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Development of Flood Frequency Curves for the Eastern Nile

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Abstract: Extreme hydrological events such as floods cause severe damage to the human society living along the rivers, Wadis and coastal areas. Reliable estimation of the magnitudes of these floods with various return periods, particularly in rivers and Wadis, is of great significance in minimizing flood damage and in designing hydraulic structures. This can be achieved through flood frequency analysis. This study aims at conducting flood frequency analysis for the Eastern Nile within Sudan. Annual maximum instantaneous flood peaks at seven stations were statistically analyzed and the underlying frequency distribution for each station was determined. Several flood frequency models have been tested, namely, Extreme Value type1, Two parameters Log Normal, Three parameters Log Normal and Person type III distribution. The selection of the best frequency model for a particular station was based on the Chi square test and minimum root mean square error. The parameters of the distributions have been determined by the method of L-moments. A regional analysis was then carried out using the Index Flood method. The results indicate that the seven stations can be grouped into two regions, namely the Blue Nile region and River Atbara region. Hence flood frequency curves were developed for the two regions.

Keywords: Annual maximum; Flood Frequency Curves; L-moments; Index Flood Method.

INTRODUCTION

A common problem encountered in many aspects of water resources engineering is that of estimating the return period of extreme hydrological events such as floods, for a site or a group of sites [1]. A reliable estimation of such extreme flood events is of great significance in minimizing damage by facilitating proper planning and design of civil engineering structures such as dams, culverts, bridges, barrages and other flood control structures. Inaccurate determination of design floods leads to over design or under design of hydraulic structures. Over design involves unnecessary high construction costs while under design may result in excessive future damages and losses. One of the widely used methods of estimating the design flood at a particular site is by performing frequency analysis of observed flood peaks over a number of years at that site. In flood frequency analysis the objective is to establish a relationship between flood magnitude and the recurrence interval or return period. That is, a past record is fit with a statistical distribution function which is then used to make inferences about future events. Identification of the true statistical distributions for the various hydrologic and meteorological data sets continues to be a major challenge facing engineers and hydrologists [2].

Flood frequency analysis involves collecting flood data, and using this data to estimate the characterizing parameters of the underlying distribution, the functional form of which is assumed known. Popular parameter estimation techniques include the method of moments and maximum likelihood estimation. Whereas the methods of conventional moments has been applied by many researchers in identification of the underlying distributions, it has one shortcoming in that it involves raising the raw data to the powers of 2,3 and 4 in order to calculate the 2nd, 3rd and 4th moments namely standard deviation, skewness and kurtosis. Thus it involves non linear transformation of data [3]. The method of maximum likelihood has been used when dealing with extreme values; however it doesn't work well when the sample size is small to moderate. Moreover its computational aspects are based on iterative procedures which require reasonable starting values [4]. Another widely used method of parameter estimation that is more superior is the L-Moments which is equivalent to probability weighted moments (PWM) [5]. The method of L-Moments equates linear combinations of the sample data to the corresponding theoretical expressions involving parameters of the statistical distributions in order to specify these parameters. They avoid non-linear transformations of data. Flood frequency analysis can also be carried out for sites having short or limited records by using regional data. The use of regional information to estimate flood magnitudes has become increasingly important since many projects which require design flood information are located in areas where flood data are either missing or inadequate [6].

The purpose of this paper is to conduct flood frequency analysis to the rivers of the Eastern Nile basin within Sudan. This basin has an area of about 0.4 million square kilometers and is spread over parts of Ethiopia, Eritrea and Sudan. It is considered as one of the most important basins in Africa due to its great potential in water resources, land resources and hydroelectric power. Within the framework of the Nile Basin Initiative (NBI), a number of benefit sharing and economic integration development projects have been identified in this basin, which when implemented will have their positive impacts on the socioeconomic conditions of the riparian countries. There is therefore a necessity for analyzing flood data throughout the basin in order to develop procedures which enable the estimation of flood magnitudes that are required for the hydrological design.

MATERIALS AND METHODS

1.1 Available Data for the Study

Daily discharge data from a total of seven gauging stations on the Blue Nile river, its tributaries Dinder and Rahad, and River Atbara were used in this study. The stations names, their locations and the period of records are shown Table 1 and Fig. 1.

Annual maximum daily discharge series were extracted from the raw data for at site flood frequency analysis while the other regional information were used in regional frequency analysis. Before conducting frequency analysis the data for each station was checked for inconsistency and dependence. Table 2 gives a summary of the basic statistical properties of

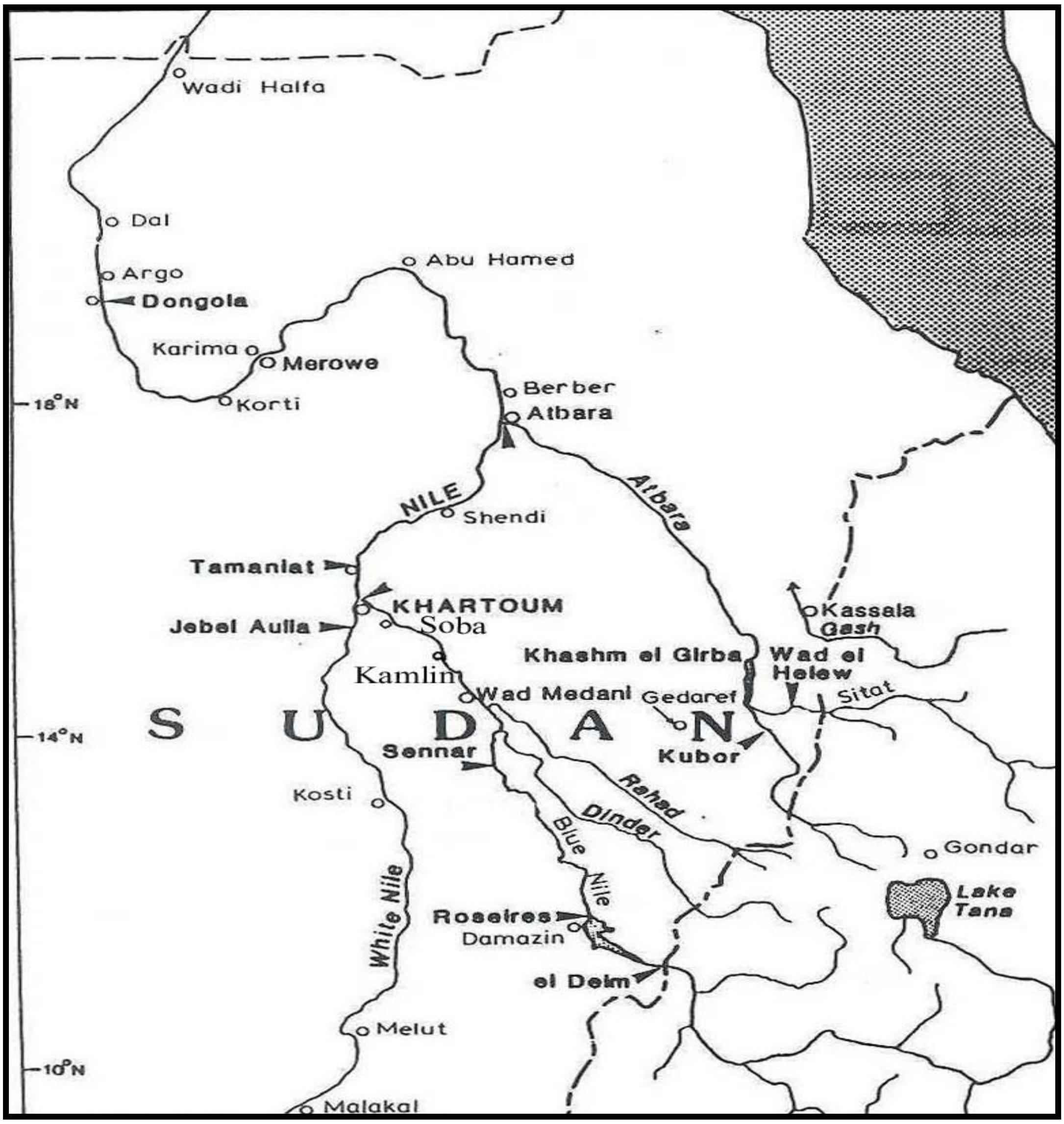

Fig. 1. Locations of stations used in the study

Table 1. Summary of the available at site and regional data

River	Station	Upstream Catchment Area km^2	Period of Record
Blue Nile	Deim	179,486	1965-2012
Blue Nile	Sennar	198,500	1965-2012
Blue Nile	Khartoum	251,486	1965-2012
Dinder River	Hawata	37,000	1972-1998
Rahad River	Gwasi	35,000	1972-1998
Atbara River	Kubur	96,393	1972-1998
Atbara River	Wad El Hileiw	42,845	1972-1998

Table 2. Summary of the basic statistical properties of flood data

Stations	Basic Statistical Parameters				
	Million m^3/day		Coefficient of variance	Coefficient of skewness	Coefficient of kurtosis
	Mean	Standered deviation			
Ed Deim	665.66	143.63	0.22	0.19	-0.82
Sennar	586.61	112.46	0.19	-0.27	-0.70
Khartoum	638.43	150.38	0.24	-0.35	0.79
Giwasi	48.23	14.32	0.30	0.79	2.95
Hawata	14.24	1.98	0.14	-1.32	4.10
Wad el Heleiw	245.80	155.90	0.63	1.53	2.62
Kubur	232.44	131.22	0.56	0.82	0.08

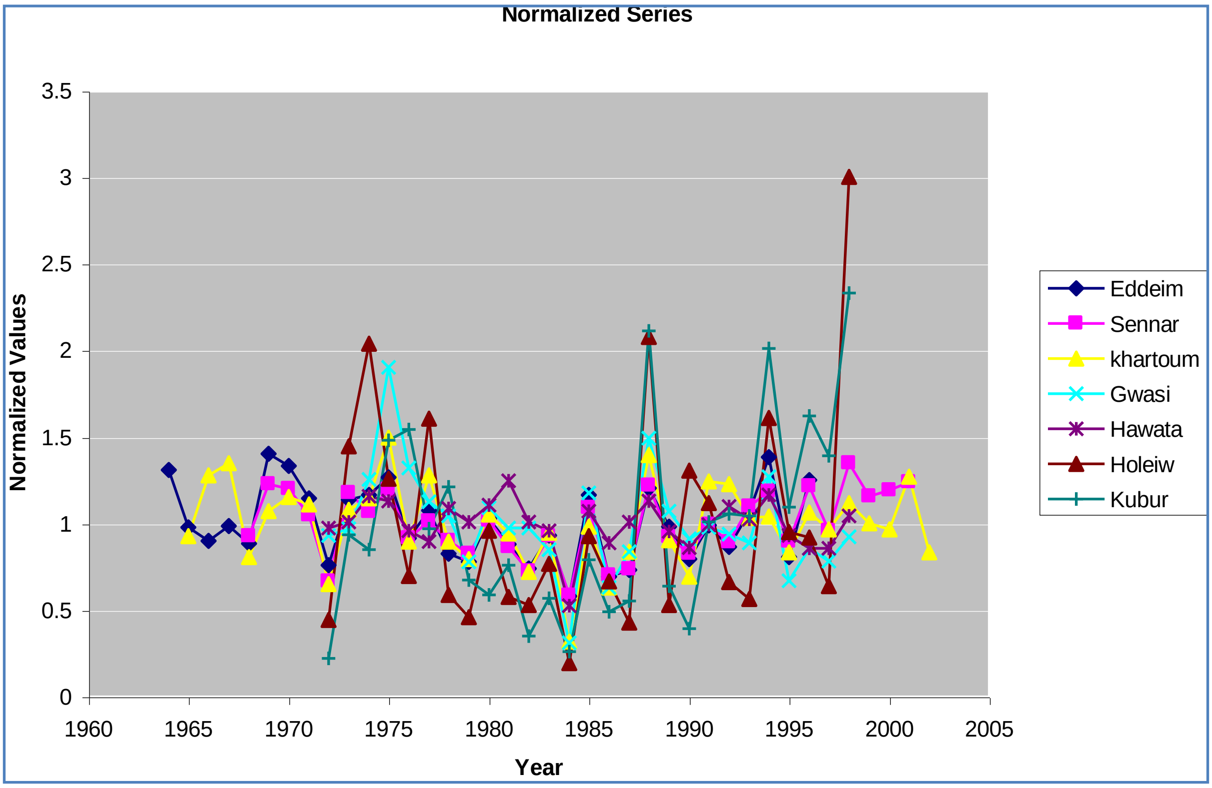

Fig. 2. Normalized discharge series at various sites

the discharge data. As can be observed, the discharge coefficient of variation values for river Atbara stations is higher than those of the Blue Nile and its tributaries. This can also be observed from the plot of the normalized discharge values shown in Fig. 2.

The coefficient of variation provides a useful measure of the hydrological variability. The different levels of variability in the observed floods between the Blue Nile and river Atbara may be attributed to the varying hydrological phenomena responsible for generating the flood events over the two sub- catchments. Furthermore, in the Blue Nile basin the stations are more downstream than the others and the peak floods are overtopped due to spilling over the flood plains. In the River Atbara sub catchment, however, the highly variable flows are due to the hilly nature of the catchment and the closeness of the stations to the catchment area

3. RESULTS AND DISCUSSION

3.1 At Site Frequency Analysis

At the site of interest, various frequency distributions were tested on the annual maximum discharge series and the most suitable distribution for that site was selected. The distributions tested were:

- The extreme value type1 (EVI)
- The 2 parameter log normal (2LN)
- The 3 parameter log normal (3LN) and
- Pearson type III (PIII)

The quantile Q_T is estimated as given by [7].

$$Q_T = a + bY_T \qquad (1)$$

where a and b are the sample estimates of the location and shape parameters respectively of the selected distribution and Y_T is a standardized variate with return period T. For estimating the parameters of a distribution, the method L-moments was employed in this analysis. The best distribution was selected on the basis of:

1. The standard Chi Square test $\chi 2$
2. The Root Mean Square Error (RMSE)

The root mean square error of estimates for each distribution is given by (Kite, 1988) as:

$$RMSE_j = \left[\frac{\sum_{i=1}^{n}(x_i - y_i)^2}{n - m_j}\right]^{1/2} \qquad (2)$$

where x_i , i = 1, 2, …. n are the recorded events , and y_i, i = 1, 2, …. n are the event magnitudes computed from the j^{th} probability distribution at probabilities computed from sorted ranks, and m_j is the number of parameters of the j^{th} distribution.

For calculating the return periods of observed flows , the series are ranked in a descending order and the return period (plotting position) is calculated using the Gringorten equation.. There are other formulae available for this purpose but due to the mild skew ness in the data under consideration the Gringorten Equation is the best to use as suggested by [8]. The formula is given as:

$$T = \frac{n}{m+1} \qquad (3)$$

where, T = return period
n = number of observation
m = rank (rank 1 for the highest recorded flood)

Table 3. RMSE and Chi-square Statistics for all Stations

	Station	Ed Deim	Sennar	Khartoum	Gwasi Dinder	Hawata Rahad	Wad El Hileiw	Kubur
EV1	RMSE	26.29	35.84	31.20	21.23	18.44	21.67	7.82
	Chi Sq	37.63	82.69	79.16	5.93	9.49	9.49	2.62
2LN	RMSE	20.12	27.12	25.45	20.49	10.36	27.32	9.67
	Chi Sq	2.03	2.00	2.54	5.93	7.82	9.49	3.27
3LN	RMSE	8.83	21.12	21.84	17.83	9.85	16.34	6.78
	Chi Sq	0.30	0.30	1.79	5.52	7.82	7.82	2.42
PIII	RMSE	19.88	16.96	28.26	25.34	12.23	21.95	12.42
	Chi Sq	0.33	13.45	4.00	5.93	9.49	9.49	6.98

Table 4. The calibration results for all the Stations (Flood values in MCM/d)

Region			Blue Nile			River Atbara	
Station	Ed Deim	Sennar	Khartoum	Gwasi	Hawata	Wd El Heleiw	Kubur
MAF*	665.6	586.6	638.42	47.66	14.35	245.79	232.44
50 year flood	975.3	792	948.3	85.10	18.3	528.2	574.67
100 year Flood	1015.6	814	985.4	91.48	18.8	583.1	652.83
200 year Flood	1062.3	837	1027.8	99.30	19.4	651.4	752.68
500 year Flood	1113.4	862	1073.3	108.37	20	731.7	873.67
1000 year flood	1147.9	878	1103.6	114.83	20.3	789.7	963.3

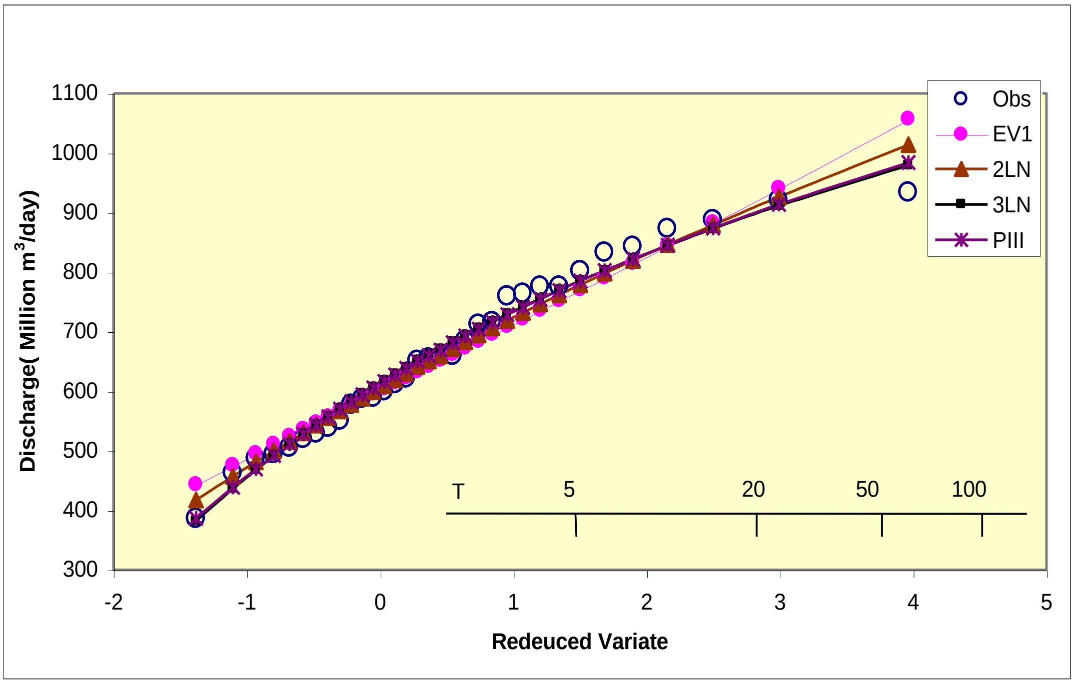

Fig. 3. Comparison of distributions at Ed Deim station

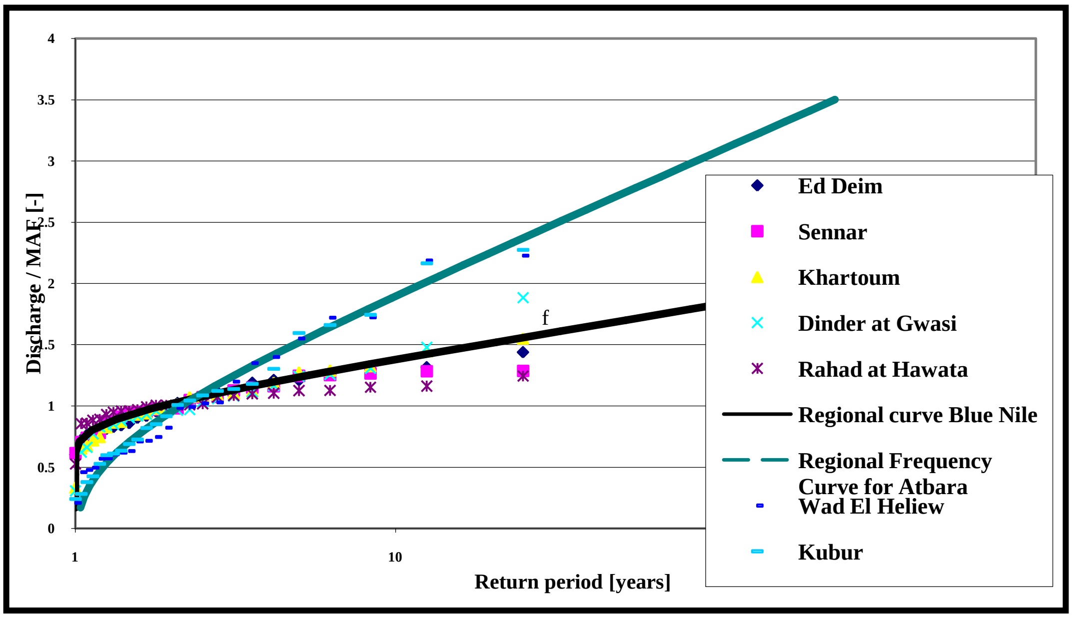

Fig. 4. Pooled regional data and regional frequency curves

At site frequency analysis using the procedure discussed above has been conducted. Full results are too many for inclusion in the paper. Therefore a summary of the results is shown in Table 3. The Chi-square and the RMSE values suggests that the 3 parameter Log normal (3LN) distribution is the best frequency model for all the stations. This can also be seen in Fig. 3 for Ed Deim station which is shown as an example. It can be observed that all the distributions are closely grouped but the 3LN is consistently the best. Table 4 shows the flood values in MCM/d for different return periods for all stations considered. .

3.2 Regional Frequency Analysis

The use of regional information to estimate flood magnitudes at sites with little or no observed data has become increasingly important since many projects which require design flood information are located in areas where observed flood data are either missing or inadequate. Regional analysis consists of analyzing the record of all gauged sites in a hydro logically homogeneous region, in order to be able to use or transfer information contained in the record of many sites to estimate quintiles at any individual gauged or ungauged catchments in the region. Hosking and Wallis [9] have discussed the various aspects of regional frequency analysis such as identification of homogeneous regions and described the different steps of regional analysis. In the present application, the discharge-return period (Q-T) relationships for all sites as previously obtained were plotted together with the discharge being expressed in dimensionless or standardized form (by dividing by the MAF). This approach is known as the Flood Index method. The results of analysis are shown in Fig. 4. It is clearly observed that the Blue Nile region and River Atbara region are not homogeneous and this, as has been mentioned before due to the varying hydrological phenomena responsible for generating the flood events over the two regions. Consequently, a regional frequency curve has been developed for each region as shown in Fig. 4.

4. CONCLUSIONS

The main objective of the work presented in this paper was to develop flood estimation procedures for the Eastern Nile basin in order to improve the design and appraisal of civil engineering structures .In view this, at site frequency analysis was carried out for 7 stations in the basin and the three parameter log normal distribution was identified as the best fit distribution for modelling instantaneous annual maximum flows. Regional Analysis showed that the seven stations could be grouped into two homogeneous regions , the Blue Nile region and River Atbara region. Consequently a regional frequency curve was developed for each of the two regions. The developed regional frequency curves could be used to estimate flood magnitudes with various return periods for ungaged catchments in any region homogeneous with the regions under consideration. The results obtained from this study are based on the data that is available. Data from other Nile basin countries could be combined with the Sudanese data used in this paper to conduct a basin wide regional frequency analysis. Flood frequency analysis requires an assumption of stationarity so that climatic trends or cycles do not affect flood flows. However, there is clear evidence that this is not the case and as reported by [10] even modest changes in climate can result in large changes in flood magnitude. Therefore further research is needed to determine how aspects of climate change can be incorporated into flood frequency analysis for design and planning purposes.

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