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Original Research Article

Regional Flood Frequency Analysis Using L-Moment in the Tributaries of Upper Blue Nile River, South Western Ethiopia

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Abstract

Flood estimation with a certain frequency is one of the most important factors for the design of hydraulic structures. It is a big problem in an area where river gauging stations are limited, or the length of records is too short to insure reliable quantile estimates. Regional flood frequency analysis using L-moments is one of the recently innovated methods to overcome this problem. In this study, the flood records of six gauged tributaries of Didessa sub-basin, Ethiopia, are examined based on L-moments procedure to investigate the hydrologically homogeneity of the region, to identify and establish the regional statistical distribution, to develop regional frequency curve and to extend the methodologies to the case of ungauged site. The result of the analysis shows that, the region is homogeneous, and Generalized Extreme Value (GEV) distribution is found to describe the distribution of extreme flood event in the region. Then regional dimensionless growth curves for the region are derived. The results presented herein can be used in Didessa sub-basin while the methodology may be applied in any other regions in Ethiopia, provided flood records are available.

Keywords: Flood frequency, Index flood, L-moments, Regionalization, Upper Blue Nile River

INTRODUCTION

The socio-economic impact of hydrological extremes (drought and flood) everywhere in the world is well recognized. In Ethiopia, there has always been a struggle to reduce the destructive impacts of water and increase its productive impacts. This struggle has intensified over the past two decades through the construction of different water infrastructures. One of the challenging issues in the development of water infrastructures is lack of an adequate hydro-climatic data set. Small numbers of gauging stations and the existing gauged stations in operation also face problems, such as shortness of records, incomplete records, and missing flow records are the most important difficulties that designers and engineers face in the hydrologic projects and water resources management in the region. Currently, ongoing hydrological research is providing adequate techniques to fill these gaps and regional flood frequency analysis is one of the methods in providing flood information (regional flood quantiles) for the region with little or no flow data available.

A number of techniques are available for estimating design floods. The estimation methods can be broadly classified into two groups: rainfall based methods and stream flow-based methods. Stream flow-based method of design flood estimation is commonly applied and which include empirical equations, and at site or regional statistical analyses (Soczynska et al. 1997). Regional flood frequency analysis is used to estimate design floods for the region with inadequate stream flow data or no data. The first regional flood frequency procedures using index flood method was introduced by the U.S. Geological Survey (Dalrymple 1960). The assumption of index flood method is that the distribution of floods at different sites in a region is the same except for a scale or index flood parameters, which reflects rainfall and runoff characteristics of each region. Index-flood based method, with the use of L-moments, can result flood predictions as good as or better than those based on the direct-regression method of regional flood-frequency analysis and the method was demonstrated and approved its potential to estimate accurate quantile in different studies (Hosking et al. 1985; Lettenmaier and Potter 1985; Jin and Stedinger 1989). There are two major parts of index-flood method. The first is the development of basic dimensionless frequency curve representing the ratio of the flood of any frequency to an index-flood (the mean annual flood). The second is the development of relations between geomorphologic characteristics of drainage areas and the mean annual flood by which to predict the mean annual flood at any point within the region. By combining the mean flood with the basic frequency curve, a regional frequency curve is produced.

The main steps applied for regional frequency analysis using L-moment are described in different studies (Hosking and Wallis 1997b; Alila 1999; Adamowski 2000) and the steps are as follows: (1) Screening of the data; L-moments are used to construct a discordancy measure which identifies unusual sites with sample L-moment ratios markedly different from the other sites; (2) Identification of homogeneous regions: the purpose of this step is to form groups of stations that satisfy the homogeneity condition. L-moments can be used to construct a summary statistics in testing heterogeneity of a region; (3) Choice of a frequency distribution: L-moment ratio diagram and/or regional average L-moments statistics (Z-statistical test) can be used in testing whether a candidate distribution gives a good fit to the region's data; (4) Estimation of the frequency distribution: Regional L-moments are used to estimate parameters of the chosen distribution. This procedure involves fitting the chosen distribution using the method of L-moments; its parameters are estimated by equating the population L-moments of the distribution to the sample L-moments derived from the observed data. The methodology has been applied successfully in modeling regional floods in a number of case studies worldwide (Glaves and Waylen 1999; Shabri and Jemain 2013; Kjeldsen et al. 2002; Seckin et al. 2010; Parida et al. 1998; Saf et al. 2008; Hussain and Pasha 2009; Kumar and Chatterjee 2005; Saf 2009).

Since the upper Blue Nile basin is poorly gauged region, advanced techniques of regional flood frequency analysis are of great importance in the region for hydrologic modeling, engineering practice for water resources and reservoirs design, and also for management and planning of weather-related emergencies, etc. In this study, the regional frequency analysis based on L-moment which is proposed by Hosking and Wallis (1997) was applied to annual maximum series (AMS) flood data from Didessa sub-basin of the upper Blue Nile River, south western Ethiopia. The main objectives of this paper are: (1) to demonstrate the application of preeminent regional flood frequency approaches to an area where river gauging stations are hardly found; (2) to test the robustness of the method to a real world case study with a relatively limited number of stations.

MATERIALS AND METHOD

Study Area and Data utilized

The Upper Blue Nile basin is located in the north-western part of Ethiopia. The topography of the basin is dominated by highlands, hills areas and valleys and the elevation varies from 480m in the border to Sudan to over 4200m near the central part of the basin (Gebremicael et al. 2013). Upper Blue Nile basin encompasses 14 sub-basins with a total area of 176,650 km2. Out of the fourteen sub-basins; Didessa, which is the study area, is located in the southern part of the basin and extends over an area of 25,800 Km2 (6.9 % area of upper Blue Nile) as well as 10.7 % of upper Blue Nile discharge generate in this sub-basin (Conway 2000). The Didessa sub-basin is geographically located between 36o 02' and 36o 46' East longitude, and between 7o 43' and 8o 13' North latitude. The mean annual rainfall ranges between 1509 mm in the southern to 2322 mm in the northern area of the catchment. The majority of the area is characterized by a humid tropical climate with heavy rainfall received during rainy season (June to August). The temperature varies from 21oC – 36 oC for daily maximum and 8oC -17oC for daily minimum temperature (Sima 2011).

Annual maximum peak flood data of six stream flow gauging sites within watershed boundary of Didessa sub-basin (Figure 1) from 14 to 25 years in record length have been provided for this study by the Ministry of Water Resource of Ethiopia. Catchment areas of these sites range from 47 km^2 (Yebu) to 9981 km^2 (Didessa) and their annual peak floods vary from 5.03 to 609.3 m^3 /s. From the total area of the Didessa sub-basin, only 11,953 km^2 covered by gauging station while the remaining 13,847 km^2 area is unguided. Most of the annual maximum peak flows at sites have been recorded in the peak flow of summer rainfall (between July and August). Table 1 shows relevant statistics about catchments and data used in this study.

Theoretical Basis for Regional Flood Frequency Analysis Using L- Moment

The L-Moments Theory

Details about the method of L-moments can be found in Hosking and Wallis (1997). In brief, Probability Weighted

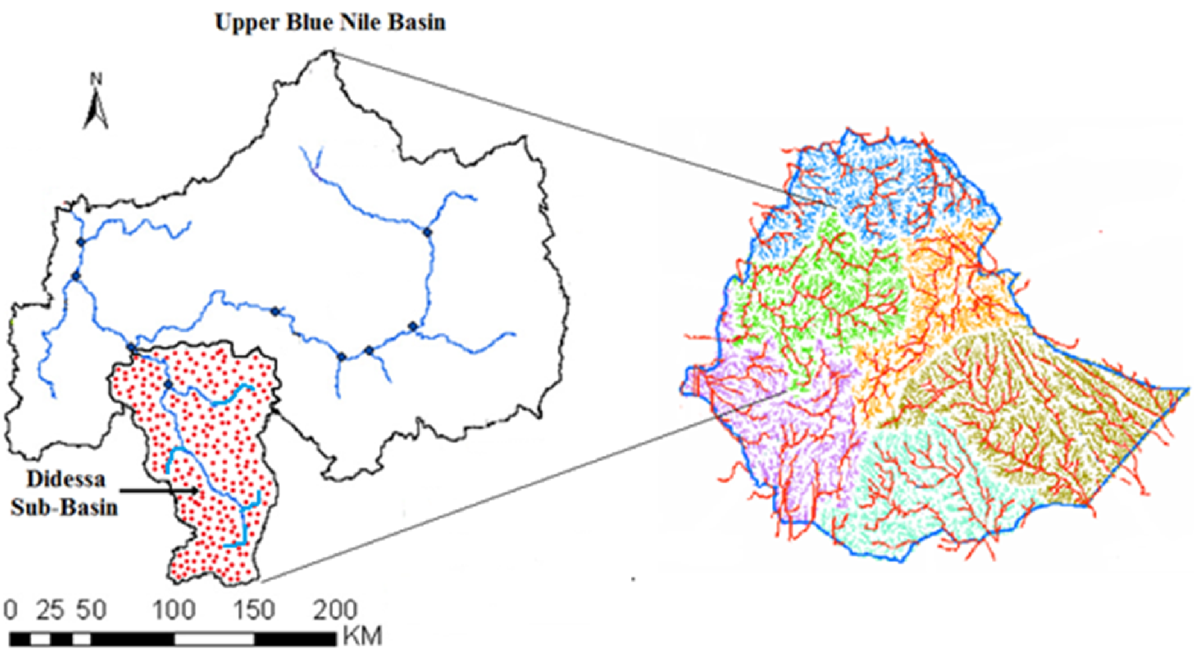

Figure 1. The Location of Didessa sub-basin in the upper Blue Nile basin and in Ethiopia

Table 1. Catchment Area, Sample Size, Sample Statistics and Discordancy Measure

Sample No	Station Name	Catchment Area (Km^2)	Sample size (Years)	Mean annual peak flow (m^3/s)	L-Cv (τ_2)	L-skewness (τ_3)	L-kurtosis (τ_4)	Discordancy measure (D_i)
1	Didessa	9981	25	609.30	0.1781	0.0807	0.2024	0.93
2	Urgessa	19	20	7.06	0.3320	0.2035	0.1012	0.23
3	Dembi	1806	20	225.93	0.1551	0.2199	0.2502	0.97
4	Tato	53	14	9.92	0.3626	0.3099	0.2265	1.48
5	Temssa	47.5	15	7.02	0.2476	0.2169	0.1673	0.87
6	Yebu	47	20	5.03	0.3931	0.3522	0.1547	1.18

Moments (PWMs) were introduced as an alternative to conventional moments to minimize the squaring and cubing of observed values (Greenwood et al. 1979). However, the method suffers from difficulties in interpretation so that Hosking (1990) introduced L-moments, which are linear combinations of probability weighted moments for the purpose of selecting a suitable probability distribution function and modeling hydrologic variables. As a result, L-moments are able robust to outlying values of data and provide better identification of the parent distribution that generated a particular sample of data (Hosking 1990; Parida et al. 1998; Glaves and Waylen 1999). PWMs of a random variable X with cumulative distribution function F(X) are defined by Greenwood et al. (1979) as:

$$M_{p,r,s} = E\left[X^p\{F(X)\}^r\{1-F(X)\}^s\right] \qquad (1)$$

Where *p*, *r* and *s* are real numbers and F(X) is the cumulative distribution function of X. The probability weighted moments $B_r = M_{1,r,0}$ is a special useful cases and for the distribution that has a quantile function X(u);

$$B_r = E\left\{X\left[F(X)\right]^r\right\} = \int_0^1 X(u)u^r du \qquad (2)$$

Where B_r is the *r*th order PWM and $F_x(x)$. Unbiased sample estimators (b_i) of the first four PMWs are given as (Hosking
and Wallis 1997b)

$$b_0 = \frac{1}{n}\sum_{j=1}^{n} x_j$$

$$b_1 = \sum_{j=1}^{n-1}\left[\frac{(n-j)}{n(n-1)}\right]x_j \qquad (3)$$

$$b_2 = \sum_{j=1}^{n-2}\left[\frac{(n-j)(n-j-1)}{n(n-1)(n-2)}\right]x_j$$

$$b_3 = \sum_{j=1}^{n-3}\left[\frac{(n-j)(n-j-1)(n-j-2)}{n(n-1)(n-2)(n-3)}\right]x_j$$

Where $X_{(j)}$ represented the ranked annual maximum series with $X_{(1)}$ being the highest value and $X_{(n)}$ the lowest value, respectively. The first four L-moment expressed in terms of PWM are (Hosking and Wallis 1997b);

$$\lambda_1 = b_0$$
$$\lambda_2 = 2b_1 - b_0$$
$$\lambda_3 = 6b_2 - 6b_1 + b_0 \quad (4)$$
$$\lambda_4 = 20b_3 - 30b_2 + 12b_1 - b_0$$

Hosking and Wallis (1997) have described three statistical measures that are useful in regional flood frequency analysis are the L-moment measure of location, and L-moment ratio measures of scale, skewness and kurtosis are:

$$\text{Location}: \quad \text{Mean} = \lambda_1$$
$$\text{Scale}: \quad \text{L-CV}(\tau_2) = \lambda_2 / \lambda_1$$
$$\text{Skewness}: \quad \text{L-Skewness}(\tau_3) = \lambda_3 / \lambda_2 \quad (5)$$
$$\text{Kurtosis}: \quad \text{L-Kurtosis}(\tau_4) = \lambda_4 / \lambda_2$$

Index Flood Procedure Based on L-Moments

The index flood method is used to determine the magnitude and frequency of flood quantiles for basins of any size, gauged or ungauged, as long as it is located within a hydrologically homogeneous region. The index flood method basically takes the assumption that, flood data at different site within a region follow the same distribution except for a scale or an index factor which is a function of the physiographic basin characteristics (Dalrymple 1960). The important condition for this procedure is the normalization of the flood data from sites with its mean annual maximum flood magnitudes (Lettenmaier and Potter 1985). At each site the AMS normalize with respect to its mean or median value.

$$k_{ij} = \frac{x_{ij}}{\mu_i} \quad (6)$$

Where μ_1 is the mean or median annual maximum flow at site i, which is normally called index-flood. Suppose the data are available from homogeneous region at N sites, each site *i* having a sample size n_i, the quantile of nonexceedance probability *F* at site *i*, $Q_i(F)$, and an observed AMS Q_{ij}, $j = 1. . . n_i$. Q_i (F), 0 < F < 1, be the quantile function of frequency distribution at site i. The key assumption of an index-flood procedure is that the frequency distributions of AMS form N sites of homogeneous region are identical apart from a site-specific scaling factor. If *q(F)* is the dimensionless T-year flow value estimated from the region, and μ_i is the index flood for site *i*, then the estimate of the T-year event at site *i*, $Q_i(F)$, can be defined by:

$$Q_i(F) = \mu_i q(F) \quad (7)$$

Hosking and Wallis (1997) considered an index flood procedure in which the parameters are estimated separately at each site. They recommend the use of a weighted average of the at-site estimates which is the L-moment of interest. The samples L-moment ratios are estimated for each site and the regional record length weighted average L-moment ratios are calculated as;

$$\hat{\lambda}_r^R = \frac{\sum_{i=1}^{N} n_i \hat{\lambda}_r^{(i)}}{\sum_{i=1}^{N} n_i} \quad (8)$$

Where *N* is the number of stations and $\hat{\lambda}_r^{(i)}$ the *r*th order sample L-moment ratio $\hat{\lambda}_r^R$ the rth order regional average sample L-moment ratio. Finally, the T-year event at site i can be estimated as;

$$\hat{X}_{T,i} = \hat{\mu}_i \hat{Z}_T \quad (9)$$

Where $\hat{\mu}_i$ is mean AMF at site i and $\hat{Z}_T$ is regional growth curve. The regional growth curve is the (1-1/T) quantile of the regional distribution of the normalized AMS (Hosking and Wallis 1993).

Regional Flood Frequency Analysis Procedure

In a regional flood frequency analysis, regional information is used to increase the reliability of flood estimates at any particular site (Burn 1997; Hosking and Wallis 2005; Pilon and Adamowski 1992). The methodology summarised in Hosking & Wallis (1997) addressed that regional frequency analysis involves four stages, the first three of which involve subjective judgment: (1) screening of data by means of the discordance measure; (2) identification of homogeneous regions by the means of heterogeneity measure, H; (3) choice of a regional frequency distribution by means of the goodness-of-fit measure, Z; and (4) parameter estimation for regional frequency distribution. These four steps were followed to conduct a regional frequency analysis for Didessa sub-basin and the statistical methods employed are discussed below.

Screening the Data Using Discordancy (D_i) Measure Test

The first step in any statistical investigation is to check that the data are suited for the analysis. Hosking and Wallis (1997) present a discordancy measure based on the *L*-moments of the sites' data used to identify erroneous data set. The discordancy measure is a single statistic based on the difference between the *L*-moment ratios of a site and the average *L*-moment ratios of a group of similar sites. According to Hosking and Wallis (1993,1997), a discordancy measure D_i for a region with *N* sites is defined as:

$$D_i = \frac{1}{3} N \left(u_i - \bar{u}\right)^T A^{-1} \left(u_i - \bar{u}\right) \quad (10)$$

where u_i is a vector containing the L-moment ratios for basin *i*, namely the L-CV (*t*), L-skewness (*t*2), and L-kurtosis (*t*3), $\bar{u}$ is the unweighted regional average for u_i, A is the matrix of sums of squares and cross products and the superscript *T* denotes transposition of a vector or matrix.

Regional Heterogeneity Measure

Hosking and Wallis (1997) proposed a heterogeneity measure (*H)*, for the identification of a homogeneous region using L-moment statistics. A homogeneity statistic, H, is a measure of the departure of V from similar statistics obtained from the simulation of a large number of realizations for a region with *N* sites. The weighted standard deviation of an L-moment ratio in a homogeneous region is calculated by the formula;

$$H = \frac{\left(V - \mu_V\right)}{\sigma_V} \quad (11)$$

Where μ_V and σ_V are the mean and the standard deviation of the values of V obtained from simulations respectively, while V is calculated from the regional data and is based on a corresponding V-statistic, defined as follows:

$$V = \left[\sum_{i=1}^{N} n_i \left(t^{(i)} - t^R\right)^2 \Big/ \sum_{i=1}^{N} n_i \right]^{1/2} \quad (12)$$

Where N is the number of sites, n_i is the record length at site i, $t^{(i)}$ is the sample L-CV at site i, and t^R is the regional average sample L-CV. For this study, in order to obtain reliable values of μ_V and σ_V, five hundred simulations was carried out using four parameter Kappa distribution for computing the measures of heterogeneity. The H criteria established by Hosking and Wallis (1993) indicate that the region is acceptably homogeneous if $H < 1$, possibly heterogeneous if $1 \leq H < 2$ and definitely heterogeneous if $H \geq 2$.

Distribution selection

After confirming the homogeneity of the study region, an appropriate distribution needs to be selected for the regional frequency analysis. In this study, the selection was carried out based on the results of a L-moment diagram and goodness-of-fit test derived from L-moment ratios as described by Hosking and Wallis (1997).

L-moment diagram

The *L*-moment diagram can be used to compare the *L*-skewness versus *L*-kurtosis relations of different distributions and data samples. This gives a visual indication of which distribution may be expected to give a good fit to a data points (at-sites values) by plotting them on a graph of L-skewness versus L-kurtosis.

Goodness-of-fit test

In addition to visual inspection and subjective judgment of distribution selection, statistical tests are required to confirm the appropriateness of the chosen distribution and to give a certain degree of confidence in it. The goodness-of-fit test for each of various distributions is defined in terms of L-moments and is termed the Z-statistic (Hosking and Wallis, 1997):

$$Z^{DIST} = \left(\tau_4^{DIST} - \bar{\tau}_4 + \beta_4\right) \Big/ \sigma_4 \quad (13)$$

where τ_4^{DIST} is L-kurtosis of the fitted distribution, $\bar{\tau}_4$ is weighted regional average L-kurtosis, β_4 is bias of $\bar{\tau}_4$, and σ_4 is standard deviation of the $\bar{\tau}_4$ obtained from simulation. The bias (β_4) and standard deviation (σ_4) of the $\bar{\tau}_4$ respectively defined as:

$$\beta_4 = \frac{1}{N_{sim}} \sum_{m=1}^{N_{sim}} \left(\bar{\tau}_4^m - \bar{\tau}_4\right) \quad (14)$$

$$\sigma_4 = \left[\left(\frac{1}{N_{sim}}\right) \left\{ \sum_{i=1}^{N_{sim}} \left(\bar{\tau}_4^m - \bar{\tau}_4\right) - \left(N_{sim}\beta_4\right) \right\} \right]^{0.5} \quad (15)$$

Where $\bar{\tau}_4^m$ is the regional average L-kurtosis and is to be calculated for the *m*th simulated region. N_{sim} is the number of simulated regional data sets generated using a Kappa distribution.

Parameter Estimation Using Index Flood Procedure

To estimate a chosen distribution's parameters and obtain quantile estimates, the regional *L*-moment algorithm is used. This procedure involves (1) fitting the chosen distribution using the method of *L*-moments; its parameters are estimated by equating the population *L*-moments of the distribution to the sample *L*-moments derived from the observed data; (2) sample *L*-moment ratios from each site are weighted according to record length and combined to give regional average *L*-moment ratios; (3) the regional mean is set equal to 1, and regional quantile estimates are derived; (4) quantile estimates are obtained by multiplying the regional quantile estimate by the index flood, which for this study is the at-site estimate of the median.

In this study, the flood quantiles are estimated by calculating the regional growth curve and the median value of annual maximum series of each site. The GEV distribution, as the best-fit distribution to regional data, is used for estimating the regional growth curve for different return periods. Although the estimates obtained by regional flood frequency analysis are reliable, still we need certain measures for the assessment of how well the proposed regional frequency distribution fit to the observed AMS, and theoretical quantiles were plotted against normalized regional quantiles.

RESULT AND DISCUSSION

Annual maximum peak flow data of six river discharge gauging stations ranging from 14 to 25 years in record length have been provided for the analysis of regional flood frequency analysis. Regional frequency analysis involves four stages: first screening of data by means of the discordance measure, second identification of homogeneous regions, third choice of an appropriate probability distribution, and finally estimation of parameters of the probability distribution (Hosking and Wallis 2005).

Discordancy Measure (Di) and Screening of the Data

In the processes of screening of the data, it is standard practice to compute a discordancy measure *Di* which identifies unusual sites that are grossly discordant with the group as a whole. Values of discordancy measure are computed in terms of the L-moments and given in Table 1 along with the catchment areas and statistical characteristics for all gauging sites of the study area. Sites with a discordancy measure greater than the critical value are considered discordant relative to the collective behavior for the proposed grouping of sites (Hosking and Wallis 1997a). It is observed that *Di* values of the 6 gauging sites are ranges from 0.23 to 1.48 which is less than the critical value 1.648. Thus data of all gauging sites are suitable for flood frequency analysis.

Heterogeneity Test

To determine whether the region is heterogeneous or not, the samples L-moment ratio of data were calculated. According to Hosking and Wallis (1997), if the heterogeneity measure $H<1$ the region is acceptably homogeneous. If $1 \leq H < 2$, the region is possibly heterogeneous and if $H \geq 2$ the region is definitely heterogeneous. The values of heterogeneity measures computed by carrying out of Monte Carlo simulations after estimating parameters of kappa distribution are H = 1.12, H_1 = 0.72, and H_2 = 0.34. The H-test statistics indicates that the region is possibly heterogeneous since $H > 1$. However, the value of H is a little bit greater than 1 and H_1 and H_2 are less than 1. In addition to this, the value of H up to 3 also acceptable (Burn 1997). Thus it is possible to consider the region as acceptably homogeneous, where thus used for the development of regional flood frequency curve.

Distribution Selection Using L-moment Diagram and Goodness-of-fit test

The relationship between population *L*–Skewness and *L*–kurtosis for a range of distributions are summarised by Hosking and Wallis (1997) and commonly applied in flood frequency analysis. For this study, the theoretical distribution included are the general extreme value (GEV), log normal (LNO), general Pareto (GPA), and gamma (GM) distributions. The regional average L-Skewness and L-kurtosis values for each site were computed and plotted combining with theoretical distribution curves in Figure 2. The expected position of data points should be scattered above and below close to the distribution curve of a suitable distribution. It can be seen from the plot that there is wide scatter in the distribution, and it is almost impossible to determine which exactly suitable distribution. But by careful examination of data points, the Generalised Extreme Value (GEV) distribution offers the best representation of the mean regional values of L-skewness and L-kurtosis and consequently was selected as an acceptable distribution for the entire area. In addition to the subjective judgment of graphical observation, Hosking and Wallis (1997) introduce *Z*-statistic, which is a goodness-of-fit measure for three-parameter distributions which measures how well the theoretical *L*-kurtosis of the fitted distribution matches the regional average *L*-kurtosis of the observed data. In order to test Z statistics, annual maximum series data were tested against the GEV, LNO, GPA, and SM distributions and the result are shown in Table 2. As we can see from the result, both GEV and GPA distributions are less than the critical value 1.64 and the value of GEV is further less than GPA vale. Thus, the criterion of goodness of fit ascertains that the GEV distribution is the most suitable distribution for the region. The estimates of the regional parameters for GEV distribution are: location parameter (ξ) is 0.854, scale parameter (α) is 0.438, and shape parameter (k) is 0.136.

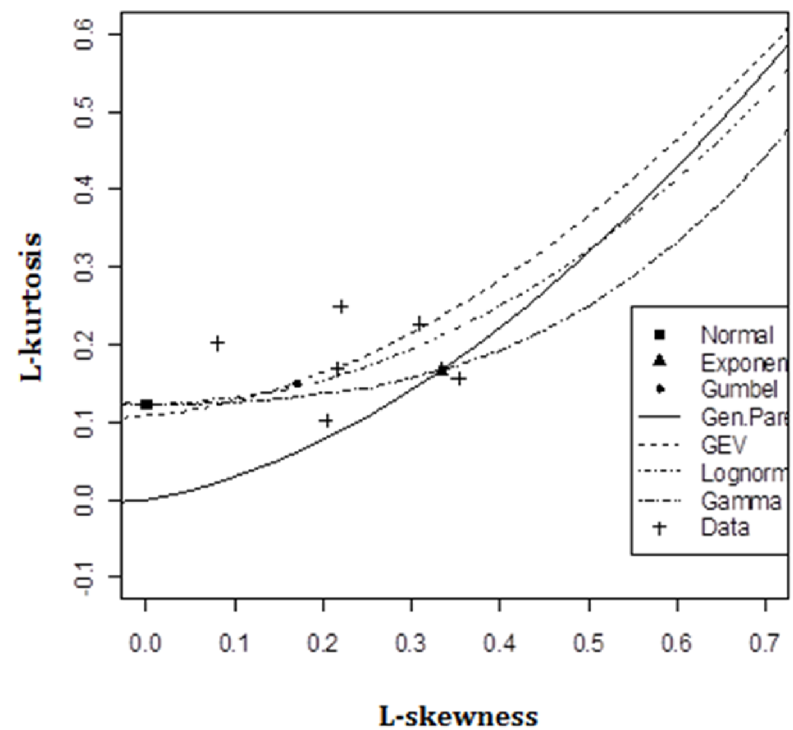

Figure 2. L-moment diagram

Table 2. Goodness of fit measure for different distributions

No	Distribution	Z^{DIST}	$\|Z^{DIST}\|$
1	GEV	-0.97	0.97
2	LNO	-3.41	3.41
3	GPA	-1.49	1.49
4	GM	2.48	2.48

Regional Flood Frequency Curves

After GEV distribution is identified as the most appropriate distribution in estimating flood quantiles in Didessa basin, the non exceedances probability for GEV distribution was computed by using the formula 7 to calculate the normalized quantiles for different return periods. The regional quantile curve together with empirical flood frequency quantile estimates are given in Figure 3. The quantile estimates for specific site in the region can be obtained by multiplying the normalized quantile with the median annual maximum flood value of the specific station. If we considered Didessa basin as a whole, the annual maximum median flood value of Didessa (601.01 m^3/s) will be used to compute the quantile of the region.

Although the estimates obtained by regional flood frequency curve are reliable, still we need certain measures for the assessment of the accuracy of these estimates. The quantile-quantile plot or Theoretical quantiles versus quantiles plot (Figure 4) is a powerful visualization method for evaluating the fit of a proposed regional flood frequency curve through the visual assessment of the linearity of the pattern of points on the plot. As we can see from the figure 4, the plotted points tend to lie reasonably along and close to a straight line and this provides a validation of regional flood frequency curve to model the observed annual maximum flood data.

Implication of this Study

Regional flood frequency analysis is a powerful tool for estimating the flood frequency distribution and calculating T-years flood to poorly gauged or ungauged watershed in order to investigate flood risks and associated hazards like sedimentation of reservoirs. The intention of this study is to demonstrate the application of regional flood frequency analysis in Didessa sub-basin to transfer the estimated quantile into the ungauged catchment in the region. The main difficulty is to estimate the index flood of the ungauged watershed. There is a practice of using

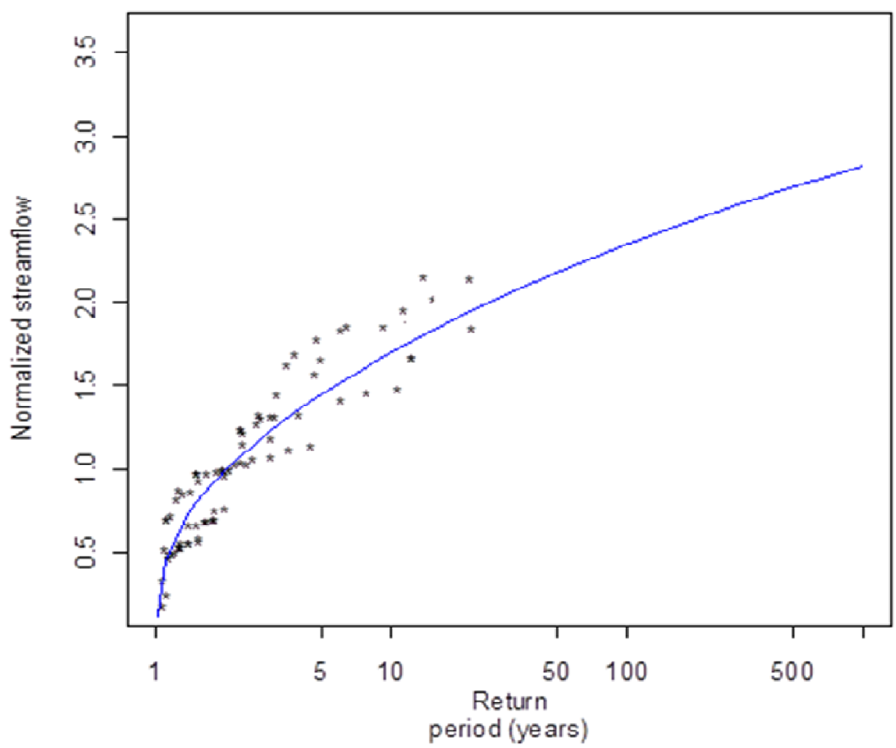

Figure 3. Regional flood frequency curve

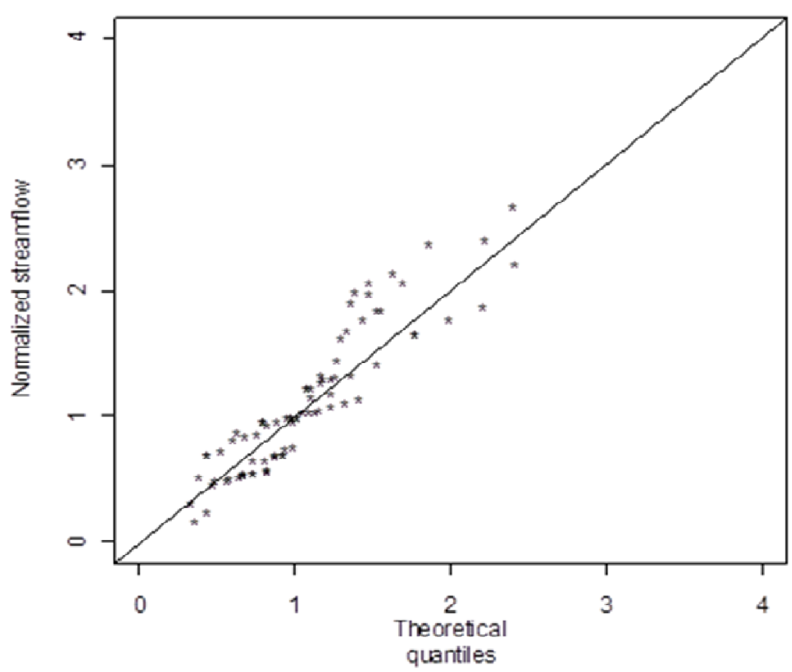

Figure 4. Theoretical quantiles versus normalized stream flow graph

mean or median annual maximum flow as index flood in different studies (Parida et al. 1998; Kjeldsen et al. 2002; Chebana and Ouarda 2009). However, median annual maximum flood is considered as an index flood in this study. For gauged watershed, the median annual maximum flood discharge is estimated from the measured stream flow series. For ungauged watershed, the median annual maximum flow can be estimated by regional regression model using physiographic and climatic catchment descriptors that the watershed shares similarity with the closest gauged watershed in the region. When the physiographic characteristics of ungauged watershed have more resemblance and within the observed ranges of the gauged watershed, the regression model extrapolated beyond the observed range will be more valid.

In addition to demonstrating the application of regional flood frequency curve for ungauged catchments, the value of this study can be recognize as disseminating the idea for further application of this method in a wider region and variables other than peak flood like precipitation, sediment load, water level, drought and other hydrological quantile in an area where long-term hydrologic-climatic gauging stations are hardly found.

CONCLUSION

Didessa sub-basin is an important drainage system in the upper Blue Nile basin with a major function for water supply in south western Ethiopia. Since the upper Blue Nile basin is poorly gauged region, estimation of floods at ungauged sites where no flow data is available has been a real problem for hydrologic modeling, engineering practice for water resources and reservoirs design, and also for management and planning of weather-related emergencies. In order to challenge this problem, regional flood frequency analysis using L-moments is one of the recently applied method in the field of hydrology.

This study provides a regional flood frequency analysis using annual maximum flows from 6 tributaries of Didessa river. The annual maximum time series were analyzed using L-moments to identify regional homogeneity, to determine appropriate probability density function of the observed data, and to develop a regional flood frequency model in the region. All station records are accepted statistically to be homogeneous using a discordancy and heterogeneity measures. Among the different distributions, GEV distribution is identified as the most appropriate distribution in estimating flood quantiles in the region. The regional flood frequency result generated from this study can be applied to ungauged catchments in Didessa river sub-basin within or in proximity of an identified homogeneous region. Moreover, the methodology used in this study can be adopted for other regions of Ethiopia provided that sufficient flood records are available.

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REFERENCES

Adamowski K (2000) Regional analysis of annual maximum and partial duration flood data by nonparametric and L-moment methods. J Hydrol 229 (3-4):219-231. doi:Doi 10.1016/S0022-1694(00)00156-6

Alila Y (1999) A hierarchical approach for the regionalization of precipitation annual maxima in Canada. J Geophys Res-Atmos 104 (D24):31645-31655. doi:Doi 10.1029/1999jd900764

Burn DH (1997) Catchment similarity for regional flood frequency analysis using seasonality measures. J Hydrol 202 (1-4):212-230. doi:Doi 10.1016/S0022-1694(97)00068-1

Chebana F, Ouarda TBMJ (2009) Index flood-based multivariate regional frequency analysis. Water Resour Res 45. doi:Artn W10435 Doi 10.1029/2008wr007490

Conway D (2000) The climate and hydrology of the Upper Blue Nile river. Geogr J 166:49-62. doi:DOI 10.1111/j.1475-4959.2000.tb00006.x

Dalrymple T (1960) Flood Frequency Analyses. US Geological Survey, Water Supply Paper 1543-A

Gebremicael TG, Mohamed YA, Betrie GD, van der Zaag P, Teferi E (2013) Trend analysis of runoff and sediment fluxes in the Upper Blue Nile basin: A combined analysis of statistical tests, physically-based models and landuse maps. J Hydrol 482:57-68. doi:DOI 10.1016/j.jhydrol.2012.12.023

Glaves R, Waylen PR (1999) Regional flood frequency analysis in southern Ontario using L-moments (vol 41, pg 178, 1997). Can Geogr-Geogr Can 43 (1):104-104. doi:DOI 10.1111/j.1541-0064.1999.tb01364.x

Greenwood JA, Landwehr JM, Matalas NC, Wallis JR (1979) Probability Weighted Moments - Definition and Relation to Parameters of Several Distributions Expressable in Inverse Form. Water Resour Res 15 (5):1049-1054. doi:Doi 10.1029/Wr015i005p01049

Hosking JRM (1990) L-Moments: Analysis and Estimation of Distributions Using Linear Combinations of Order Statistics. Journal of the Royal Statistical Society Series B (Methodological) 52 (1):105-124. doi:10.2307/2345653

Hosking JRM, Wallis JR (1993) Some Statistics Useful in Regional Frequency-Analysis. Water Resour Res 29 (2):271-281. doi:Doi 10.1029/92wr01980

Hosking JRM, Wallis JR (1997a) Regional frequency analysis : an approach based on L-moments. Cambridge University Press, Cambridge ; New York

Hosking JRM, Wallis JR (1997b) Regional Frequency Analysis: An Approach Based on L-Moments. Cambridge University Press, London, UK

Hosking JRM, Wallis JR (2005) Regional Frequency Analysis: An Approach Based on L-Moments. Cambridge University Press,

Hosking JRM, Wallis JR, Wood EF (1985) Estimation of the Generalized Extreme-Value Distribution by the Method of Probability-Weighted Moments. Technometrics 27 (3):251-261. doi:Doi 10.2307/1269706

Hussain Z, Pasha GR (2009) Regional Flood Frequency Analysis of the Seven Sites of Punjab, Pakistan, Using L-Moments. Water Resour Manag 23 (10):1917-1933. doi:DOI 10.1007/s11269-008-9360-7

Jin MH, Stedinger JR (1989) Flood Frequency-Analysis with Regional and Historical Information. Water Resour Res 25 (5):925-936. doi:Doi 10.1029/Wr025i005p00925

Kjeldsen TR, Smithers JC, Schulze RE (2002) Regional flood frequency analysis in the KwaZulu-Natal province, South Africa, using the index-flood method. J Hydrol 255 (1-4):194-211. doi:Doi 10.1016/S0022-1694(01)00520-0

Kumar R, Chatterjee C (2005) Regional flood frequency analysis using L-moments for North Brahmaputra region of India. J Hydrol Eng 10 (1):1-7. doi:Doi 10.1061/(Asce)1084-0699(2005)10:1(1)

Lettenmaier DP, Potter KW (1985) Testing Flood Frequency Estimation Methods Using a Regional Flood Generation Model. Water Resour Res 21 (12):1903-1914. doi:Doi 10.1029/Wr021i012p01903

Parida BP, Kachroo RK, Shrestha DB (1998) Regional Flood Frequency Analysis of Mahi-Sabarmati Basin (Subzone 3-a) using Index Flood Procedure with L-Moments. Water Resour Manag 12 (1):1-12. doi:Doi 10.1023/A:1007970800408

Pilon PJ, Adamowski K (1992) The Value of Regional Information to Flood Frequency-Analysis Using the Method of L-Moments. Can J Civil Eng 19 (1):137-147

Saf B (2009) Regional Flood Frequency Analysis Using L-Moments for the West Mediterranean Region of Turkey. Water Resour Manag 23 (3):531-551. doi:DOI 10.1007/s11269-008-9287-z

Saf B, Dikbas F, Yasar M (2008) Regional flood frequency analysis of the lower west Mediterranean subregion of Turkey with L-moments. Fresen Environ Bull 17 (4):427-433

Seckin N, Yurtal R, Haktanir T, Topaloglu F (2010) Regional Flood Frequency Analysis of Ceyhan River Basin in Turkey Using L-Moments Method. Fresen Environ Bull 19 (11A):2616-2624

Shabri A, Jemain AA (2013) Regional flood frequency analysis for Southwest Peninsular Malaysia by LQ-moments. J Flood Risk Manag 6 (4):360-371. doi:Doi 10.1111/Jfr3.12023

Sima BA (2011) Flow Regime and Land Cover Changes In the Didessa Sub-Basin of the Blue Nile River, South - Western Ethiopia. Master E, Uppsala University, Sweden

Soczynska U, Nowicka B, Somorowska U, Kupczyk E, Suligowski R (1997) Prediction of design storms and floods. Friend'97-Regional Hydrology: Concepts and Models for Sustainable Water Resource Management (246):297-303