Journal of Hydrology 381 (2010) 174–180

Contents lists available at ScienceDirect

Journal of Hydrology

journal homepage: www.elsevier.com/locate/jhydrol

Regionalisation of low flow frequency curves for the Peninsular Malaysia

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ARTICLE INFO

Article history:
Received 7 October 2008
Received in revised form 18 September 2009
Accepted 22 November 2009

This manuscript was handled by K. Georgakakos, Editor-in-Chief, with the assistance of Kieran O'Connor, Associate Editor

Keywords:
Mean annual evaporation
Mean annual rainfall
Low flow
Frequency curve
Regionalisation
Regression analysis and ungauged catchment

SUMMARY

Regional maps and equations for the magnitude and frequency of 1, 7 and 30-day low flows were derived and are presented in this paper. The river gauging stations of neighbouring catchments that produced similar low flow frequency curves were grouped together. As such, the Peninsular Malaysia was divided into seven low flow regions. Regional equations were developed using the multivariate regression technique. An empirical relationship was developed for mean annual minimum flow as a function of catchment area, mean annual rainfall and mean annual evaporation. The regional equations exhibited good coefficient of determination (R^2 > 0.90). Three low flow frequency curves showing the low, mean and high limits for each region were proposed based on a graphical best-fit technique. Knowing the catchment area, mean annual rainfall and evaporation in the region, design low flows of different durations can be easily estimated for the ungauged catchments. This procedure is expected to overcome the problem of data unavailability in estimating low flows in the Peninsular Malaysia.

Introduction

Sustainable water resources planning and management requires adequate gauging data to enable quantification of water quality and quantity (Oyebande, 2001). Information is also required on the river flow patterns and availability of water within the catchment. Lack of adequate hydrological data introduces uncertainty and difficulty in the design and management of water resources systems. The most critical challenge in water resources projects (for irrigation, industrial, domestic, hydropower and environmental) is to establish the reliability of water availability at the point of interest. For any unregulated catchment (with no dams, reservoirs, weirs, etc.), reliability of water availability at the intake is determined from the low flow characteristics of the stream. The critical flow features of interest to designers are flow duration (day), magnitude (m^3/s) and frequency (return period in years). The design duration of low flow represents the tolerance of the user to periods of water unavailability. The magnitude for the specified duration dictates the amount of water available for the user(s). Finally the frequency of the occurrence of a particular magnitude of low flow reflects the risk associated with failure to achieve the water supply objective(s), which is determined based on the socio-economic importance of the scheme.

Estimation of flow characteristics of ungauged catchments is usually based on transferring or extrapolating information from gauged to ungauged sites, a process called regionalisation (Galea et al., 2007; Jevelle et al., 2002; Smakthin, 2001; Nathan and McMahon, 1990; Bullock and Andrews, 1997; Hall and Minns, 1999). Several regionalisation approaches have been used, the most common method being that which involves the derivation of empirical relationships between the flow and the catchment characteristics (Gan et al., 1990; Riggs, 1990). These relationships are in most cases region specific. Therefore, regions within which they are applicable have to be delimited, for example using hydrometric zones (Mimikou, 1984). Flow characteristics at an ungauged site are estimated by applying the predictive equation developed for its particular hydrometric zone (NERC, 1975; IH, 1980). Regionalisation also can be done by the application of self-organising feature maps (SOFMs) and fuzzy logic, which have been applied by Srinivas et al. (2008) as a clustering technique for the regionalisation of river flows.

Catchments that belong to the same hydrometric zone, however, may not necessarily have similar hydrological responses since

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doi:10.1016/j.jhydrol.2009.11.039

geographical proximity is not a sufficient condition for hydrological homogeneity (Acreman and Sinclair, 1986). Meijerink (1985) found that morpho-lithological characteristics could be used to identify catchment groups with similar hydrological responses. An alternative approach to the delimitation of regions with similar hydrological responses, i.e. regions that are hydrologically homogenous, is the use of multivariate techniques such as multiple regression, cluster and discriminant analysis (Tasker, 1982; Nathan and McMahon, 1990; Burn and Boorman, 1993; Zrinji and Burn, 1994). Ideally, only catchment characteristics should be used for cluster analysis. This enables determination of membership of an ungauged catchment on the basis of its catchment characteristics, to a region with a known relationship between flow and catchment characteristics. The selection of these catchment characteristics is problematic since different sets of predictive variables will identify different clusters. Nathan and McMahon (1990) demonstrated that a combination of multiple regression, cluster analysis and multidimensional plotting improved the delimitation of these hydrologically homogenous regions within which predictive equations for flow characteristics can be developed.

The regional approach of low flow analysis for ungauged catchments has been used in many countries including Malaysia (DID, 1985; Drayton et al., 1980; Taylor and Goh, 1976 and IH, 1980). A sufficient amount of good quality hydrometeorological data should be available from a set of neighbouring gauged catchments to estimate the required low flow characteristics of their ungauged counterparts. Industrial, agricultural and urban developments have increased demand on water resources and pressure to provide information on the water availability in rivers that have sparse or no data. In many instances, especially for the small-scale projects, economic and social pressures do not permit delay to allow for acquisition, screening and analysis of streamflow data. Responding to the urgent need for information on low flows, Hydrological Procedure (HP No.-12) was first prepared by Department of Drainage and Irrigation (DID), Malaysia in 1976 (Taylor and Goh, 1976). However, hydrological procedures are dynamic and such documents need upgrading periodically to account for the changes in landuse, weather and meteorological patterns. As such, the HP No.-12 was updated in 1985, using data up to 1982 (DID, 1985). That existing HP No.-12 has one shortcoming, namely, that the user has to refer to two regionalised maps to estimate the low flows. Moreover, it has not been updated during the last two decades. Thus, there was a need to upgrade the HP No.-12 to estimate low flows in the Peninsular Malaysia. The main objective of this study was to develop a simplified but reliable procedure for estimating low flows in the Peninsular Malaysia.

Methodology

Study area

The study was focussed on the Peninsular Malaysia, which is located in the sub-tropical humid region of the globe. Being located within longitudes 1–5° North and latitudes 100–104° East, the study area is influenced by the equatorial environment and located outside the volcanic, tornado, and severe drought belts. Two rainy seasons (north–east and south–west monsoons) and local convective thunderstorms contribute significant amount of storm events resulting in mean annual rainfall of about 2500 mm (DID, 2000). Although located in the humid region, the peninsula experiences occasional draught spells, the most recent one being in the year 1998. The main causes of low flow are dry spells, low rainfall incidents and increased soil imperviousness due to urbanisation.

Data used

Eighty two (82) stations in the Peninsular Malaysia, with length of records varying from 10 to 37 years (up to 1997) were selected for the analysis. The actual low flow (in m^3/s) of 1, 7 and 30 day durations at the selected stations were collected from DID's data archive. Selection of the river gauging stations included the consideration of tidal influence, any major flow control structure and catchment size (larger than 20 km^2, to be consistent with the conditions selected for the existing HP No.-12). After proper screening of the data, seventy eight (78) stations were accepted for the analysis. Discharge data collected after the construction of any major control structure upstream of the station were not considered. The effect of water abstraction for domestic, industrial and irrigation water supply on the stations was ignored as the data on the abstraction rate was not available. However, the stations were included for the study. It was assumed that $Q_{D,T(\mathrm{Cal})} = \left(\frac{Q_{D,T(\mathrm{Obs})}}{\mathrm{MAM}_{(\mathrm{Obs})}}\right) \times \mathrm{MAM}_{(\mathrm{Cal})}$; where $Q_{D,T}$ is the low flow of D-day duration with a T-year return period. The mean annual minimum (MAM) flow (m^3/s) was calculated for each year based on the 1-day low flow data of each station. The subscripts "(cal)" and "(Obs)" indicate calculated and observed (recorded) values. Mean Annual Evaporation (AE, in mm) was extracted from the data archive of the DID, Malaysia. The catchment areas at the river gauging stations were calculated from the digitisation of topographical maps using AutoCAD software.

Statistical analyses

Several distributions were tested (three types of generalised extreme value – GEV, Log-normal and Log-Pearson III) for the frequency analysis of low flows. Generally, the extreme value (EV III) distribution showed good fit with most of the low flow data, which was in agreement with the distribution used in the last upgrading of the HP No.-12 (DID, 1985). The low flows of various return periods were predicted by the method of moments as given by Haan (1977). However, this requires an awkward solution for the shape parameter of the GEV distribution.

$$Q_T = Q_{\mathrm{mean}} + \sigma K \tag{1}$$

in which Q_T = the magnitude of the event for a return period of T years; Q_{mean} = the arithmetic mean value of the annual low flow events; σ = the standard deviation from the mean; K = the chow frequency factor for extreme values, which depends on the type of distribution used.

The D-day low flow values for the return periods of 1.11, 1.25, 2, 5, 10, 20, 25 and 50 years were divided by the station's $\mathrm{MAM}_{(\mathrm{Obs})}$ value to get dimensionless low flow in the form of $Q_{D,T(\mathrm{Obs})}/\mathrm{MAM}_{(\mathrm{Obs})}$. These ratios were, then, plotted against the reduced variate (y) expressed in terms of return period (T) as given in Eq. (2) below (Cunnane, 1978; Victor, 1994). Depending on the number of data, the values of T were calculated either by Eqs. (3) or (4).

$$y = -\ln\left\{\ln\left(\frac{T}{T-1}\right)\right\} \tag{2}$$

The Kolmogorov-Smirnov test was done (with α = 0.05) to check the goodness of fit of the data. Data of the stations that showed goodness of fit statistic falling above its 95% confidence limit (under the null hypothesis) were accepted for the regional grouping. The following plotting position formulas were selected for the study. They were also used in the previous versions of the HP No.-12 (Taylor and Goh, 1976 and DID, 1985):