CHARACTERISTICS OF MONTHLY AND ANNUAL RAINFALL OF THE UPPER BLUE NILE BASIN

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ABSTRACT

The Upper Blue Nile Basin is relatively wet with mean annual rainfall of 1423 mm (1960-2002) with standard deviation of 125 mm. The rainfall statistics is based on 32 rainfall stations with varying length of record. This mean rainfall is similar to a mean annual rainfall reported for a longer period of record (1900-1998). The annual rainfall has a normal probability distribution. The year-to-year rainfall variation is relatively small with a coefficient of variation of 0.09. The 100-year-drought basin annual rainfall is 1132 mm and the 100-year-wet basin annual rainfall is 1745 mm. The dry season is from November through April. The wet season runs from June through September with 74 percent of the annual rainfall and with low variation and skewness. October and May are transitional months. Monthly rainfall probability distribution varies from month to month fitting to Gamma-2, Normal, Weibull and Lognormal distributions. Monthly and annual rainfalls for return periods 2, 5, 10, 25, 50 and 100-year dry and wet patterns are presented. Spatial distribution of annual rainfall over the basin is mapped and shows high variation with the southern tip receiving as high as 2049 mm and the northeastern tip as low as 794 mm annual average rainfall.

INTRODUCTION

The Blue Nile Basin is the main source of the Nile River with a drainage area of 324,530 km^2 (Peggy and Curtis, 1994). Eighty six percent of the annual flow of the Nile comes from the Blue Nile Basin (59 percent) and 14 percent from the Barro-Akobo-Sobat sub-system and 13 percent from the Tekeze/Atbara/Gash sub-system (Degefu, 2003). The remaining 14 percent comes from the equatorial lakes after losses of evaporation in the Sudd region and Machar marshes (Degefu, 2003). The Upper Blue Nile River Basin (Figure 1) is 176,000 km^2 in area (Conway, 2000).The Upper Blue Nile Basin is relatively wet. Annual rainfall ranges from over 2000 mm in the Southwest to a 1000 in the northeast (Conway, 2000). Bewket and Conway (2007) reported mean annual point rainfall of 1445, 1665, 1542, 1349 mm rainfall at Bahir Dar, Chagni, Dangla and Debremarkos, respectively. Peggy and Curtis (1994) reported 1521 and 1341 mm long-term average annual rainfall for Bahir Dar and Debremarkos, respectively. Kebede et al. (2006) reported 1451 mm average annual rainfall for Bahir Dar based on observations from 1960 to 1992.

Rainfall is the most important hydrologic parameter in rain-fed agriculture. The frequency of low rainfall events determines the frequency of drought while the frequency of high rainfall events determines high stream flow occurrences. Point and regional rainfall frequency analysis characterize the temporal and spatial variation of rainfall over a region. Point rainfall frequency analysis is the temporal characterization of rainfall from a single gauge. Spatial mapping of the characteristics of all gauges in a region provides the spatial characteristics of rainfall. Regionally averaged rainfall frequency analysis characterizes rainfall over the region. Decent data length and quality is needed for temporal and spatial characterization of rainfall. Conway et al. (2004) studied the history of rainfall and temperature monitoring network and available records in Addis Ababa, Ethiopia and concluded that there are very few numbers of sites where continuous rainfall and temperature measurement records are available. In the absence of long term concurrent rainfall observations in a basin, efforts need to be made to make the most use of existing data as much as possible.

RAINFALL DATA ANALYSIS

The Upper Blue Nile Basin spatial average rainfall was generated by computing average values from 32 rainfall gauges. The period of record for each station varies and there are frequent data gaps. For each month of analysis, the average of all gauges with record was computed as an estimated basin-wide average monthly rainfall. Annual basin spatial average rainfall was computed as a sum of the monthly estimated basin rainfall. Figure 2 depicts the rain gauge network that was employed in the analysis.

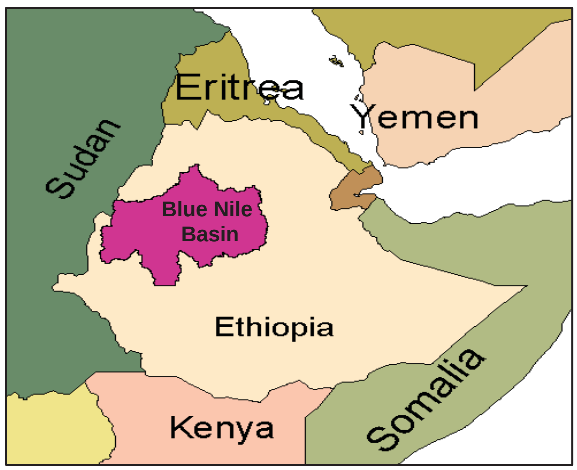

Figure 1. Location of the Upper Blue Nile River Basin in Ethiopia.

Monthly Rainfall Data Statistics

Temporal statistical characteristics of monthly spatially averaged rainfall is shown in Table 1. Based on the mean (μ), January has the lowest rainfall and July has the highest monthly rainfall. The standard deviation (σ) is relatively high for the dry season and transitional months. The dry season months are November, December, January, February, March and April. The wet season months are June, July, August and September. May and October are transitional months, respectively from dry season to wet season and from wet season to dry season. The coefficient of variation, c.v. (σ/μ) of the wet season months is small indicating that these months have low variation. For comparison, South Florida, a 46,400 sq. km basin has c.v. of 0.53, 0.46, 0.45 and 0.52 for the wet months of June, July, August and September (Ali et al., 2000). The dry season months have higher c.v. indicating that the year-to-year variation for these months is high. The degree of skewness is high in the dry season months relatively than in the wet season months. January, February, May, July, August, November and December are Leptokurtic (Kurtosis > 3). January, February, November and December have higher skewness and c.v. than the other months. Monthly rainfall and cumulative monthly rainfall is depicted in Figure 3 distinctly showing dry and wet seasons. The change in slope in May and October demonstrates that these months are transitional months.

Figure 2. The Upper Blue Nile Basin rain gauge network used in this analysis.

Table 1. The Upper Blue Nile Basin monthly rainfall statistics and best-fit probability distribution.

Month	Mean mm	Standard Deviation mm	Coefficient of Variation	Skewness	Kurtosis	Distribution 90% C.I.
January	10.4	10.5	1.00	1.90	7.43	Gamma
February	15.0	12.3	0.82	1.14	4.31	Weibull
March	42.0	21.2	0.51	0.26	2.62	Normal
April	57.9	28.6	0.49	0.31	2.93	Normal
May	124.6	42.4	0.34	0.19	3.44	Normal
June	197.2	28.6	0.15	-0.10	2.58	Weibull
July	331.9	42.0	0.13	0.38	3.80	Gamma
August	320.2	42.7	0.13	-0.07	3.60	Normal
September	197.6	35.4	0.18	0.57	2.90	Lognormal
October	86.8	43.9	0.51	0.51	2.84	Gamma
November	26.9	20.6	0.76	1.09	3.58	Gamma
December	12.7	10.5	0.83	1.45	6.46	Weibull

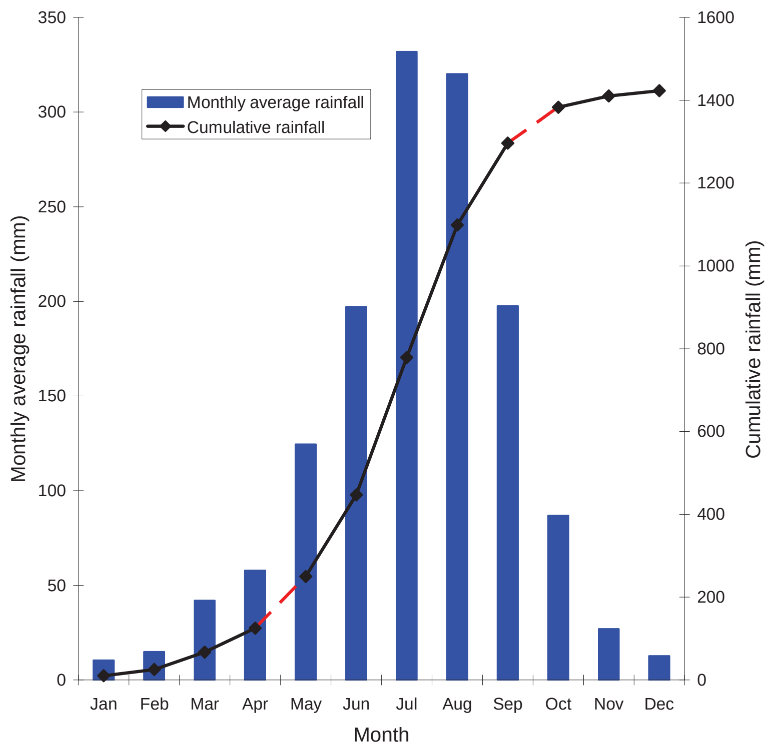

Figure 3. Monthly average and cumulative rainfall for the Upper Blue Nile Basin.

Frequency Analysis of Monthly Rainfall

Frequency analysis of monthly rainfall requires the selection of the best-fit theoretical probability distribution for each month's spatially average rainfall. A probability distribution is selected from a list of commonly applied statistical probability distribution models. The models were Normal, Gamma-2, Lognormal and Weibull. Each model was fitted to each month rainfall and the best-fit model was selected based on the ratio of computed Chi-square (χ^2) to the tabular χ^2.

$$\chi^2 ratio = \frac{\chi^2 computed}{\chi^2 table} \qquad (1)$$

When χ^2 ratio is less than 1, the model is accepted and greater than 1, the model is rejected at 90 percent confidence interval. Once selection of model is completed, a month's rainfall histogram and frequency is plotted. Figure 4a and 4b depict observed histogram and theoretical frequency distribution fitting for each month.

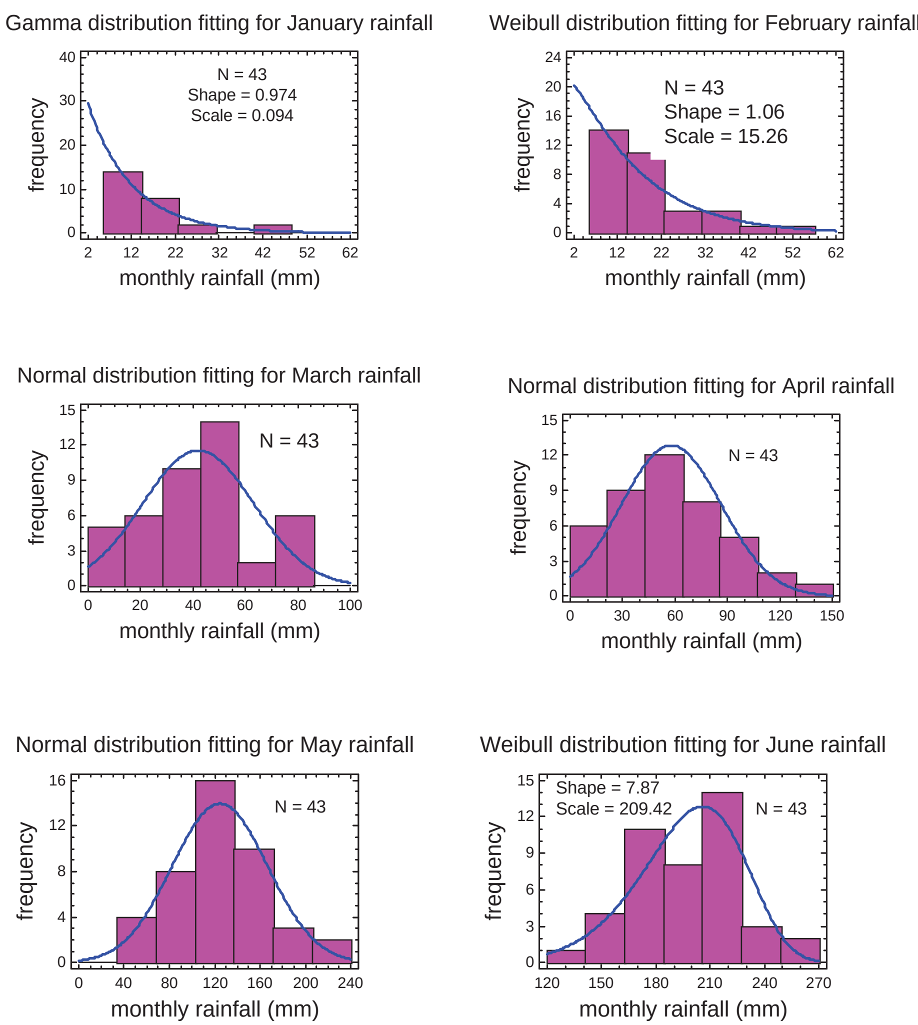

Figure 4a. January-June observed and theoretical distributions for the Upper Blue Nile Basin monthly rainfall.

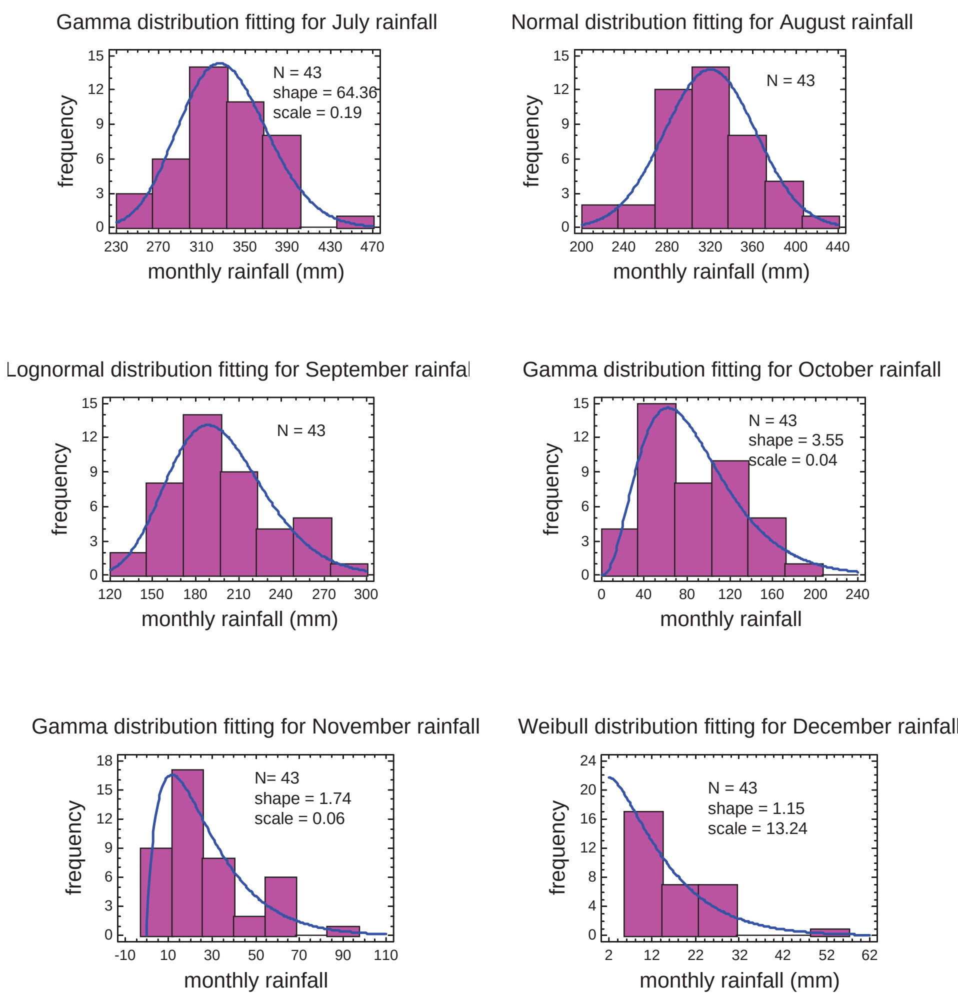

Figure 4b. July-December observed and theoretical distributions for the Upper Blue Nile Basin monthly rainfall.

Rainfall return period is a probabilistic measure of the likelihood of occurrence of a given amount of rainfall. Return periods for dry (below average) and wet (above average) rainfall patterns were computed for return periods of 2, 5, 10, 25, 50 and 100-year. Return periods in years were computed as follows from the Cumulative Density Function (CDF) for each month's respective distribution fitting.

$$DryReturnPeriod = \frac{1}{1-CDF} \quad \text{for CDF} \leq 0.5 \qquad (2)$$

$$WetReturnPeriod = \frac{1}{CDF} \quad \text{for CDF} \geq 0.5 \qquad (3)$$

Return period for dry and wet pattern rainfall for each month is depicted in Table 2. The 2-year values are the monthly mean values as estimated by the respective probability distribution model. Months fitted with Normal Distribution have means similar to the arithmetic means. The other model estimated means deviate from the arithmetic means due to the characteristics of the distributions (Table 1).

Table 2. Dry and wet return periods for monthly rainfall of the Upper Blue Nile Basin.

Month	Dry					2-yr	Wet				
	100-yr	50-yr	25-yr	10-yr	5-yr		5-yr	10-yr	25-yr	50-yr	100-yr
January	0.0	0.1	0.3	1.0	2.3	7.2	16.4	23.9	33.6	41.0	48.6
February	0.4	0.7	1.2	2.6	4.9	12.4	24.9	33.4	44.1	51.8	59.2
March	0.0	0.0	4.8	14.8	24.1	42.0	59.9	69.2	79.2	85.6	91.4
April	0.0	0.0	7.8	21.2	33.8	57.9	81.9	94.5	108.0	116.7	124.5
May	26.4	37.9	50.7	70.5	89.1	124.6	160.1	178.7	198.5	211.3	222.8
June	119.6	130.2	141.9	159.4	174.7	200.7	222.5	232.5	242.2	248.0	253.0
July	243.2	252.5	263.1	280.1	296.7	330.1	366.1	385.9	407.7	422.3	435.7
August	220.8	232.5	245.4	265.4	284.2	320.2	356.1	374.9	394.9	407.9	419.5
September	129.2	135.6	143.0	155.3	167.8	194.6	225.6	243.8	264.8	279.3	293.0
October	15.0	19.2	24.8	35.4	47.8	78.9	121.2	148.3	181.4	205.2	228.3
November	1.1	2.0	3.2	6.2	10.2	22.1	40.9	53.9	70.6	83.1	95.4
December	0.3	0.6	1.0	2.2	4.0	10.2	20.4	27.5	36.2	42.5	48.7

Annual Rainfall Statistics and Probability Distribution

The Upper Blue Nile Basin is relatively wet with annual mean rainfall of 1423 mm (1960-2002) with standard deviation of 125 mm (Figure 5). The rainfall statistics is based on 32 rainfall stations with varying length of record. Conway (2000) reported a mean annual basin rainfall of 1421 mm based on 11 gauges for the period 1900-1998. The Upper Blue Nile Basin annual rainfall probability fits normal distribution at a confidence level of 90 percent (Figure 6). Annual dry and wet return periods computed from normal probability cumulative density functions are shown in Figure 7 for dry and wet return periods of 2, 5, 10, 25, 50 and 100-year. The 100-year drought annual basin rainfall is1132 mm while the 100-year wet annual rainfall is 1745 mm.

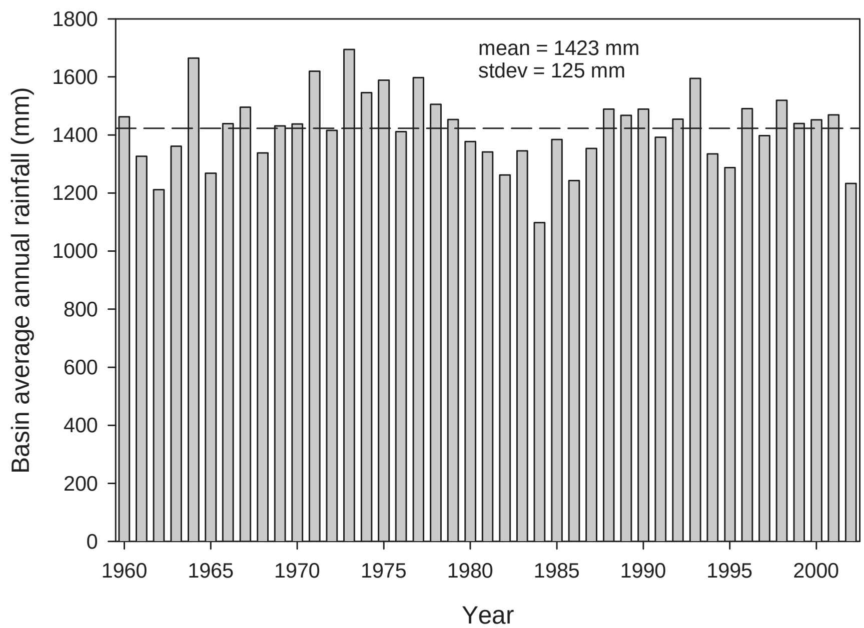

Figure 5. The Upper Blue Nile Basin average annual rainfall (1960-2002).

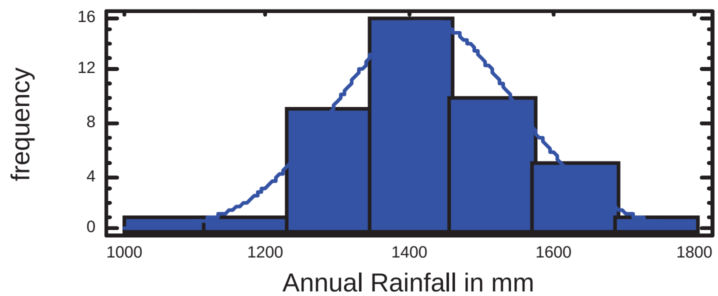

Figure 6. Observed and theoretical probability distributions for annual rainfall of the Upper Blue Nile Basin.

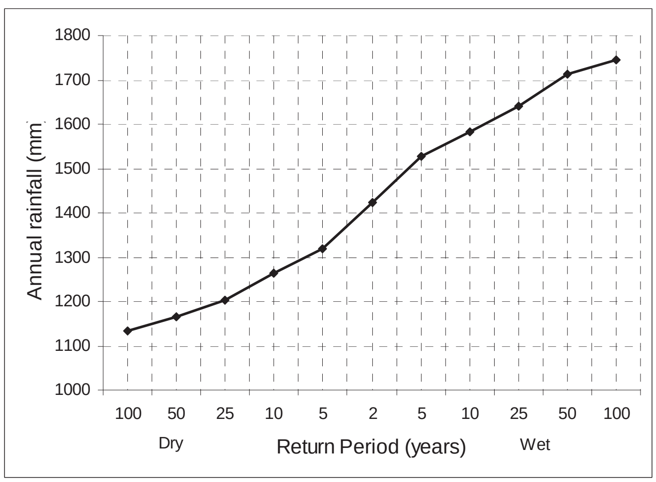

Figure 7. Dry and wet annual rainfall return periods for the Upper Blue Nile Basin.

Spatial Variation of Rainfall over the Upper Blue Nile Basin

Spatial variation of rainfall over the basin is high with a coefficient of variation of 0.25. Rainfall amount varies generally from the southwest to the northeast decreasingly. The highest annual average rainfall of 2049 mm is in the southern tip of the basin and the lowest average annual rainfall of 794 mm is in the northeast. Average rainfall over the basin is spatially mapped using 28 rain gauge annual average records. Isohyetal map was generated using the Kriging interpolation package in SURFER Version 8 with linear variogram (Figure 8).

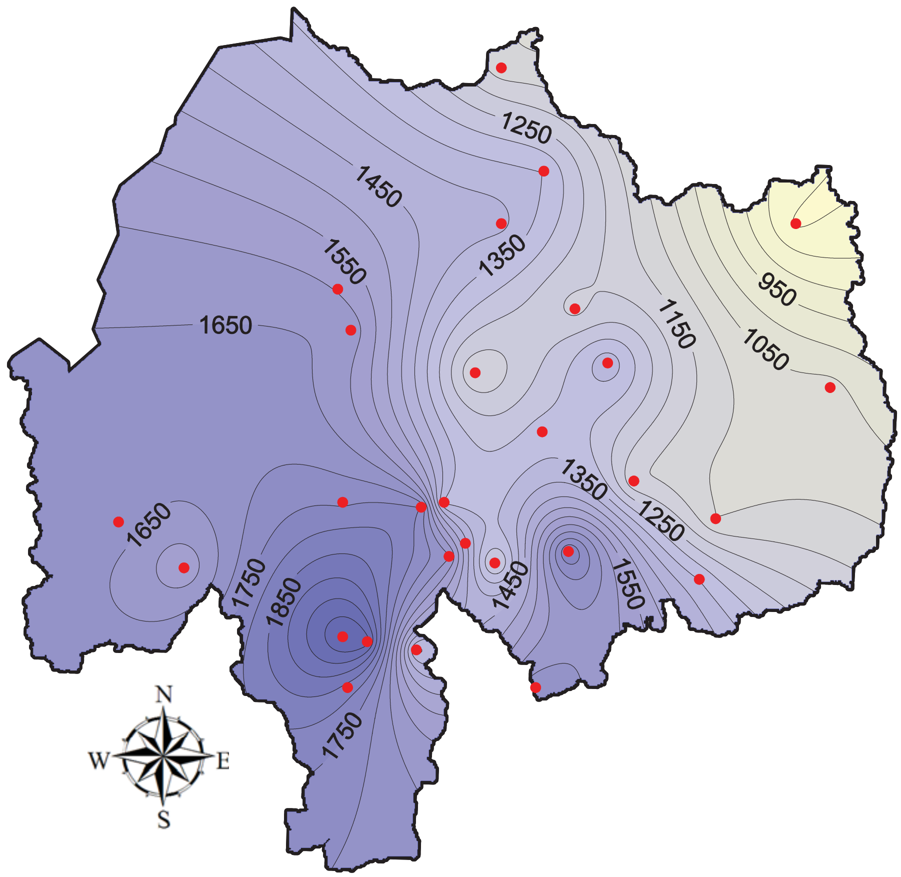

Figure 8. Spatial distribution of the Upper Blue Nile Basin average annual rainfall with rain gauge locations.

SUMMARY

The Upper Blue Nile Basin spatial average rainfall was analyzed to determine spatial and temporal statistical characteristics and derive applicable information. The Upper Blue Nile Basin is relatively wet with mean annual rainfall of 1423 mm (1960-2002) with standard deviation of

125 mm. The rainfall statistics is based on 32 rainfall stations with varying length of record. This mean rainfall is similar to a mean annual rainfall study for a longer period (1900-1998). The annual rainfall has a normal probability distribution. The year-to-year rainfall variation is relatively small with a coefficient of variation of 0.09. The 100-year drought basin annual rainfall is 1132 mm and the 100-year wet basin annual rainfall is 1745 mm. The dry season is from November through April. The wet season runs from June through September with 74 percent of the annual rainfall and with low variation and skewness. October and May are transitional months. Monthly rainfall probability distribution varies from month to month fitting to Gamma-2, Normal, Weibull and Lognormal distributions. Monthly and annual rainfalls for return periods 2, 10, 25, 50 and 100-year dry and wet patterns are presented. Spatial distribution of annual rainfall over the basin shows high variation with the southern tip receiving as high as 2049 mm and the northeastern tip as low as 794 mm annual average rainfall.

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