Homogeneity Testing for Peak Discharge in Catchments in the Equatorial Nile Basins

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ABSTRACT

Regional flood frequency analysis deals with the identification of homogeneous regions of which the distribution of peak flows from sites from in such a region are similar. Once a homogenous region is identified, standardized data from different sites within the region can be pooled together and a single frequency curve applicable to the region can be derived.

The data used in this study includes Annual Maximum Annual Flood (MAF) series of daily discharges from 28 river gauging stations located in the Nile Equatorial Basin. These data were quality controlled using single mass analysis, and time series plots to check any inconsistencies before the MAF series were extracted. The regional homogeneity testing was done independently for stations in Kenya and Tanzania because of the large variations in the length of records.

The methods used for regional homogeneity testing are the heterogeneity measure statistics, the use of L-moments diagrams and at-site regional analysis. L-moments are defined as linear combinations of probability weighted moments (PWM). L-moment ratio diagrams are based on simple measure of the dispersion of the sample L-moments such as linear combination of: the coefficient of variation (L-CV), the skewness (L-CS) and kurtosis (L-CK). In this case the method of assessing heterogeneity is based on visual assessment of the dispersion of the at-site L-moments of the observed and simulated region. Heterogeneity statistics are also computed on the basis of L-moment ratios.

The regional analysis approach, used with Tanzanian data, is based on the empirical distributions determined for all the sites within the region. The average of the empirical distributions is determined to represent the frequency curve for the region. Based on the Quantile-Quantile (Q-Q) plots, Extreme Value Type I (EV1) was the selected theoretical distribution used to derive the regional frequency curve for the Tanzania data using the method of PWM to estimate the parameters. The regional frequency curve in this case is derived by regional averaging of dimensionless at-site order statistics.

The results of the study indicated that the stations in the Kenyan part of the basin can be considered to be moderately heterogeneous and cannot entirely be represented by a single distribution in regional analysis. The L-moment ratio diagrams for the observed and simulated data show some dissimilarity while the absolute value of the heterogeneity measure statistics is 1.25. The result of regional analysis based on empirical distributions grouped together the Tanzanian stations into relatively homogeneous region.

Keywords: L-moment ratios, homogeneity grouping, discordancy measure, heterogeneity measure, Quantile-Quantile (Q-Q) plots
1. INTRODUCTION

In many water-engineering applications, the available time series are too short for a reliable estimation of extreme events. The difficulties are related to the uncertainty in the calibration of the appropriate extreme value distribution. Regionalization provides a means to cope with this problem by assisting in the identification of the shape of the extreme value distribution, leaving only a measure of scale (or more general, an ‘index’) to be estimated from the at-site data.

Identification of homogeneous regions where the distribution of peak flows is similar is important for regional flood frequency analysis. Once a homogenous region is identified, standardized data from different sites within the region can be pooled together and a single frequency curve applicable to the region can be derived. In cases where adequate rainfall or river flow records are not available at or near the site of interest, it is difficult for hydrologists and engineers to derive reliable flood estimates directly and regional studies can be useful.

This paper focuses on the application and comparison of techniques for homogeneity testing. Discharge data from the Nile Equatorial basins in Kenya and Tanzania were considered.

1.1 DATA AND STUDY AREA

Data Available

The data that have been used to carry out the homogeneity testing includes Maximum Annual Flood (MAF) series of daily discharges from 28 river gauging stations located in the Nile Equatorial Basin (9 stations located on the Tanzanian side and 19 stations located on the Kenyan side). The list of river gauging stations used in the study is presented in Table 1. From the table, it can be observed that stream flow records from the Tanzanian side are only available for the period from 1970 to 1982 and the record length of available data varies from 9 to 11 years. Record lengths on the Kenyan side range between 32 and 47 years. These data were quality controlled using mass curve, double mass curve methods, and time series plots to check any inconsistencies before the MAF series were extracted.

For the purpose of flood frequency analysis two methods of sampling are of relevancy i.e. Maximum Annual Flood (MAF) series or Partial Duration (PD) series. The MAF series consist of the maximum flows for each year, and is the most frequent sampling method used among the two common series. One of the aspects in favor of the MAF series is the reasonable assumption that the data series is not serially correlated, i.e., successive values are independent. This property is an important prerequisite for the subsequent statistical treatment of data. A disadvantage of MAF series is that the second or third, etc., highest events in a particular year may be higher than the maximum event in another year and yet they are totally disregarded.

The PD series, on the other hand, consists of flood peak events above a certain threshold magnitude. The threshold is generally selected low enough so that at least one event in each year is included in the series. It is important that each event that is included in the PD series must be separate and distinct so that the sampled events are independent.

The regional homogeneity testing was done for Kenya and Tanzania stations independently because of the large variations in the length of records. However, MAF populations at several sites are assumed not to be dependent on catchment size, Cunnane (1989). Table 1 gives an overview of the stations considered in the study while figure 1 shows the distribution of the stations within the Nile equatorial basin.

Figure 1: Map of the study area and the location of river gauging stations for the study.

2. METHODS FOR HOMOGENEITY TESTING

Sites are grouped when they have similar catchment characteristics, e.g. flood response, when a regionalized flood frequency analysis is conducted, Cunnane (1989). Hosking and Wallis (1993) developed several tests for use in regional studies. They gave guidelines for judging the degree of homogeneity of a group of sites, and for choosing and estimating a regional distribution. The three regional homogeneity measures selected for this study are the heterogeneity measure statistics, and the use of L-moment ratio diagrams and at-site regional analysis. L-moment ratio diagrams as a tool for identifying a regional distribution have been used in many studies, including Chowdhury et al. (1989), Pilon & Adamowski (1992), Vogel & Fennessey (1993), and Vogel et al. (1993a, 1993b). Another method for homogeneity test is based on estimated dimensionless 10-year floods developed by Lu & Stedinger (1992).
Table 1: List of discharge stations used in the analysis

<table>
<thead>
<tr>
<th>Serial no.</th>
<th>River</th>
<th>Station</th>
<th>Area (km²)</th>
<th>Country</th>
<th>Period of record</th>
<th>Years of record</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Ngono</td>
<td>Muhutwe</td>
<td>780</td>
<td>Tanzania</td>
<td>1971-1982</td>
<td>9</td>
</tr>
<tr>
<td>2</td>
<td>Ngono</td>
<td>Kalebe brg</td>
<td>1185</td>
<td>Tanzania</td>
<td>1970-1982</td>
<td>10</td>
</tr>
<tr>
<td>3</td>
<td>Ngono</td>
<td>Kyaka rd brg</td>
<td>2608</td>
<td>Tanzania</td>
<td>1970-1982</td>
<td>11</td>
</tr>
<tr>
<td>4</td>
<td>Ruvuma</td>
<td>Mwendo ferry</td>
<td>-</td>
<td>Tanzania</td>
<td>1970-1982</td>
<td>10</td>
</tr>
<tr>
<td>5</td>
<td>Kagera</td>
<td>Nyakanyasi</td>
<td>48228</td>
<td>Tanzania</td>
<td>1970-1978</td>
<td>9</td>
</tr>
<tr>
<td>6</td>
<td>Moame</td>
<td>Mabuki brg</td>
<td>1410</td>
<td>Tanzania</td>
<td>1970-1982</td>
<td>11</td>
</tr>
<tr>
<td>7</td>
<td>Magogo</td>
<td>Shinyanga rd</td>
<td>1212</td>
<td>Tanzania</td>
<td>1970-1982</td>
<td>11</td>
</tr>
<tr>
<td>8</td>
<td>Simiyu</td>
<td>Road crossing</td>
<td>10659</td>
<td>Tanzania</td>
<td>1970-1978</td>
<td>9</td>
</tr>
<tr>
<td>9</td>
<td>Simiyu</td>
<td>Ndagalu</td>
<td>10560</td>
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<td>1970-1982</td>
<td>11</td>
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<tr>
<td>10</td>
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<td>1be06</td>
<td>808</td>
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<td>1956-1984</td>
<td>29</td>
</tr>
<tr>
<td>11</td>
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<td>1be01</td>
<td>715</td>
<td>Kenya</td>
<td>1956–1975</td>
<td>20</td>
</tr>
<tr>
<td>12</td>
<td>Noigameget</td>
<td>1bc01</td>
<td>681</td>
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<td>1950-1985</td>
<td>36</td>
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<tr>
<td>13</td>
<td>Nundoro</td>
<td>1cb08</td>
<td>167</td>
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<td>1964-1984</td>
<td>21</td>
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<tr>
<td>14</td>
<td>Sergoit</td>
<td>1ca02</td>
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<td>Kenya</td>
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<tr>
<td>15</td>
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<td>Kenya</td>
<td>1960 – 1989</td>
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<td>16</td>
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<td>1jf06</td>
<td>394</td>
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<td>1964-1988</td>
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<tr>
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<tr>
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<td>1ee01</td>
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<td>Kenya</td>
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<td>Kenya</td>
<td>1950-1985</td>
<td>36</td>
</tr>
<tr>
<td>20</td>
<td>Nzoia</td>
<td>1da02</td>
<td>8417</td>
<td>Kenya</td>
<td>1950-1988</td>
<td>39</td>
</tr>
<tr>
<td>21</td>
<td>Yala</td>
<td>1fe02</td>
<td>1577</td>
<td>Kenya</td>
<td>1962-1985</td>
<td>24</td>
</tr>
<tr>
<td>22</td>
<td>Kipkarren</td>
<td>1ce01</td>
<td>2440</td>
<td>Kenya</td>
<td>1950-1987</td>
<td>38</td>
</tr>
<tr>
<td>23</td>
<td>Kipwen</td>
<td>1cb09</td>
<td>80</td>
<td>Kenya</td>
<td>1964-1984</td>
<td>21</td>
</tr>
<tr>
<td>24</td>
<td>Little nzoia</td>
<td>1bb01</td>
<td>1474</td>
<td>Kenya</td>
<td>1957-1985</td>
<td>29</td>
</tr>
<tr>
<td>25</td>
<td>Rongit</td>
<td>1bg07</td>
<td>684</td>
<td>Kenya</td>
<td>1961-1984</td>
<td>24</td>
</tr>
<tr>
<td>26</td>
<td>Nyando</td>
<td>1gd04</td>
<td>2520</td>
<td>Kenya</td>
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<tr>
<td>27</td>
<td>Kuja Migori</td>
<td>1kc03</td>
<td>3046</td>
<td>Kenya</td>
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<tr>
<td>28</td>
<td>Kipkarren</td>
<td>1cd01</td>
<td>67</td>
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<td>1932-1987</td>
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compared several goodness-of-fit tests for the regional Generalized Extreme value (GEV) distribution and found that a new chi-square test based on the L-coefficient of variation and the L-skewness outperformed other classical tests. The heterogeneity measure, and the L-moment ratio methods for identification of homogeneous regions are briefly discussed below.

2.1 Heterogeneity measure statistics

The statistics of the standardized flood data such as the coefficient of variation ($C_v$), coefficient of skewness ($C_s$), coefficient of kurtosis ($C_k$) and the index flood $Q_{max}/\bar{Q}$; where $Q_{max}$ are the flood series or annual maximum series and $\bar{Q}$ is the mean flood) are considered to be constant across a homogeneous region, Hosking(1986, 1990). Departures from such assumptions could lead to a bias in the flood estimates at some sites. Those catchments whose $C_v$, $C_s$, $C_k$ and $Q_{max}/\bar{Q}$ values happen to coincide with the regional mean values would not suffer such bias. Under this method, the hydrologic homogeneity can
Furthermore statistics such as the linear combination of PWM (L-moments) can be used to estimate the degree of heterogeneity in a group of sites and to assess whether they might reasonably be treated as a homogeneous region, Hosking et al. (1993). The method of heterogeneity measure statistics was based on the L-moments which are defined below:

**L-moments**

For a random variable $X$ with cumulative distribution function $F$, the following quantiles:

$$
\beta_r = E\{X[F(X)]^{(r)}\}
$$

(1)

are the Probability-Weighted Moments (PWMs), defined by Greenwood et al. (1979) and used to estimate the parameters of the probability distributions. Hosking (1986, 1990) defined L-moments to be linear combinations of PWMs:

$$
\lambda_{r+1} = \sum_{k=0}^{r} P'_{r,k} \beta_k
$$

(2)

where: $\beta_k$ are the PWMs with $k=0, 1, 2, \ldots, r$

$\lambda_{r+1}$ are the L-moments with $r=0, 1, 2, \ldots, k$

and for $r, k$ $P'_{r,k}$ is given by

$$
P'_{r,k} = (-1)^{r-k} \binom{r+k}{k} \binom{r}{k}
$$

(3)

In particular the first four L-moments are given as:

$$
l_1 = b_0 b_1, l_2 = 2 b_1 - 6 b_2 + 20 b_3 - 30 b_4 + 12 b_5, l_3 = b_3 \ldots
$$

(4)

L-moment ratios are the quantities $t = l_2/l_1$ and $t_r = l_{r+1}/l_r, r = 3, 4, \ldots$

Figures 2 and 3 are examples of L-moment ratio diagrams. L-moments are similar to but more convenient than PWMs because they are more easily interpretable as measures of distribution shape. In particular, $l_1$ is the mean of the distribution, a measure of location; $l_2$ is a measure of scale; $t_3$ and $t_4$ are measures of skewness and kurtosis, respectively. The L-CV, $t_2 = l_2/l_1$, is analogous to the usual coefficient of variation.

$$
l_{r+1} = \sum_{k=0}^{r} P'_{r,k} b_k
$$

(5)

such that the first sample L-moment would be $l_1$ for $r=0$

and $b_k$ is given by

$$
b_k = \frac{1}{n} \sum_{i=1}^{n} (j-1)(j-2) \ldots (j-r) Q_j
$$

(6)

Then $l_1$ is an unbiased sample-based estimator of $l_1$. The estimators $t_i = l_i/l_j$ of $t_i$ are consistent but not unbiased. The quantities $l_1, l_2, l_3, t_3$ and $t_4$ are useful summary statistics for data samples. They can be used to judge which distributions are consistent with a given data sample (Hosking, 1990). Details can be found in Hosking et al. (1993) among others.

Heterogeneity measure statistic by means of L-moments
In a homogeneous region, all sites have the same population L-moment ratios. Their sample L-moment ratios will, however, be different owing to sampling variability.

The easiest, but subjective, method of assessing heterogeneity is by visual assessment of the dispersion of the at-site L-moments such as the L-moment coefficient of variation (L-CV), the L-skewness (L-CS) or the L-kurtosis (L-CK). This can be done based on a plot of L-CS versus L-CV or L-CK, commonly referred to as L-moment diagrams, Hosking et al. (1993).

An alternative and more objective simple measure of the dispersion of the sample L-moments is the standard deviation of at-site L-CVs. L-CVs are used in this study because between-site variation in L-CV has a much larger effect than variation in the L-CS or L-CK on the variance of the estimates of quantiles, except those in the far tail of the distribution (Hosking et al., 1985a). Simulation can be used in order to establish the kind of dispersion that would be expected. By repeated simulation of a homogeneous region with sites having record lengths the same as those of the observed data, the mean and the standard deviation of the chosen dispersion measure can be obtained (Madsen et al., 1997b). The level of homogeneity or heterogeneity measure, \( H \), of a region then can be expressed as:

\[
H = \frac{Y - \hat{Y}}{\sigma} \quad \text{(7)}
\]

where \( Y \) is the statistic or variable considered to test the homogeneity, \( \hat{Y} \) the mean of the simulated values for this variable and \( \sigma \) is the standard deviation of the simulated values, Hosking et al. (1993) and Burn (1997).

However, a more appropriate statistic compares the observed and the simulated dispersion, through the weighted standard deviation (\( V \)) of the at-site L-CVs, Burn (1997). This expressed as:

\[
V = \frac{\sum_{i=1}^{N} n_i (t_i' - \bar{t})^2}{\sum_{i=1}^{N} n_i} \quad \text{(8)}
\]

where \( t_i' \) and \( \bar{t} \) are the sample L-CVs at each site \( i \) and the regional mean L-CV respectively, while \( n_i \) are the sample record lengths at each site \( i \) and \( N \) is the number of sites.

Group average L-moment ratios, with sites weighted proportionally to their record lengths are:

\[
\bar{t}_i, \bar{t}_3, \bar{t}_4, \ldots\]

where the sample L-moment ratios at site \( i \) are denoted by \( t_2, t_3, t_4, \ldots \).

Then a Gumbel distribution is fitted to the regional average L-moment ratios, which are the mean sample L-moment ratios obtained from a finite sample. The regional average L-moment ratio is computed from the site values which are weighted proportionally to their record lengths as shown in Equation 9.

Finally, a similar number of regions as the observed \( N_{\text{sim}} \) is to be simulated from the Gumbel distribution; the regions are homogeneous and have no cross correlation or serial correlation, and sites have the same record lengths as the observed data. For each simulated region calculate \( V \) and from the simulations determine the mean and standard deviation of the \( N_{\text{sim}} \) values of \( V \) and call these \( m_v \) and \( s_v \).

Mathematically, equation 6 can be written as:

\[
H = \frac{V - \mu_V}{\sigma_V} \quad \text{(10)}
\]

in which \( H \) is the heterogeneity measure statistic.

The region is regarded as “acceptably homogeneous” if \( |H| < 1 \), “possibly heterogeneous” if \( 1 < |H| < 2 \), and “definitely heterogeneous” if \( |H| \geq 2 \) (Hosking and Wallis, 1993).

### 2.2 Regional distribution analysis

This approach is based on the empirical distributions determined for all the sites within the region. The average of the empirical distributions is determined to represent the frequency curve for the region. Empirical distributions are determined for each site by ranking the standardized data (after dividing by the scale parameter) in ascending order and then assigning to each of the ranked standardised flow magnitudes the probability of non-exceedance by using the Gringorten plotting position formula. This plotting probability is unbiased and suitable for Gumbel and exponential paper.

The Gringorten formula is expressed as:

\[
F_i = \frac{i - 0.44}{N + 0.12} \quad \text{(11)}
\]
sample member. The results of using an empirical approach are presented in section 3.

Regional flood frequency analysis can also be based on the L-moments: The L-moment ratios $l_1$, $l_2$, $l_3$, …, $l_p$ are estimated by the corresponding sample L-moments of the at-site statistics. Hosking et al. (1985a), Lettenmaier and Potter (1985), Wallis and Wood (1985), Lettenmaier et al. (1987), Hosking and Wallis (1988), and Potter and Lettenmaier (1990) have shown that index flood procedures based on PWMs or L-moments yield robust and accurate quantile estimates.

In this study, the Q-Q plots were used to select best the theoretical distributions using the 9 locations in Tanzania. The method of Q-Q plots has been discussed by Opere et al. (2006). The regional frequency curve is derived by regional averaging of dimensionless at-site order statistics such as obtained by division of MAF series, $Q$, by the mean MAF, $\bar{Q}$, at each site and fitting a distribution, Cunnane (1989).

It should be noted that the equation of the regional frequency curve is given by:

$$Q(T) = 0.801 + 0.3451 y(T)$$

with $y(T)$ the reduced variate $-\ln(-\ln(F(Q))$.

3. RESULTS AND DISCUSSIONS

Results from the methods that were used to determine regional homogeneity are presented in this section. The discharge data were subjected to various statistical tests for homogeneity. One of these methods is based on visual assessment of the L-moment statistics while the other involves the computation of homogeneity measure statistics as presented in section 2.

3.1 Homogeneity measure statistic

The method of Homogeneity measure statistic involves the computation of a heterogeneity measure statistics based on the observed and simulated data and governed by equation 9. The 19 regions on the Kenyan side were simulated using Gumbel (EV1) distribution. This distribution has been selected in a previous study to fit the annual maximum series for this region, Opere et al. (2006).

Based on the methods described under section 2.1, the computed H statistic was -1.25 and since $|H| < 2$, the region is possibly heterogeneous.

3.2 L-moment ratio diagrams

The L-moment ratio diagrams (Figure 2) shows the results of the visual assessment of the dispersion of the at-site L-moments obtained by plotting L-CV versus both L-CS. Figure 3 on the other hand is a plot of L-CK versus L-CS.

![Figure 3: L-moment ratio diagrams for L-kurtosis (L-CK) and L-skewness (L-CS) for 19 locations in Kenya](image)

The results in Figure 2 show dissimilarity in the spread of the observed and simulated statistics (L-CV and L-CS). Figure 3 depicts a similar spread of the observed and simulated statistics (L-CK and L-CS). This is an indication that the stations belong to a moderately heterogeneous region and cannot entirely be represented by a single distribution in regional analysis.

3.3 Results of regional analysis based on EV1 as a theoretical distribution

For each of the 9 stations in Tanzanian, empirical distributions were plotted to each site. A regional flood frequency distribution was then derived. Example of the results based on empirical distributions is shown in Figure 4 for the Tanzanian stations. Plots of empirical distributions for all the stations, i.e. plots of ranked standardized flow versus non-exceedance probability, were plotted on the same graph.

From Figure 3 it is observed that the empirical distributions for the different sites plot relatively
4. CONCLUSION

The results indicated that the 19 locations on the Kenyan side of the Lake Victoria basin could be grouped into a moderate heterogeneous hydrological region and therefore only at-site flood frequency analysis could be recommended. Further test would be required to investigate the level of heterogeneity and ascertain whether the region could be divided into two or more homogeneous regions.

On the other hand, observations from the sites on the Tanzanian side of the basin, based on empirical distributions fitting, indicated that the stations in the region constitute a single homogenous region which suggests that a single theoretical extreme value distribution can be used to derive a regional frequency curve for the Lake Victoria sub-basin in Tanzania. Referring to the calibration results reported in Opere et al. (2006), the selected distribution to fit the Maximum Annual Flood (MAF) series was the EV1/Gumbel distribution for the 9 Tanzanian sites. On this basis the EV1/Gumbel distribution was used to derive the regional frequency curve for the region. The derived curve is shown in Figure 4. It can be observed from Figure 4 that EV1/Gumbel distribution fitted by PWM method gives a good fit to the observed data.

On this basis of Q-Q plots, EV1 was chosen and parameters estimated using the method of PWM (Table 2). This distribution was further used to the regional frequency curve for the region presented in figure 4.

4. CONCLUSION

The results indicated that the 19 locations on the Kenyan side of the Lake Victoria basin could be grouped into a moderate heterogeneous hydrological region and therefore only at-site flood frequency analysis could be recommended. Further test would be required to investigate the level of heterogeneity and ascertain whether the region could be divided into two or more homogeneous regions. On the other hand, observations from the sites on the Tanzanian side of the basin, based on empirical distributions fitting, indicated that the stations in the region constitute a single homogenous region which suggests that a single theoretical extreme value distribution can be used for each of the sites to derive the regional frequency curve for the region presented in figure 4.
regional frequency curves for the Tanzanian side. The homogeneity grouping in Tanzania formed the fundamental base for regional modeling. On this basis the EV1/Gumbel distribution using the PWM method of parameter estimation was used to derive the regional frequency curves for the Tanzanian side of the basin. This observation was different from the 19 Kenyan locations which could be fitted to different alternative distributions. Therefore no single distribution could be recommended for regional analysis for the Kenyan locations.

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REFERENCES