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# SEASONAL VARIATION OF FLOOD ESTIMATES IN THE UK

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## ABSTRACT

Flood is one of the most common and significant natural disasters in the world. Over recent decades, accelerated population growth and changes in land use patterns have resulted in increased human vulnerability to floods. Flood estimates are essential for a range of engineering design and planning purposes, including hydraulic structures construction, flood-plain management and flood risk mapping. Even though accurate flood estimates can reasonably reduce potential flood risk by improving the reliability of flood mitigation methods, previous research indicates that conventional methods for flood estimation in the UK still contain uncertainties. This study analyses the seasonal variation of flood estimates at 62 catchments distributed throughout the UK aiming to provide new knowledge and information for improving flood estimation in the UK. The flood seasonality has been investigated from hourly river flow records by using Generalised Logistic (GL) flood frequency curves derived from L-moments. The results indicate that the monthly variation in index flood, parameter $k$ and $\beta$ for the GL flood frequency curves can reflect a distinct seasonality in river flooding of most parts in the UK. The general trend is that the flood risk is high in winter, and low in summer.

**Keywords:** Flood estimates, Seasonality, Generalised logistic distribution, Flood risk, UK

## 1 INTRODUCTION

Every year, floods lead to numerous fatalities. River flooding is one of the most common and significant natural disasters over the world. The impacts of floods on human beings include direct mortality and indirect damages such as widespread damage of crops, property and infrastructure. Nowadays, problems become more critical since accelerated population growth and changes in land use patterns have resulted in increased human vulnerability to floods in recent decades (Güneralp et al., 2015). Climate change is also believed to have increased the frequency and intensity of extreme rainfall (Arnell and Gosling, 2016; Winsemius et al., 2016; Hirabayashi et al., 2013). Flood estimation is a crucial component for flood control including both structural measures and non-structural measures, such as flood-control reservoirs, dikes or levees, flood warning and land-use planning. Accurate flood estimates can reasonably reduce potential flood risk by improving the reliability of flood control measures. However, Kjeldsen (2014) indicated that the conventional method for flood estimation in the UK still contain uncertainties, mainly related to ungauged catchments and in particular to the index flood estimation. Thus, improving flood estimation is regarded as one of the most vital hydrological issues in the UK.

Understanding the dominant mechanisms of flooding is essential for improving flood estimation (Ye et al., 2017; Berghuijs et al., 2016). River flooding displays evident variation both seasonally and spatially (Villarini, 2016; Cunderlik at al., 2004; Lecce, 2000; Archer, 1981). Flood seasonality is commonly regarded as a prominent indicator for the investigation of flood-generating mechanisms (Beurton & Thieken, 2009; De Michele & Rosso, 2002). Analysis of flood seasonality can provide important insights on the flood generating processes and their controlling factors (Diakakis, 2017; Berghuijs et al., 2016; Villarini 2016). Many studies have already investigated the seasonality of floods in several parts of Europe (Diakakis, 2017; Köplin et al., 2014; Villarini et al., 2011; Beurton & Thieken, 2009). In the UK, only few studies have been carried out, and most of them only focus on a regional scale analysis of flood seasonality in Wales (Macdonald et al., 2010) or in Scotland (Black and Werrity, 1997). There is still a limitation in representing the seasonal variation of flood estimates for the whole UK. This study explores and analyses the seasonal variation of flood estimates among each month at 62 catchments distributed throughout the UK aiming to provide new knowledge and information for improving the flood estimation in the UK.

## 2 DATA AND METHODS

### 2.1 Study area and data

The study area includes the territory of the UK, except for Northern Ireland. The UK lies in the higher mid-latitudes between 49° and 61° N, and it is well known for its unsettled weather because it is always in or close to the path of the polar front jet stream. The climate in the UK is defined as a temperate maritime climate, with mild wet winters and warm wet summers. This study considered hourly river flow records during the period of 1999-2008 for 76 catchments from the UK Benchmark Network (UKBN) to capture flow characteristics of peak floods with the annual maximum hourly flood flow. These can be considered as 'near-natural' catchments less affected by human disturbances such as urbanisation, river engineering, and water abstractions (National River Flow Archive, 2018). Figure 1 illustrates the spatial distribution of the 76 gauging stations in the UK. The detailed information about catchment characteristics is summarized in *https://nrfa.ceh.ac.uk/data/search*. It is noted that this study considers flow data from the 62 catchments, which have sufficient valid data covering every month during the 10-year record.

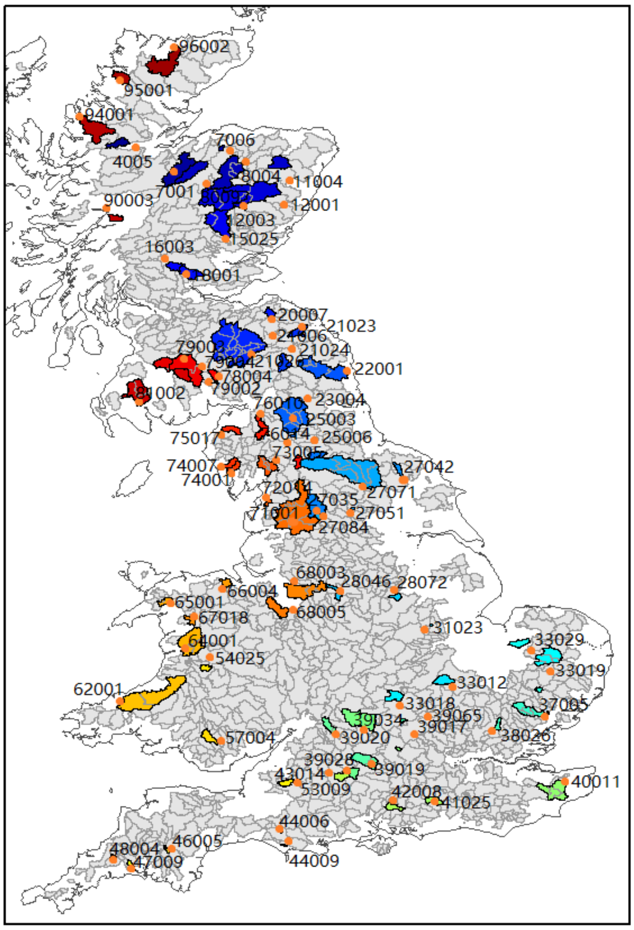



**Figure 1**. Spatial distribution of the 76 Benchmark catchments in the UK

### 2.2 Method

In this study, an index flood method was applied for the statistical analysis of flood estimates, where a flood frequency curve is derived as the product of an index flood and a dimensionless growth curve. The index flood can be considered as a typical size of floods for a particular catchment. Median values of annual maximum hourly flow (QMED) were adopted as the index flood followed by the UK Flood Estimation Handbook (FEH) (Institute of Hydrology, 1999). The dimensionless growth curve represents a normalised flood frequency curve for a catchment, which is a probability distribution fitted to annual maximum flows that have been standardised by dividing each flow value in the series by the index flood (QMED). Here, the Generalised Logistic (GL) distribution was selected to derive the growth curve and its parameters were estimated from L-moments. It is known that the FEH recommends the GL distribution to better represent the annual maximum series for the UK flood data. The GL distribution is a three-parameter distribution defined by:

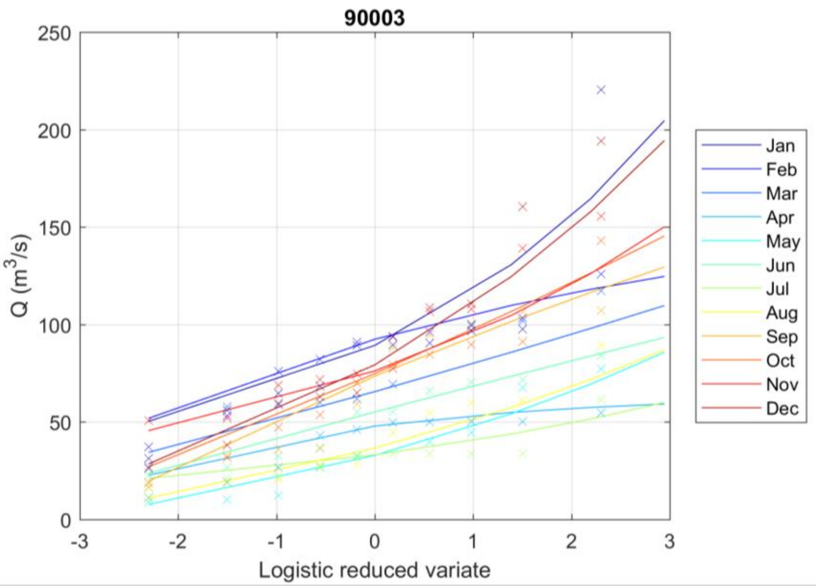
$$x(T) = 1 + \frac{\beta}{k}\{1-(T-1)^{-k}\} \quad (k \neq 0) \qquad [1]$$

where $T$ is a return period, $k$ is a shape parameter and $\beta$ is a scale parameter. As the flood frequency curve illustrates the relationship between flow and return period, it is also referred to as a variate versus reduced-variate plot (Reed & Robson, 1999). For the GL distribution, the appropriate frequency scale is the logistic reduced variate $y_L$ , defined by:

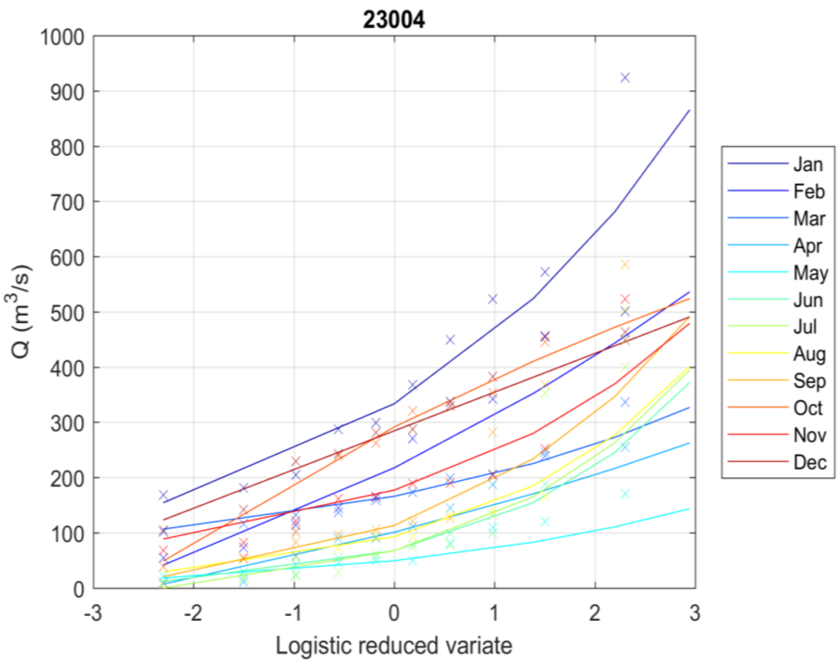
$$y_L = \ln(T-1) \qquad [2]$$

## 3 RESULTS AND DISCUSSION

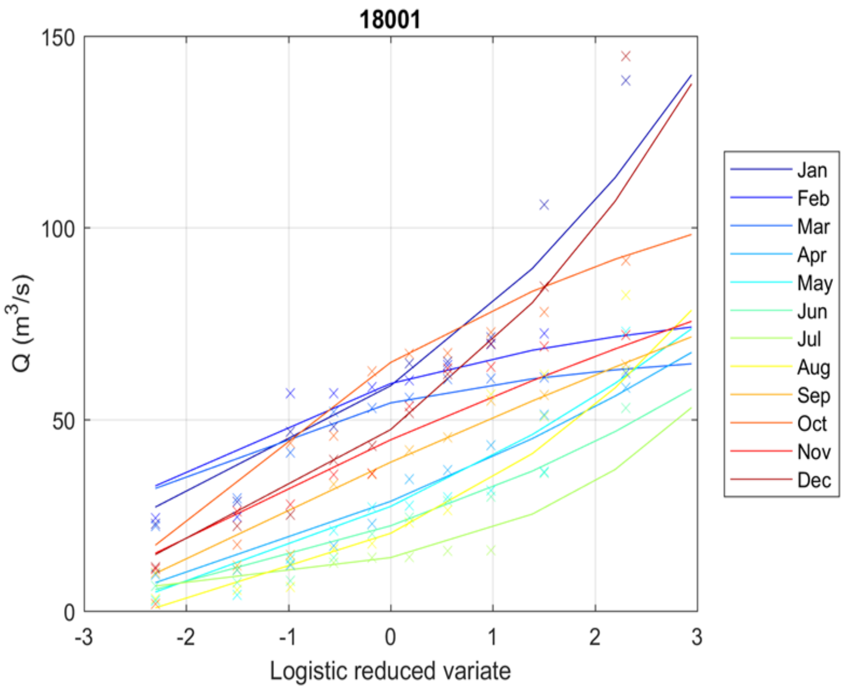
In order to explore seasonality of flood estimates, monthly flood frequency curves for each catchment have been analysed, depending on different return periods of 1.1, 2, 5, 10 and 20 years, respectively. Additionally, the results from the GL distribution were compared with the observed flood data from the Weibull plotting position. The comparison results for three representative catchments are summarized in Figure 2.




(a)




(b)

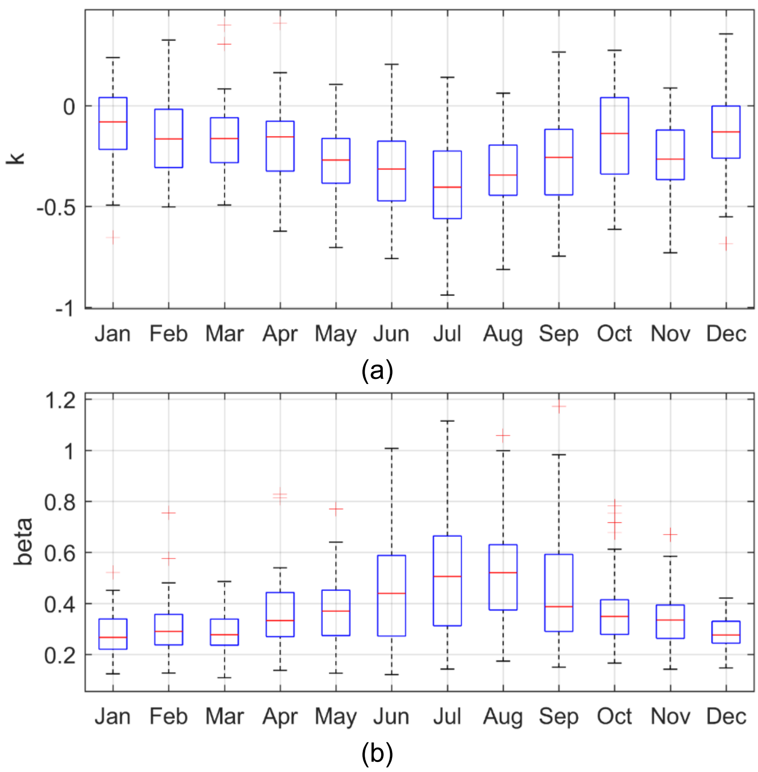



(c)

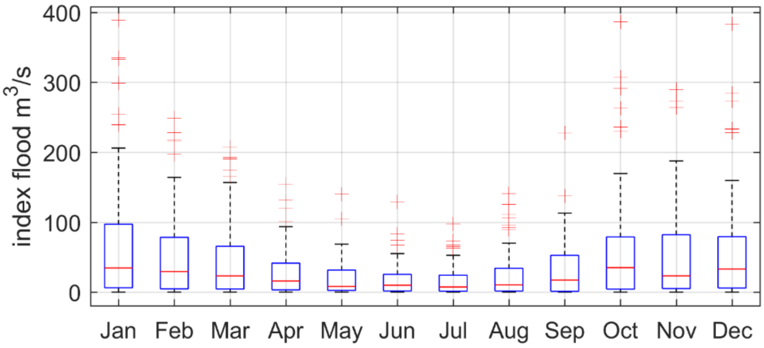
**Figure 2**. Monthly flood frequency curves for three representative catchments in the UK (here, the cross marks represent observed flood data from the Weibull plotting position): (a) 90003 – River Nevis (Claggan); (b) 23004 – River South Tyne (Haydon Bridge); and (c) 18001 – Allan Water (Kinbuck)

At first, it indicates that the flood frequency curves have evident monthly variations. For the gauging station 90003, the 20-year flood represents a range from 60 $m^3/s$ to 151 $m^3/s$ except for January and December with 204 $m^3/s$ and 194 $m^3/s$, respectively. At the station 23004, the flood frequency curves for each month are different from each other; the 20-year flood varies from 150 $m^3/s$ to 540 $m^3/s$ and reaches 875 $m^3/s$ in January. Similarly, most of the 20-year flood at the station 18001 are between 55 $m^3/s$ and 98 $m^3/s$ except for January and December with approximately 140 $m^3/s$. This diversity of the flood frequency curves for each month can be also identified in the rest of 62 catchments, which indicates a distinct seasonality of flood risk in the UK. The monthly flood frequency curves also vary in the curvature. It is worthwhile to point out that most of them are concave upward. Specifically, they are convex only for February and April (90003), October (23004) and February, March and October (18001), respectively. These plots also show that the GL flood frequency curve underestimates the peak flood events for longer return periods (i.e., 10-year or 20-year) compared with the observations plotted by means of the Weibull plotting position. The underestimation of the GL flood frequency curve is larger in winter (wet months) than that in summer (dry months).

To examine this seasonality in greater detail, the estimated $k$ and $\beta$ parameters for the GL distribution and the index floods of the 62 catchments are summarized in Figure 3. It indicates that the $k$ parameters vary in each month and they are close to zero with median values of -0.138 (December) and -0.103 (January) in the wet winter season. However, it shows a much smaller value of -0.397 (July) in the dry summer season. It should be noted that the shape parameter $k$ determines the curvature of the GL curve. That is, the GL curve is concave when $k$ is negative and vice versa. The $\beta$ parameters present a wider spread of values with large medians of 0.444, 0.499, 0.511 and 0.441 from June to September during the dry summer season. On the other hand, the median $\beta$ values for the wet winter season are 0.283 (December) and 0.281 (January), respectively. Because the scale parameter $\beta$ determines the slope of the GL curve, it results in much steeper slopes of the GL curve for the wet winter season than those for the dry summer season. It is noted that the median index floods of the 62 catchments are only 8.3 $m^3/s$ in May, 9.9 $m^3/s$ in June and 7.3 $m^3/s$ in July. In contrast, they are 33.1 $m^3/s$, 34.6 $m^3/s$ and 29.4 $m^3/s$ in December, January and February, respectively. It reveals the seasonality of potential flood risk with higher index floods in winter.






(c)

**Figure 3**. Monthly variations of the parameters of the GL distribution and the index floods with box plots: (a) k; (b) $\beta$; and (c) index flood

Most of the catchments have the wettest month in January (34 catchments), December (11 catchments) and October (10 catchments) with the maximum index floods while the driest months in June (12 catchments) and July (25 catchments) with the minimum index floods. The seasonal variation represented by the wet winter and dry summer seasons is clearly identified from the monthly normalised index floods (Figure 4). It represents monthly index floods 10% to 140% higher than the average index flood in December and 40% to 60% lower than the average one in June and July.

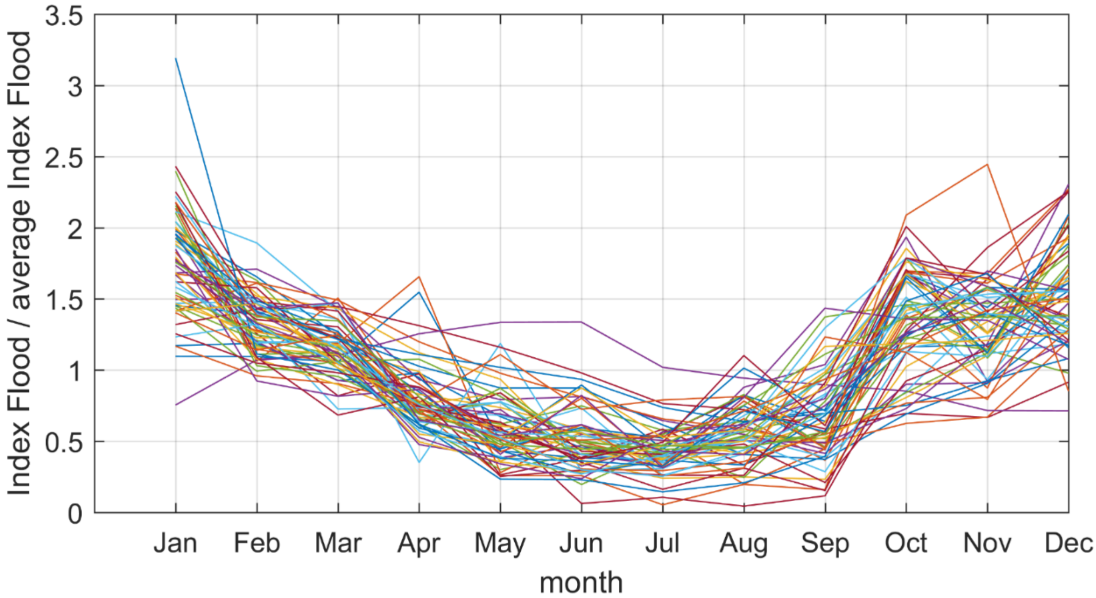



**Figure 4**. Normalised monthly index floods for the 62 catchments in the UK

This study investigates the flood frequency curves for each month to provide new insight into the seasonal variation in river flooding in the UK. The seasonality of flood events can be useful for flood risk estimation in engineering design and construction projects either in or adjacent to rivers (Sivapalan et al., 2005). Furthermore, it can be valuable for the more economic design of hydraulic structures with appropriate construction periods (David, 1981). However, this study only focuses on exploring the existence of river flood seasonality in the UK, but without going further to explore the factors that possibly cause this seasonality. A future study could be addressed to better consider controlling factors using multivariate analysis involving different factors including precipitation characteristics, land use, geology, topography, or catchment size etc. Furthermore, the impacts of climate change and anthropogenic influences on flood events can increase the uncertainty of the conventional flood frequency analysis. Therefore, it can be also considered to further explore the flood seasonality for the UK using a nonstationary flood frequency analysis method for better flood estimation in a changing environment.

## 4 CONCLUSIONS

This study analysed the monthly flood frequency curves to investigate flood seasonality in the UK. The GL distribution was considered to estimate flood frequency curves for each month from hourly river flood records during ten years at 62 catchments covering the entire UK. It was found that the catchments in the UK have evident seasonal variation of flood estimates indicated by the wet winter and dry summer seasons. It depends on the index flood, shape parameter $k$ and scale parameter $\beta$ for the monthly GL flood frequency curves. Most of the catchments have the wettest month in January or December and the driest month in June or July, which was determined by the index floods for each month. The monthly index floods of the 62 catchments were much higher and spread wider in the winter wet season than the dry summer season. Conversely, the values of scale parameter $\beta$ were higher and much closer to one in summer than those in winter. Almost all the $k$ parameters were negative and only few in wet winter months were positive. It results in most of the monthly GL curves are concave while few are convex. The monthly GL flood frequency curves were compared with the observations from the Weibull plotting position, which revealed that they underestimated the peak flood events for relatively longer return periods, especially for the wet months. As the estimation of monthly flood risks can provide practical information for construction, maintenance and design of hydraulic structures, it can be suggested for the future study to further consider controlling factors of this seasonality and nonstationary flood frequency analysis.

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