IDENTIFICATION AND DELINEATION OF HYDROLOGICAL HOMOGENEOUS REGIONS - THE CASE OF BLUE NILE RIVER BASIN -

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Abstract

Blue Nile River Basin has been regionalized into similar flood producing characteristics based on statistical values of at site data. The basin was delineated in to five homogeneous regions. Accordingly, region one comprises the widest portion of the basin, covering 37.6 % of the area. It includes the upper Guder catchment, middle and lower Didesa, lower part of the main Abbay basin and Dinder catchment.

Region two covers Beles, Gilgel Abbay, Fincha and lower Guder sub catchment. Region three includes upper Didesa, Anger and upper part of main Abbay (Blue Nile Falls).

Region four, which is the smallest portion of the basin area, about 3.3 %, embraces southern part of Gojam high lands, extreme upper course of Gilgel Abbay and Bir-Temcha catchment. This basin is typically characterized by hilly and mountainous topography.

Region five incorporates Gumera, Rib, Beshlo, Jema, Dabus and Muger catchments. Except one station (on Idris River) in region three, all regions have shown satisfactory results for homogeneity tests.

For the developed five regions the most likely fit candidate distributions have been also selected. Accordingly, for region one Generalized Logistic & Log Normal distribution; for region two Gamma, Pearson III & Log Pearson III distributions; for region three, Log Normal distribution; for region four and region five, Generalized Logistic and Generalized Extreme Value were preferred as a candidate distributions.

1 Introduction

1.1 Background

Regionalization refers to grouping of basins into homogeneous regions. In other words, regionalization means identification of homogeneous regions, which contain stations of similar flood producing characteristics.

Several studies have shown that delineation of regions in the past has often relied on physiographic, political or administrative boundaries (Getachew, 1996). The resulting regions were assumed to be homogenous in terms of hydrologic response. This assumption actually is not true as it may have very different relief and stations within the same geographical region. Areas with high correlation will cause some bias in the regionalization (Wiltshire, 1985; Cunnane, 1989, Roa & Hamed, 2000).

The importance of homogeneity has been demonstrated by Hosking et al (1985), Wiltshire (1986). Homogeneity implies that regions have similar flood generating mechanisms. A more specific definition of a homogeneous region delineates an area consisting sites with the same standardized frequency distributional form and parameters. Such a region must be geographically continuous and it forms a basic unit for carrying out regional frequency analysis for estimation of flood magnitude for water resource project planning and design.

1.2 Description of Study Area

The Blue Nile (Abbay) River Basin, from now onwards called BNRB, lies in the western part of Ethiopia, between 70 45’ and 120 45’N, and 340 05’ and 39045’E as shown in Fig 1.

The study area covers about 192,953 square kilometer with total perimeter of 2440 km. It accounts for almost 17.1% of Ethiopia's land area and about 50% of its total average annual runoff.

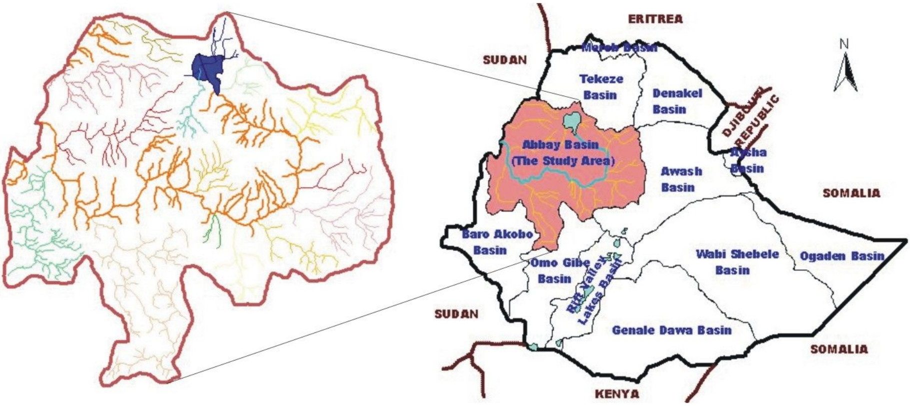


Figure 1.1 Map of the Ethiopian's River Basins with the study basin

The climate of Abbay basin is dominated by an altitude ranging from 590 meters to more than 4000 meters. The influence of this factor determines the rich variety of local climates. Ranging from hot to desert-like climate along the Sudan boarder the rich variety also includes temperate climate on the high plateau and cold on the mountain peaks.

The annual rainfall varies between about 800mm to 2,220 mm with a mean of about 1420mm (Master Plan of BNRB – Main Report). In this study 78 stations were considered for the analysis. The distribution of the stations within the basin is high at the central, northern & southern part of the basin. Where as, the north-west part of the basin does not have sufficient stations. Generally, the distributions of the gauging stations used in this study have shown in figure 1.2.

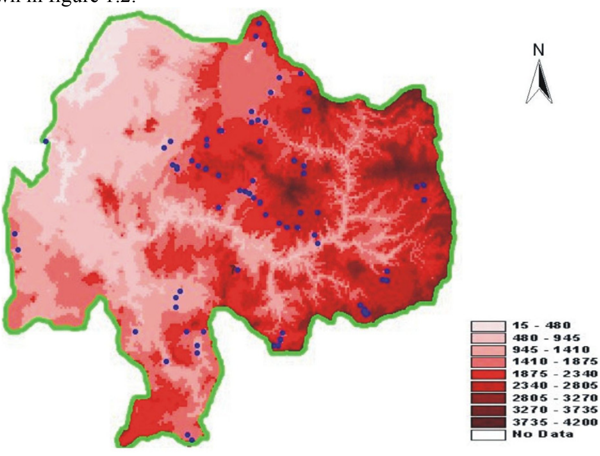


Figure 1.2 The distribution of hydrological gauging stations within Abbay basin

2 Methodology and Data Analysis

2.1 Methodology and procedure

The approach used for regionalization is the Index flood method which comprises the observed flow data. They were pooled at the region to provide a more precise estimate of standardized statistical parameters in the regionalization procedure. Generally the study involves the following procedures:

- Collection of hydrological and meteorological data, topographical map and digitized map of the basin.
- Checking of data for consistency and independence
- Computation of statistical parameters of selected stations within the basin
- Regionalization of the basin into homogeneous regions based on statistical values using GIS – Arc View
- To carry out homogeneity tests for the established regions

2.2 Previous Study

Different researchers have attempted different approach to identify homogeneous regions. Such as geographical region/space (The Flood Study Report NERC, 1975, Matalas et.al, 1975); Catchment characteristics (Wiltshire, 1985); Climatic characteristics (Pearson, 1991b). For BNRB, Admassu (1989) conducted a comprehensive investigation related to flood frequency analysis. On this paper regionalization of homogeneous regions was made on the basis of monthly rainfall pattern and geographical proximity. This may not be guaranteed as they may have different statistical response within the same rain fall pattern of the identified regions.

2.3 Source and Availability of Data

For the purpose of this study, various data have been collected from different agencies, which include time series data, topographical data and a digitized map of the study area. From time series data, peak series flow data is the most important one for this study. 78 hydrological gauging stations from the Ministry of Water Resource collected data in a duration of 25 years average. The digitized maps of the basin were collected from MoWR GIS Department. The topographical map with scale of 1:250,000 were gathered from Ethiopian Mapping Authority.

2.4 Filling and Extension of Data

Regression analysis was used to fill the missing monthly data and to extend those short lengths recorded data. The latter were accepted by satisfactory correlation coefficient of minimum 6.2 and maximum 0.997. The correlation was done based on neighboring station and geographical proximity.

2.5 Consistency of Data

Double mass curve analysis was used to check the consistency of data. The selection of the station depends on the geographical location of the stations i.e. its neighboring stations were used to check the reliability of that station data and correction were made accordingly. To minimize the effect of outliers in this study, L-Moment and Probability Weighted Moment statistical computation methods have been used.

3 Regionalization of Blue Nile River Basin

3.1 Flood Statistics of Blue Nile River Basin

Flood statistics of Blue Nile River basin stations were computed using both conventional moment and L-moment methods. However, L-Moment method is a powerful and efficient method to compute any statistical parameters. Such methods can give unbiased estimation of sample parameters and also cannot be easily influenced with the presence of outliers. (Roa & Hamed, 2000)
Generally, the statistical parameters computed include:

- Mean $(\overline{Q}, \ell_1)$
- Standard deviation (σ)
- Coefficient of variation (C_V, LC_v)
- Coefficient of skew ness (C_s, LC_s)
- Coefficient of kurtosis (Ck, LCk)

Conventional Moment

Moments about the origin or about the mean are used to characterize probability distributions. Moments about the origin are the expected values of powers of a random variable. For a distribution with a probability density function f(x), the r[th] moment about the origin is given by

$$\mu'_r = \int_{-\infty}^{\infty} x^r\, f(x)\, dx,\quad \mu'_1 = \mu = mean \quad (3.1)$$

The central moments

$$\mu_r = \int_{-\infty}^{\infty} (x - \mu'_1)^r\, f(x)\, dx,\qquad \mu_1 = 0 \quad (3.2)$$

Sample moments m'_r & m_r

$$m'_r = \frac{1}{N}\sum_{i=1}^{N} X_i^r,\qquad m'_r = \overline{X} = \text{Sample mean} \quad (3.3)$$

$$m_r = \frac{1}{N}\sum_{i=1}^{N} (X_i - \overline{X})^r,\qquad m_1 = 0 \quad (3.4)$$

These sample moments are often biased and may be corrected (Cunnane, 1989)

$$m_2 = \frac{1}{N-1}\sum (x_i - \overline{x})^2 \quad (3.5)$$

$$m_3 = \frac{N}{(N-1)(N-2)}\sum (x_i - \overline{x})^3 \quad (3.6)$$

$$m_4 = \frac{N^2}{(N-1)(N-2)(N-3)}\sum (x_i - \overline{x})^4 \quad (3.7)$$

The conventional moment ratios are defined

$$C_V = \mu_2^{1/2} \Big/ \mu_1^1 \quad \text{(3.8)}$$

$$C_S = \mu_3 \Big/ \mu_2^{3/2} \quad \text{(3.9)}$$

$$C_K = \mu_4 \Big/ \mu_2^2 \quad \text{(3.10)}$$

Where
C_v - Coefficient of variation
C_s - Coefficient of skew-ness
C_k - Coefficient of Kurtosis

L-Moments

Advantages of L-Moments

L- Moments are analogous to conventional moments but are estimated by linear combinations of an ordered data set, namely L-statistics. (Roa & Hamed, 2000)

The following are advantage of L-moments: (Cunnane, 1989)

I. Compared to conventional moments, L-moments can characterize a wide range of distributions
II. Sample estimates of L-moments are so robust that they are not affected by the presence of outlier in the dataset.
III. They are less subjected to bias in estimation
IV. L-moments yield more accurate estimates of the parameters of a fitted distribution. Even some time parameter estimated from samples are more accurate than maximum likelihood.
V.

Hosking (1986) defined the L-moments of a real value random variable X in terms of probability weighted moments (PWMs) as:

$$L_r = (-1)^{r-1} \sum_{k=0}^{r-1} P_{r-1,k} M_k \quad \text{(3.11)}$$

Where

$$P_{r,k} = (-1)^{r-k} \binom{r}{k} \binom{r+k}{k} \quad \text{(3.12)}$$

L_r = the r^th L- moment

$$M_{10k} = \sum_{j=0}^{k} (-1)^j \binom{k}{j} M_{1j0} \quad \text{(3.13)}$$

Hosking (1986), gave the unbiased estimators of M_{10k} and M_{1j0} as:

$$\hat{M}_{10k} = \frac{1}{N}\sum_{i-1}^{N}\left[\binom{N-i}{k}\Big/\binom{N-1}{k}\right] x_i \qquad k = 0,1,2 \cdots N-1 \quad \text{.......(3.14)}$$

$$\hat{M}_{1j0} = \frac{1}{N}\sum_{i=1}^{N}\left[\binom{i-1}{j}\Big/\binom{N-1}{j}\right] x_i \qquad j = 0,1,2, \cdots N-1 \quad \text{.......(3.15)}$$

Where i = rank of observed flow data in ascending order

The first few moments are:

$L_1 = M_{100}$
$L_2 = M_{100} - 2 * M_{101}$
$L_3 = M_{100} - 6 * M_{101} + 6 * M_{102}$
$L_4 = M_{100} - 12 * M_{101} + 30 * M_{102} - 20 * M_{103}$

Like the conventional moments, L-moments can be used to specify and summarize probability distributions. In particular L_1, the first L- moment, is the mean of a statistical distribution and is identical to the first conventional moment. L_2 is a linear measure of spread or dispersion analogous to standard deviation. L-moment ratios, which are analogous to conventional moment ratios, are defined by Hosking (1990) (Roa & Hamed, 2000) as:

$$\tau = L_2 / L_1 \quad \text{.......(3.16)}$$

$$\tau_r = L_r / L_2, \; r \geq 3 \quad \text{.......(3.17)}$$

Where L_1 = measure of location

τ = measure of scale and dispersion (LC_v)

τ_3 = measure of skew ness (LC_s)

τ_4 = measure of kurtosis (LC_k)

Instead of τ and τ_r, t and t_r are used for sample L- moment ratios.

To compute the above parameters using L-moment method is some cumbersome with spread- sheet (Excel). Therefore FORTRAN program (FFA-AS / statistics) has been developed for calculation. These parameters, later on, are basic important for regionalization, selection of distribution and robust method of estimation and various tests.

3.2 Bases for regionalization

The index- flood method (Hosking, 1993) is based on the hypothesis that floods from different catchments within a region normalized by their mean annual flood come from a single distribution. An essential prerequisite for this procedure is the standardization of the flood data from sites with different flood magnitudes. The most common practice is to standardize data i.e. division by an estimate of the at- site mean, thus

$$X_i = Q_i / \overline{Q} \quad \text{.......(3.18)}$$

Where $\overline{Q} = \frac{1}{N}\sum_{i=1}^{N} Q_i$

Then the Quantile Q_T is estimated as

$$Q_T = \overline{Q}\,\tilde{X}_T \quad \text{...} \quad (3.19)$$

The mean annual flood is the index- flood.

3.3 Identification of Regions

The (LC_S, LC_K) of standardized flow values of each stations has been plotted on L-moment ratio diagram (LMRD) of various distribution functions as shown below.

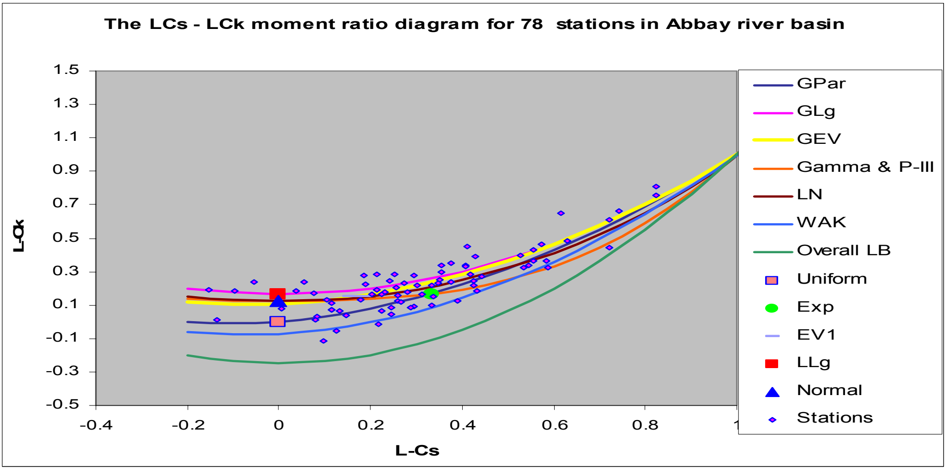


Figure 3.1 LMR diagram of gauging stations of Abbay basin for standardized flow

Those stations close to a single distribution were considered as homogeneous stations. Thereby, five groups of stations were identified as shown on the map below.

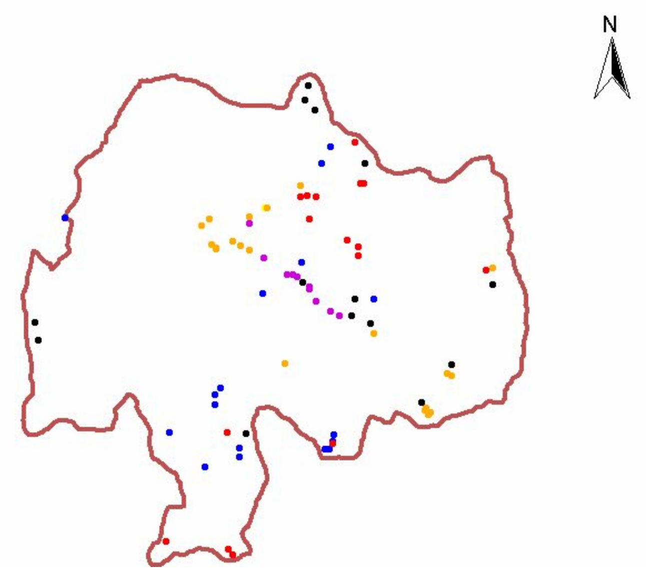


Figure 3.2 Identified homogeneous stations

3.4 Delineation of Homogeneous Regions

The tool used in delineation of homogenous regions where GIS (Arc-view 3.3) software. All stations under analysis were identified according to their geographical location (latitude and longitude) on the digitized map of the basins. For each stations the statistical values (LC_s , LC_k) which were computed in section 3.2 where given.

In addition, the preliminary identification of the region using LMRD mentioned above where identified on separate field to geo-code with different color. It is assumed that (LC_S, LC_K) values of one station varies linearly with (LC_S, LC_K) values of the neighboring stations.

So from GIS screen, the distance between one station and its neighboring station was determined and (LC_S, LC_K) values where interpolated to fix the boundary between two stations of different regions. The procedures followed in the delineation of the area boundary were as follows:

I. To compute the (LC_s, LC_k) value of each station
II. To identify the location of stations along the distributions of LMRD
III. To identify the group based on step II
IV. To interpolate between LC_s and LC_k values of two stations of different groups to fix two boundaries, one from the LC_s and the other from LCk values.
V. The boundary of the region is fixed between the mid ways of the two boundaries found in step IV.

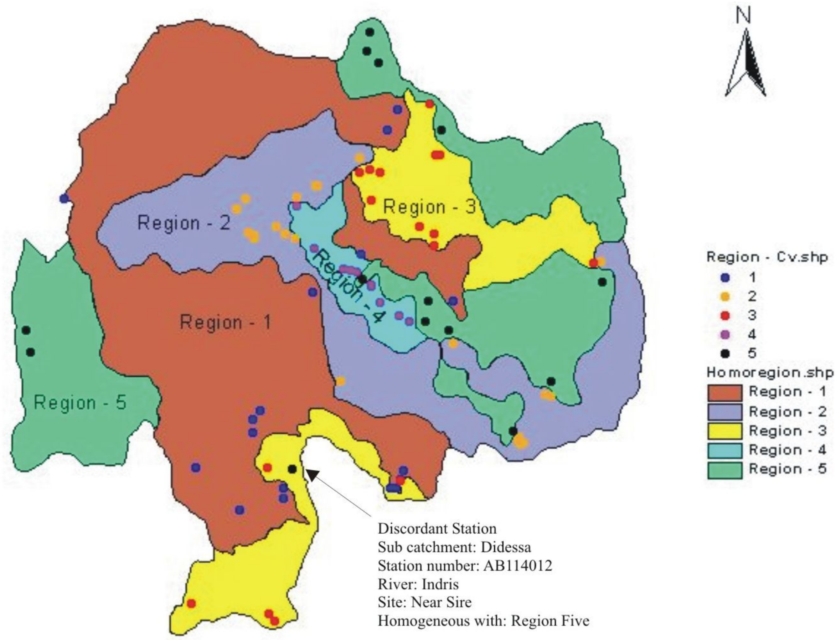


Figure 3.3 The delineated homogeneous regions of Abbay basin

3.5 Homogeneity Tests

The preliminary identified regions have to be checked by various homogeneity tests.
The tests used in this study were:

I. Discordance measure test
II. Cv – based Homogeneity test.
III. LCv – based Homogeneity test.
IV. Statistical compar

I Discordance measure

The discordance measure intended to identify those sites that are grossly discordant with the group as a whole. The discordance measure D estimates how far a given site is from the center of the group. (Roa & Hamed, 2000)

If $U_i = \left[t^{(i)}, t_3^{(i)}, t_4^{(i)} \right]^T$ is the vector containing the t , t_3 and t_4 values for site (i), then the group average for NS sites within the region is given by

$$\overline{U} = \frac{1}{NS} \sum_{i=1}^{NS} U_i \qquad (3.20)$$

The sample covariance matrix is given by

$$S = (NS - 1)^{-1} \sum_{i=1}^{NS} \left(U_i - \overline{U}\right)\left(U_i - \overline{U}\right)^T \qquad (3.21)$$

The discordance measure is defined by

$$D_i = \frac{1}{3}\left(U_i - \overline{U}\right)^T S^{-1}\left(U_i - \overline{U}\right) \qquad (3.22)$$

A site (i) is declared to be unusual if D_i is large. A suitable criterion to classify a station as discordant is that D_i should be greater than or equal to 3.

II CV and LCV – Based Homogeneity Test

In regionalization, assumptions must be made about the statistical similarity of the sites in a region. To investigate whether those has been met or not many researchers as Lettenmailer (1989), Lettenmailer et.al (1987) and Cunnane (1989) have used the values of mean coefficient of variation (CV) and the site – to – site coefficient of variation of the coefficient variation (CC) of both conventional and L – moments of the proposed region (Melsew, 1996).
According to the researchers, the higher the values of CV and CC the lower the performance of index flood method for the considered region. According to Lettenmailer (1985), this is due to the dominance of the flood quantile estimation variance by the variance of the at – site sample mean. Hence for better performance of the index flood method, CC should be kept low (Melsew, 1996). In this research also both conventional and L – moments have been used to calculate Cv, LC_V and their respective CC, value. The procedures are described below.

i) For each site in a region calculate mean, standard deviation and coefficient of variation Cv

$$\overline{Q_i} = \frac{\sum_{j=1}^{n_i} Q_{ij}}{n_i} \qquad (3.23)$$

$$\sigma_i = \sqrt{\frac{\sum_{j=1}^{n_i}\left(Q_{ij} - \overline{Q}_i\right)^2}{n_i - 1}} \qquad (3.24)$$

$$CV_i = \frac{\sigma_i}{\overline{Q}_i} \qquad (3.25)$$

Where Q_{ij} = the flow rate of station j in region i
= the mean flow rate for site i
= Standard deviation of Q_{ij} for site i
Cv_i = Coefficient of variation of site i

For calculation of LCV use,

$$LCv_i = \frac{L_{2i}}{L_{1i}} \qquad (3.26)$$

Where, LCvi is the dimensionless coefficient of variation calculated from L-moments and the respective expressions for L_1 and L_2 are as defined above.

ii) For each region, using the statistics calculated in step 1, compute the regional mean, CV and LCv; standard deviation of CV and LCv, and finally the corresponding C using the following relations

$$\overline{CV} = \sum_{i=1}^{N} \frac{CV_i}{N} \quad \text{(3.27)}$$

$$\sigma_{CV} = \sqrt{\frac{\sum_{i=1}^{N} \left(CV_i - \overline{CV}\right)^2}{N}} \quad \text{(3.28)}$$

$$CC = \frac{\sigma_{CV}}{\overline{CV}} \quad \text{(3.29)}$$

Where: N- number of sites in a region
- mean coefficient of variation of the region
- Standard deviation of at – site CV values.

The same procedure holds true for the corresponding L – moment values.
Criteria: The region declared to be homogenous if CC < 0.30.

III. Statistical Comparison

Statistical values, like coefficient of variation, coefficient of skew ness and kurtosis show a clear distinct distribution on graph when plotted. Especially lower moments LCv & LCs and moment ratios are good indicators of homogenous region.

3.6 Result of Homogeneity Tests

Discordance test Summary

From the result one station (114012) in Region 3 is discordant. It is related with region 5. However, it is not possible to delineate with region 5 & also is not recommended to delineate this station as one region. As a result this station was considered as a discordant station, and specific flood frequency curve was developed for it which is exactly alike with region five.

Cv & LCv homogeneous tests

FORTRAN program is developed for these tests. The overall output of the program is summarized in Appendix F, Table F.2. In addition to this, the end result is revised in table 3.3 below. According to the result all stations of the respective regions satisfy homogeneity criteria for both conventional and L – moment CV – based homogeneity tests.

Table 3.1 Result of CV – based homogeneity tests for the regions in BNRB

Region	CC value		Conclusion
	ConvCV-based method	L-moment CV-based Method	
One	0.144	0.148	Homogeneous
Two	0.216	0.204	Homogeneous
Three	0.287	0.231	Homogeneous
Four	0.203	0.192	Homogeneous
Five	0.290	0.233	Homogeneous

Statistical Comparison

In this case the homogeneity of the stations was checked by comparing various statistical parameters such as Cv, Cs, Ck, LCv, LCs and LCk within the region as shown in figure 3.3 and 3.3. When these statistical values are plotted as in figures 3.3 and 3.4, they show layers or group of regions that indicate different regions. Moreover, the coefficient of variation was found to be a good indicator of homogeneity of stations; whereas higher moments are not efficient in indicating homogeneity of stations.

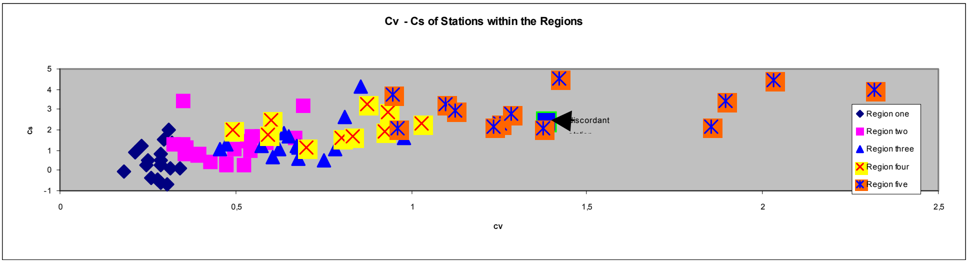
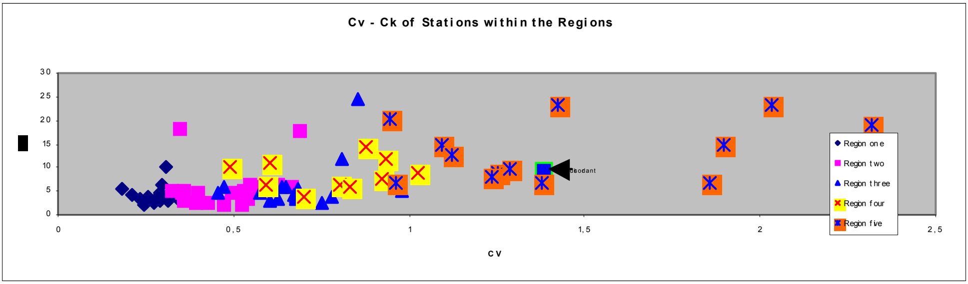


Figure 3.4 Graph for statistical values comparison (Cont'd)



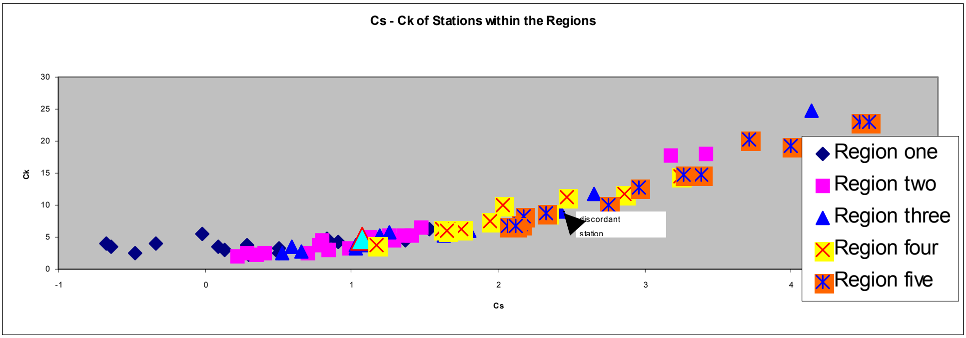


Figure 3.4 Graph for statistical values comparison (Cont'd
)

3.7 Selected Distributions for the Identified Regions

For the identified regions above using L-Moment ratio diagram the parent distributions in which the flood data series come from is selected from the regional average of LCs and LCk value as shown on the graph 3.5.

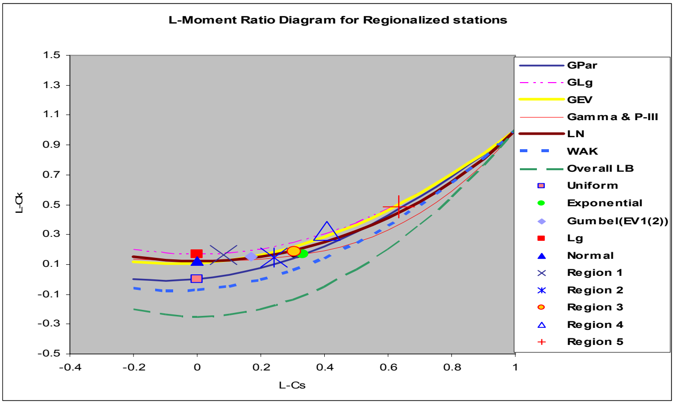


Figure 3.5 Regional average LMRD for the established regions

Accordingly, for region one Generalized Logistic & Log Normal distribution and for region two Gamma, Pearson III & Log Pearson III distributions are selected. For region three, Log Normal distribution is chosen. Generalized Logistic and Generalized Extreme Value are selected as candidate distributions for region four and region five. The selection of best fit distribution with its robust parameter estimation method from the candidate distributions for each region is another task which needs further investigation.

Table 3.2 Summary of land features, catchments characteristics, sub basin names for the established regions

Name of the region	Total area & Perimeter	Location / Catchment	General characteristics (particulars)
Region one	Area 75164 km^2 Perimeter 2727 km	Upper Guder-kale, middle & lower Didessa-Anger, lower part of main Abbay, Dinder & Shinfa-Rahad lower Tana catchments & high lands of Gojam	Elevation from 700m to 1500m & 3000 to 4000m at Gojam high lands; rainfall varies from 900 to 1600mm & also up to 2000mm at high land areas; Topography from level to undulating plains, rolling plains low plateau plains & gorges; Slope ranges from 0.1 to 15 % with land cover mostly shrub land.
Region two	Area 41315 km^2 Perimeter 2154 km	Beles, Gilgel Abbay, Fincha, lower Guder-Kale Catchments, extreme upper course of Jema-Wenchit	Elevation from 1200 to 3000m; rainfall 1000 to 1600mm; slope of the area 0.5 to 30 %; topography from low plateau plains to mid plateau plains, level to undulating plains; land use open wood land, from moderately to dominantly cultivated, grass land.
Region three	Area 27784 km^2 Perimeter 1821 km	Upper Didesa-Anger, Bahir Dar, Tis Abbay (Blue Nile Falls), Mota region	Elevation from 1500 to 3800m; rainfall 1000 to 1400mm & up to 2000mm at high land; slope 0.5 to 70 %; topography low plateau, plains hills & mountains; moderately to dominantly cultivated land and also forest, woodland, grassland cover
Region four	Area 6515 km^2 Perimeter 526 km	Bir-Temcha, southern part of Gojam high lands, Extreme upper course of Gilgel Abbay	Elevation 2000 to 3700mm; rainfall 1200 to 2000mm; slope 10 to 70 %; land use cultivated from moderately to dominantly; topography hills & mountains, rolling plains, & low plateau plains
Region five	Area 49222 km^2 Perimeter 2654 km	Gumera, Rib, Bijena-Beshlo, Jema-Wenchit, Dabus, Muger-Urga'A	Elevation from 1000 to 3500m; rainfall 1000 to 1600mm; slope 0.1 to 50 %; land use grassland, swamp, shrub land, moderately to dominantly cultivated; topography level to undulating plains, low plateau, gorges, high plateau plains

4 Conclusion and Recommendation

4.1 Conclusion

Despite many attempts made by research hydrologists to delineate homogeneous regions, no general methodology is accepted yet universally. Here, regionalization was made on the statistical values (LCs and LCk) of index flood of each stations. The concept based on assumption that the index flood series, of stations from the same region, come from the same parent of distribution. The proposed five regions satisfied the homogeneity test applied in the study. Except one station (114012) in region three is discordant with the existing region and homogeneous with region five. Peak flow data series of each station of the same region will fit the same type of distribution. This is the advantage gained from regionalization concept that has been used in this study. The types of distribution, most likely to fit data of each region, were identified from the regional average statistical value of L – Moment ratio.

4.2 Recommendation

- Delineation of homogeneous regions based on statistical parameter of gauged sites could be one of an alternative method of regionalization, to identify stations of similar flood producing characteristics.
- Lower moments such as Cv, LCv, and graph of Cv-Cs, LCv-LCs, Cv-Ck, LCv-LCk are found to be good indicator of homogenous stations in this study.
- The selection of best fit single distribution and also vigorous parameter estimation method require further investigation.

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