of the most informative ways to display streamflow characteristics throughout the discharge range, regardless of the occurrence sequence.



500 The first aim of this work was to determine the characteristics of low flow by using frequency analysis. Based on the results of the low flow frequency analysis, Lognormal 2P distribution methods were used to predict the magnitude of low flow. Lognormal 2P distribution provides a good fit to annual minimum flow data at each station, and the Kolmogorov-Smirnov test was conducted as an indicator of performance. From the result, the range means the low flow of rivers in Selangor is between 0.75 to 19.47 m<sup>3</sup>/s.

505 Drought is a phenomenon of water shortage when the water supply is below the average level. This study developed a useful principle of using threshold level methods to describe the characteristics of streamflow droughts. From this study, we can make the following conclusions:

- 1) The threshold level using the Q percentile based on the flow duration curve was used as an average level to separate the occurrence of droughts events or otherwise. The number of days and duration of droughts for a station can show the severity of the drought that occurs.
- 2) The drought characteristics were analysed from time-series below a threshold level (Q90) without removing the minor drought. The magnitude and duration of drought characteristics were determined by the value difference between the time series and the threshold level value.
- 3) The highest drought events are 39 episodes with a mean volume of the deficit is 557.46 m<sup>3</sup>/s while the lowest events of drought are ten (10) episodes with the mean volume of the deficit is 127.71 m<sup>3</sup>/s.

520 The rate of low flow at the recurrence interval of 10-year was used to ensure the minimum storage-draft rate required to sustain the water demand during low flow periods. The restructure of the minimum storage draft rate must be done by hydrologist at a particular return period to ensure the streamflow gauging station has enough water to be supplied to the user during the low flow and drought periods. Based on the analysis of the study, the estimated minimum storage-draft rates for each station cannot meet the water demand during low flow at specific return periods, which is 10-year recurrence interval for this research.

525 This research is essential to water resources management. Low flow analysis and water availability enable water resource management to make more realistic decisions on water restrictions and provisions for cities and populations. Understanding the concept of low flow and the predictive significance of river storage-rates can also help in managing sustainable water catchment. This study also helps in emphasising the natural flow of water to provide a water supply for continuous use during low flow. Additionally, through this research, the concept of low flow analysis and the predictive significance of minimum storage draft rate can be developed to produce more efficient water resource management systems during the dry season in Selangor, Malaysia.

530 *Competing interests.* The authors declare that they have no conflict of interest.

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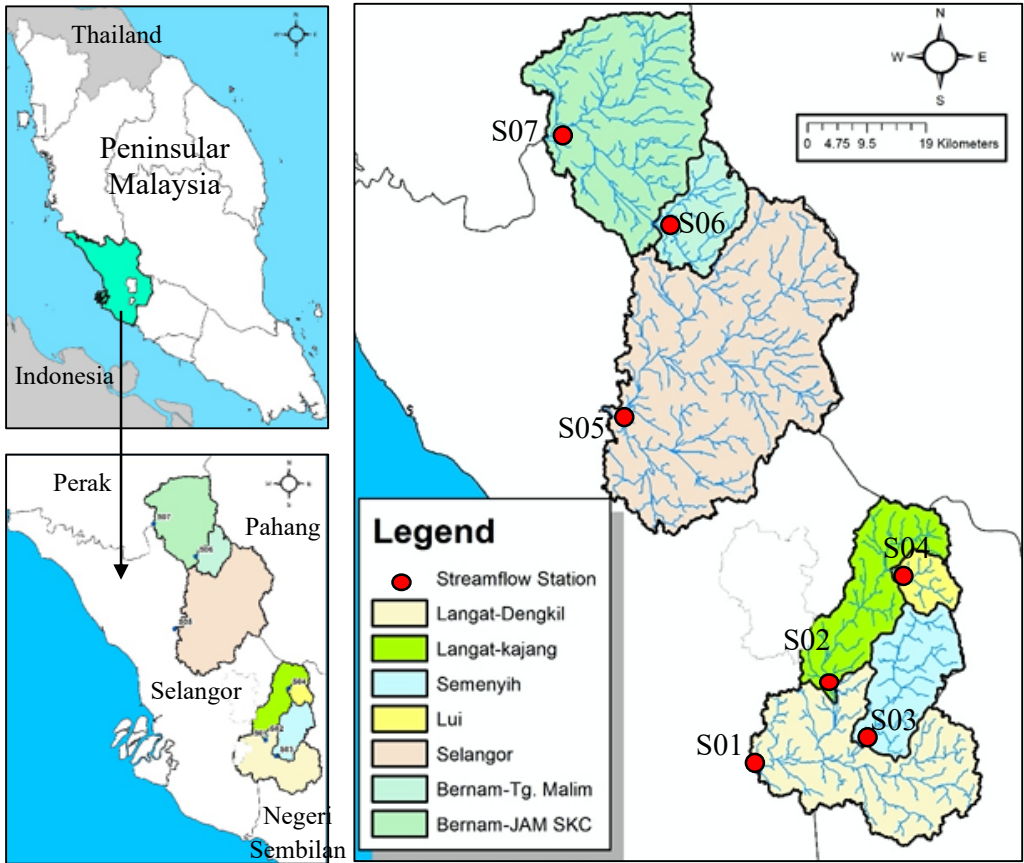
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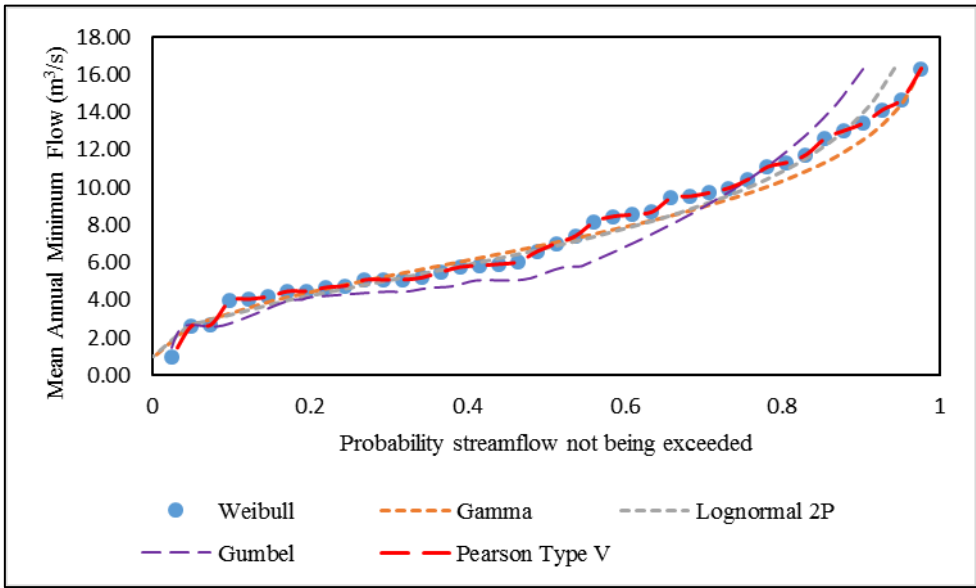
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**Figure 1: River basin and streamflow station in Selangor.**



715 Figure 2: Probability of mean annual minimum flow for station 1.

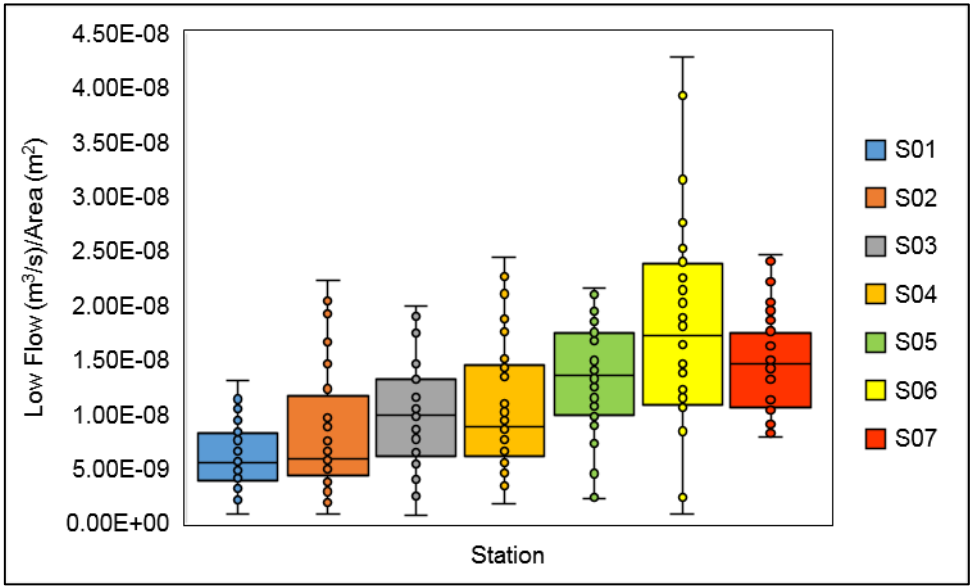
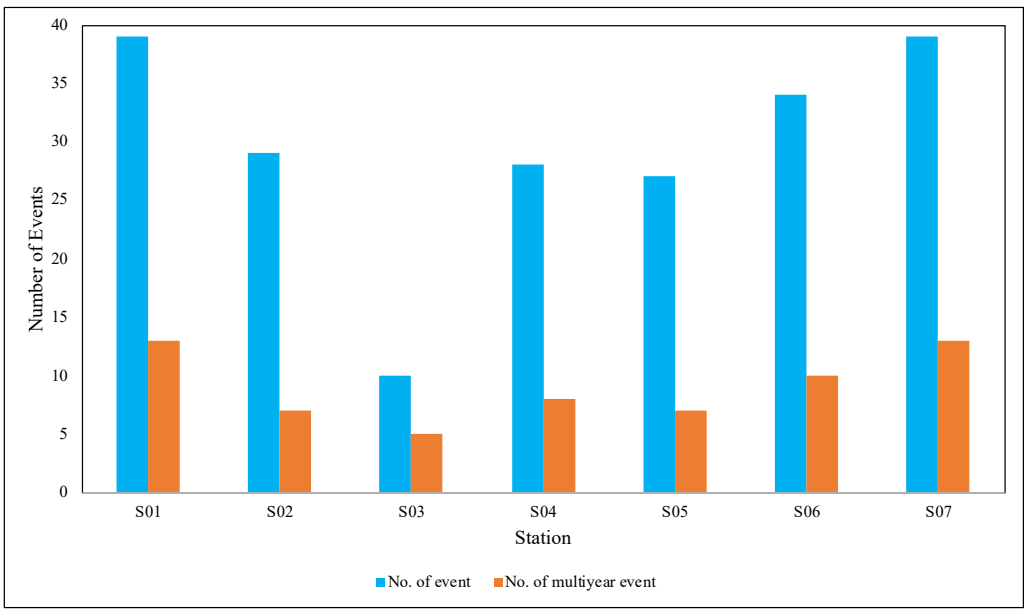
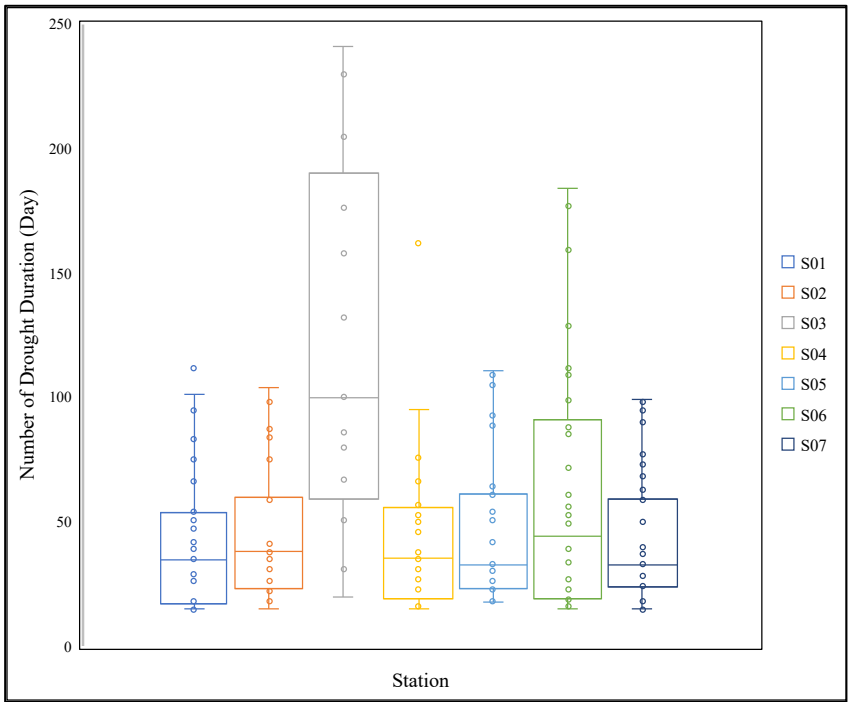


Figure 3: The boxplot low flow per watershed catchment area.



720 **Figure 4: Number of drought events.**



**Figure 5: The number of drought duration (days).**

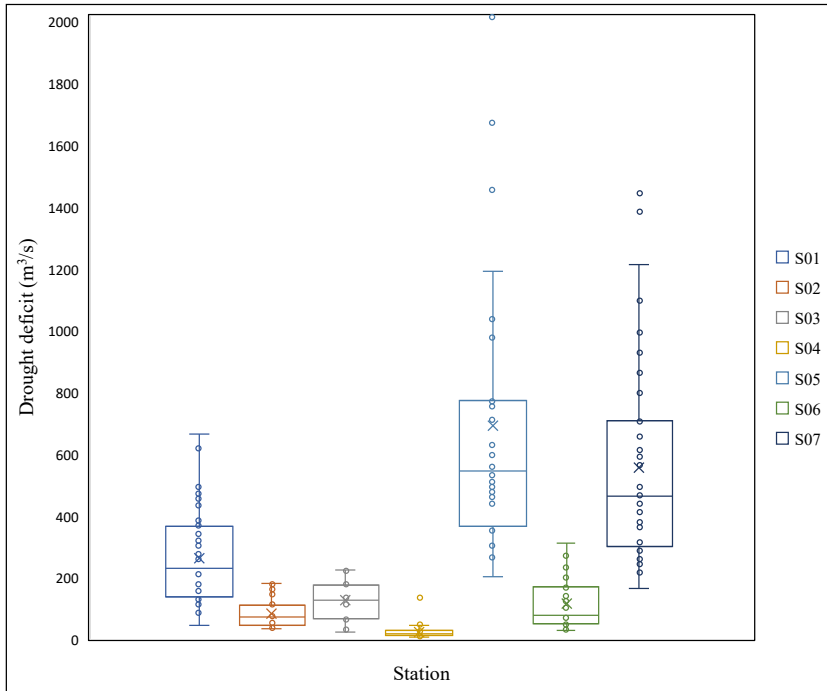


Figure 6: The drought deficit for all station.

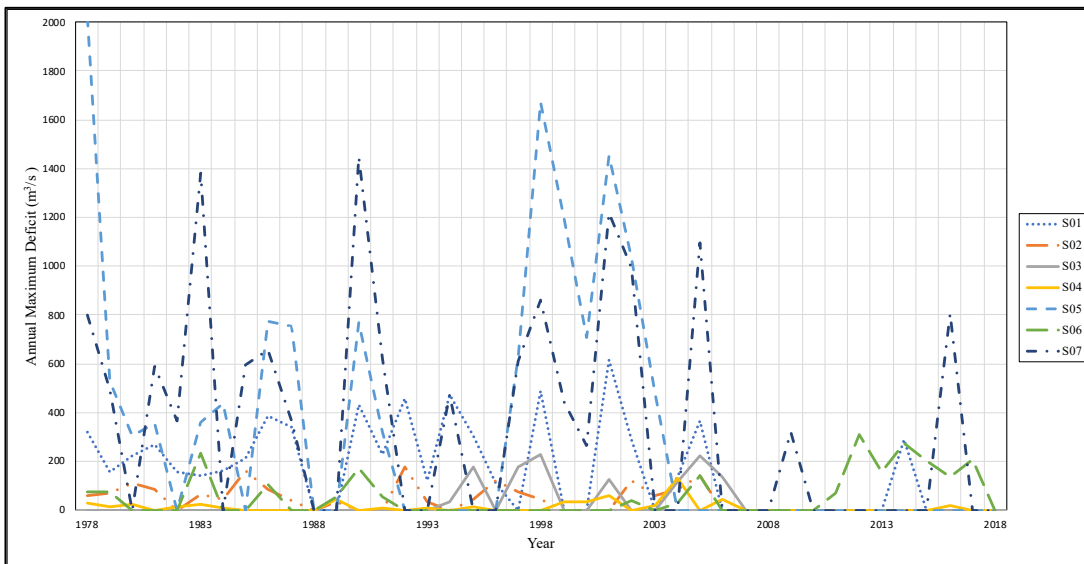


Figure 7: Time series of annual maximum deficit ( $\text{m}^3/\text{s}$ ).

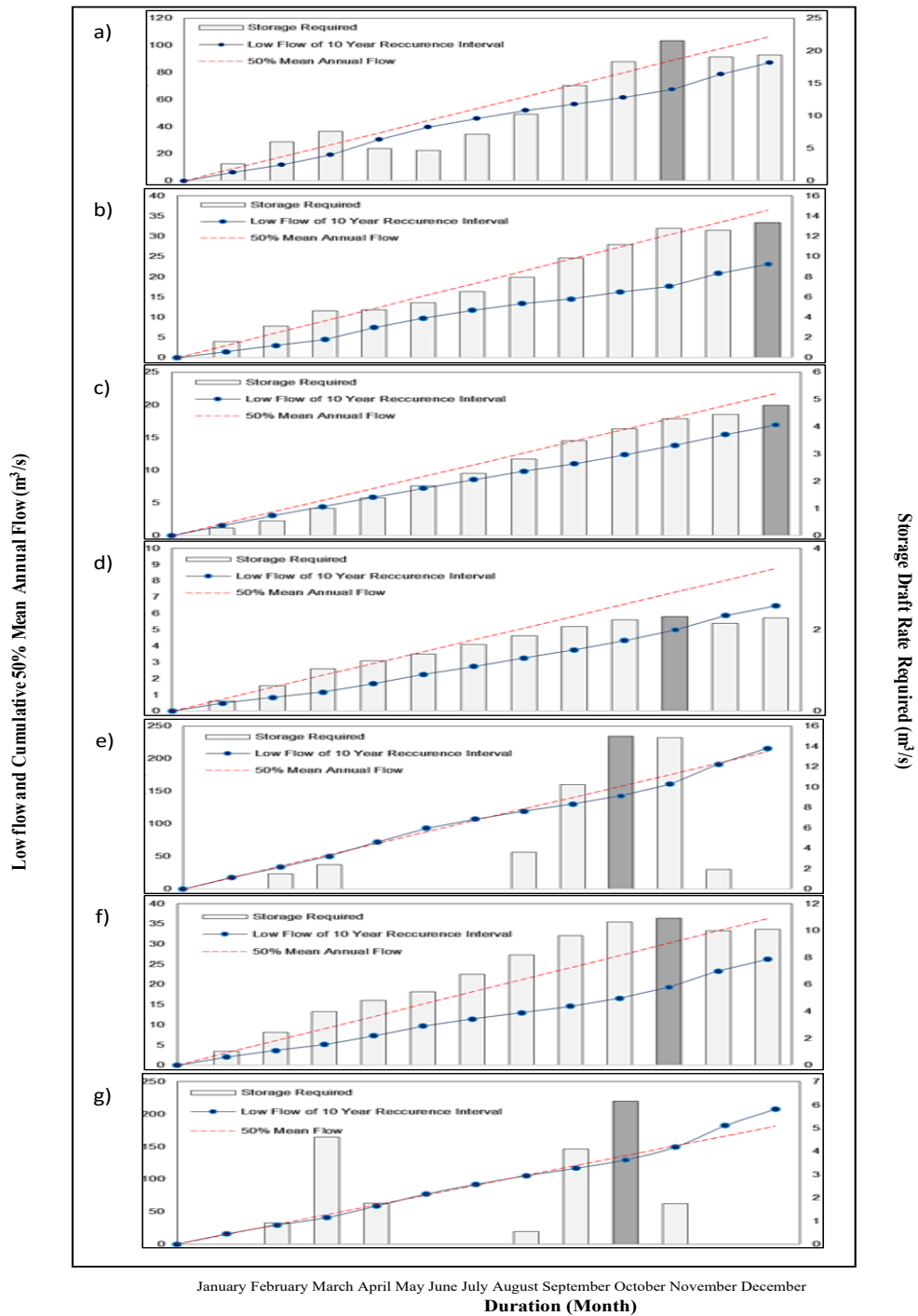


Figure 8: Minimum storage draft rate with cumulative 50% mean flow (a) S01 (b) S02 (c) S03 (d) S04 (e) S05 (f) S06 (g) S07.

**Table 1** The characteristics of streamflow gauging stations in Selangor.

Station No.	River Name	River basin	Location		Area (km <sup>2</sup> )
			Coordinate (WGS)		
S01	Langat-Dengkil	Langat	02°51'20" N	101°40'55" E	1240
S02	Langat-Kajang	Langat	02°59'40" N	101°47'10" E	380
S03	Semenyih	Langat	02°54'55" N	101°49'25" E	225
S04	Lui	Langat	03°10'25" N	101°52'20" E	68
S05	Selangor	Selangor	03°24'10" N	101°26'35" E	1450
S06	Bernam- Tg. Malim	Bernam	03°40'45" N	101°31'20" E	186
S07	Bernam-JAM SKC	Bernam	03°48'15" N	101°21'50" E	1090

740 **Table 2** Probability density function for Gamma, Gumbel, Lognormal 2P and Pearson type-3 distributions

No.	Distribution	Probability Density Function	References
1	Gamma	$f(x) = \frac{\beta^{-\alpha} x^{\alpha-1}}{\Gamma(\alpha)} \exp\left(-\frac{x}{\beta}\right)$ <p><math>\alpha &gt; 0, \beta &gt; 0, x &gt; 0</math>, where <math>\alpha</math> is the location parameter, and <math>\beta</math> is the scale parameter</p>	(Baran-Gurgul, 2018)
2	Gumbel	$F_x(x) = \exp\left[\exp\left(\frac{x-\beta}{\alpha}\right)\right]$ <p><math>-\infty &lt; x &lt; \infty; -\infty &lt; \beta &lt; \infty; \alpha &gt; 0</math>. The <math>\alpha</math> and <math>\beta</math> parameters are parameters of scale and location.</p>	(Zou et al., 2018)
3	Lognormal 2P	$f(x) = \frac{1}{x\sqrt{2\pi\beta^2}} e^{-\frac{(\ln x - \alpha)^2}{2\beta^2}}$ <p><math>x &gt; 0, \alpha &gt; 0, \beta &gt; 0</math>.</p>	(Win and Win, 2014)
4	Pearson type- 3 (PE3)	$f(x) = \frac{\lambda^\beta (x - \epsilon)^{\beta-1} e^{-\lambda(x-\epsilon)}}{\Gamma(\beta)}$ <p><math>x \geq \epsilon</math>.</p>	(Bhatti et al., 2019)

**Table 3 The statistical analysis for time series of streamflow (1978 - 2017).**

Station No.	Mean Flow (m <sup>3</sup> /s)	Minimum Flow (m <sup>3</sup> /s)	Maximum Flow (m <sup>3</sup> /s)	Standard Deviation	Skewness	Kurtosis
S01	34.32	1.00	552.62	31.326	4.027	35.819
S02	10.23	0.30	153.87	9.595	4.197	32.222
S03	5.17	0.15	32.41	3.730	2.296	8.996
S04	2.07	0.12	11.93	1.426	1.967	5.726
S05	55.12	3.17	272.59	35.083	1.558	3.163
S06	8.86	0.14	52.51	5.851	1.491	3.716
S07	47.57	8.57	244.75	28.845	1.427	2.744

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**Table 4 Trend analysis for time series period ('+': Positive trend, '-' : Negative trend, and '0': No trend).**

Station	Statistics	1978-1985	1986-1993	1994-2001	2002-2009	2010-2017	Whole Period
S01	Mean	30.05	30.97	36.01	35.40	39.15	34.32
	Minimum	3.96	2.68	1.00	4.46	8.54	1.00
	Maximum	411.73	275.17	165.62	552.62	269.78	552.62
	Mann-Kendall	+	+	0	+	-	+
	Sen's Slope	2.61	0.58	0.56	1.76	-1.40	0.30
S02	Mean	8.05	7.58	8.15	15.00	12.35	10.23
	Minimum	1.10	1.27	0.30	0.70	2.31	0.30
	Maximum	153.87	77.86	35.50	133.14	63.09	153.87
	Mann-Kendall	+	+	+	+	+	+
	Sen's Slope	0.23	0.25	0.75	2.13	0.08	0.15
S03	Mean	5.86	6.05	2.67	5.05	6.23	5.17
	Minimum	1.59	1.90	0.15	0.45	2.36	0.15
	Maximum	25.42	30.18	9.24	32.41	30.78	32.41
	Mann-Kendall	+	+	0	+	-	-
	Sen's Slope	0.24	0.05	0.01	0.93	-0.73	-0.02
S04	Mean	1.65	1.71	2.62	1.71	2.65	2.07
	Minimum	0.24	0.39	0.25	0.12	0.59	0.12
	Maximum	5.96	5.68	11.53	8.41	11.94	11.94
	Mann-Kendall	+	-	-	+	-	+
	Sen's Slope	0.16	-0.08	-0.23	0.09	-0.17	0.02

Station	Statistics	1978-1985	1986-1993	1994-2001	2002-2009	2010-2017	Whole Period
S05	Mean	53.74	56.26	52.3	57.69	55.61	55.12
	Minimum	13.61	13.04	3.17	10.56	17.23	3.17
	Maximum	185.29	205.99	263.84	272.76	208.41	272.76
	Mann-Kendall	+	+	-	+	-	+
	Sen's Slope	2.53	1.85	-2.99	4.32	-3.22	0.06
S06	Mean	7.76	8.36	13.86	10.1	4.22	8.86
	Minimum	2.09	1.57	2.4	1.97	0.14	0.14
	Maximum	30.4	30.49	44.39	52.51	19.42	52.51
	Mann-Kendall	+	+	-	+	-	-
	Sen's Slope	0.40	0.13	-0.59	0.26	-0.74	-0.06
S07	Mean	48.66	41.6	48.05	48.09	51.42	47.57
	Minimum	9.72	10	10.2	8.57	15.5	8.57
	Maximum	244.75	150.59	149.26	190.16	199.82	244.75
	Mann-Kendall	-	+	-	+	-	+
	Sen's Slope	-1.08	1.41	-2.52	0.53	-0.89	0.20

**Table 5 Estimated parameters for the Gamma, Gumbel, Lognormal 2P and Pearson type 3 distributions.**

Distribution	Parameters						
	S01	S02	S03	S04	S05	S06	S07
Gamma	$\alpha = 4.24$	$\alpha = 1.92$	$\alpha = 4.08$	$\alpha = 3.20$	$\alpha = 8.13$	$\alpha = 1.83$	$\alpha = 9.69$
	$\beta = 1.78$	$\beta = 1.53$	$\beta = 0.55$	$\beta = 0.24$	$\beta = 2.52$	$\beta = 2.10$	$\beta = 1.60$
Gumbel	$\sigma = 5.92$	$\sigma = 1.92$	$\sigma = 1.78$	$\sigma = 0.57$	$\sigma = 17.17$	$\sigma = 2.55$	$\sigma = 13.42$
	$\mu = 2.89$	$\mu = 1.64$	$\mu = 0.87$	$\mu = 0.33$	$\mu = 5.94$	$\mu = 1.68$	$\mu = 5.47$
Lognormal 2P	$\sigma = 8.09$	$\sigma = 3.10$	$\sigma = 2.45$	$\sigma = 0.75$	$\sigma = 20.65$	$\sigma = 3.70$	$\sigma = 16.46$
	$\mu = 4.81$	$\mu = 2.21$	$\mu = 1.63$	$\mu = 0.42$	$\mu = 7.49$	$\mu = 2.79$	$\mu = 6.92$
Pearson type-3	$\alpha = 1.07$	$\alpha = 2.46$	$\alpha = 2.87$	$\alpha = 7.78$	$\alpha = 0.60$	$\alpha = 2.00$	$\alpha = 0.63$
	$\beta = 5.00$	$\beta = 5.00$	$\beta = 5.00$	$\beta = 5.00$	$\beta = 5.00$	$\beta = 5.00$	$\beta = 5.00$



**Table 6 The values of the Kolmogorov-Smirnov (KS) test**

<b>Station</b>	<b>Distribution</b>	<b>KS test statistics</b>	<b>P-Value (%)</b>	<b>Rank</b>
S01	Gamma	0.09	91.10	2
	Gumbel	0.09	85.81	3
	Lognormal 2P	0.08	96.26	1
	Pearson type 3	0.23	2.04	4
S02	Gamma	0.09	90.74	2
	Gumbel	0.10	82.41	4
	Lognormal 2P	0.09	88.23	3
	Pearson type 3	0.07	97.96	1
S03	Gamma	0.09	88.10	2
	Gumbel	0.09	89.84	1
	Lognormal 2P	0.10	82.75	3
	Pearson type 3	0.12	58.66	4
S04	Gamma	0.10	81.81	2
	Gumbel	0.11	74.30	3
	Lognormal 2P	0.09	90.04	1
	Pearson type 3	0.19	9.89	4
S05	Gamma	0.08	94.01	1
	Gumbel	0.09	89.56	3
	Lognormal 2P	0.09	90.62	2
	Pearson type 3	0.35	0.01	4
S06	Gamma	0.12	63.54	4
	Gumbel	0.07	99.05	1
	Lognormal 2P	0.10	82.96	2
	Pearson type 3	0.11	74.18	3
S07	Gamma	0.10	84.06	3
	Gumbel	0.09	89.90	2
	Lognormal 2P	0.08	96.08	1
	Pearson type 3	0.36	0.01	4

**Table 7 The return period of low flow at all streamflow stations.**

Station No.	Low Flow at Return Period (m <sup>3</sup> /s)						
	1-year	2.3-year	5-year	10-year	25-year	50-year	100-year
S01	21.42	18.19	15.27	12.63	9.13	6.49	3.85
S02	10.60	8.83	7.24	5.80	3.89	2.44	1.00
S03	6.44	5.45	4.55	3.73	2.66	1.84	1.02
S04	2.25	1.90	1.58	1.29	0.91	0.62	0.34
S05	48.40	41.54	35.35	29.72	22.29	16.67	11.05
S06	13.09	10.91	8.93	7.14	4.78	2.98	1.19
S07	34.56	30.14	26.15	22.53	17.74	14.12	10.49

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**Table 8 The threshold level values for Q70, Q80, Q90, and Q95.**

Station No.	Q <sub>70</sub> (m <sup>3</sup> /s)	Q <sub>80</sub> (m <sup>3</sup> /s)	Q <sub>90</sub> (m <sup>3</sup> /s)	Q <sub>95</sub> (m <sup>3</sup> /s)
S01	17.36	13.29	<b>9.80</b>	7.21
S02	5.14	4.04	<b>2.99</b>	2.34
S03	3.10	2.44	<b>1.47</b>	1.05
S04	1.26	1.01	<b>0.69</b>	0.54
S05	32.56	27.26	<b>21.52</b>	17.72
S06	5.19	4.14	<b>2.91</b>	2.14
S07	28.94	23.69	<b>18.78</b>	15.83