



## **Relative Accuracy of Pearson (3) and Log-Pearson (3) Distributions using three parameter estimation methods for modelling Hydrological Flood Data of Indus River at Sukkur Barrage**

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### **Abstract**

In this study, Pearson (3) and Log-Pearson (3) distributions are fitted on the data of flood peaks at Sukkur barrage, using Method of Moment (MOM), Maximum Likelihood Method (MLM) and probability weighted Moments (PWM) for quantile estimation  $\chi^2$ -test, S-K test, probability plot correlation Coefficient (PPCC), root mean square errors (RMSE), coefficient of skewness (Cs), Coefficient of Kurtosis ( $C_k$ ) and L – moment ratios are used for comparison and testing of the distribution and methods of estimation.

LP (3) appears better than P (3) while MLM is more efficient than MOM. A flood of 1.233 million cusecs is expected to pass through Sukkur barrage during next 100 years by fitting LP (3), using MLM. Thus there is a need for taking suitable steps to save the structure of the barrage as its present capacity is only 0.9 million cusecs.

**Keyword:** Pearsaon (s), & log pearson distributions.

### **1. Introduction**

A knowledge of magnitude – frequency relationship should be used in the design of dams, high ways, bridges, water supply systems, and flood control structure. Frequency analysis is a tool in effective design. It avoids over designing which though result to increased safety, involves higher costs. The efficiency is achieved by relating cost to uncertainty using frequency analysis.

Expected differences in the results between the actual data and the estimated data will be in the magnitude at high return period  $T_r$ , i.e, at the tail of the density function and their estimation is faced with risk and uncertainty.

For uniformity, consistency and capability in planning and design of Water Management project, it is desirable that the same probability distribution be used by all agencies in the country. But it does not work, as length of data, choice of method of estimation; changes in the climate and construction of barrage upstream on the river affect the results of frequency analysis and the choice of probability distribution.

Realizing the need of selection of a particular probability distribution and an efficient method of estimation we attempt to fit some suitable distributions on river Indus, at Sukkur. Various investigation propose different distribution to fit a particular type of hydrological random variables. The distributions contain parameters estimated from sample data. Mathematically, the more parameters in a function, the more flexible it is in fitting empirical distribution. More over, use of a given distribution I subject to the validity of estimation methods. Thus the selection of a probability distribution is an optimizing problem between the flexibility and reliability of the estimated parameters.

Inspired by the works of Butto, H.B and Shaikh, N.M [4], and Nixon [5]. We had fitted Gumbel and GEV distribution [11], Normal and Log-Normal distributions [10] to the data of flood peaks of Indus river at Sukkur, for 99 years. The results are as follows:

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Table-01A Normal and log normal distributions

Sampling Size	Distribution/ Curve (Best Method of Estimation)	Flood Estimates for 100 years (million cusecs)	Investigation
85	Faster-III	1.20	Bhutto & Shaikh
85	Hazen	1.21	Bhutto & Shaikh
99	Gumbel (MLM)	1.23	Memon & Shaikh
99	Log Normal (MOM)	1.25	Memon & Shaikh
43	Pearson Type-I	0.853	Nixon
76	Pearson Type-II	1.24	Nixon

Design capacity of Sukkur barrage was 1.2 million cusecs in (1932). in (1941) due to some technical reasons capacity of the barrage had been reduced to 0.9 million cusecs. In (1976), 1.201 million cusecs flood had actually passed and more than 1.1 million cusec had actually crossed the barrage four times, luckily without damaging the structure. Nixon [5] had calculated 7.7 lac cusecs as the mean annual flood for 43 years, and 11.5 lac cusecs for 76 years, at Sukkur. Fitting Pearson Type I skew curve on the data for 43 years, the upper limit is 8.53 lac cusecs and lower limit is 3.68 lac cusecs. But using the data for 76 years, the upper limit is 12.4 lac cusecs and that the flood of magnitude of 12.0, 11.0 and 10.0 lac cusecs are expected to occur once, thrice and even times in a century, respectively.

In this study P (3) and LP (3) have been fitted using MOM, MLM, and PWM, compared and tested using Goodness of fit test,  $C_s$ ,  $C_k$ , L-moment ratios and S. E's of quantile estimates.

P (3) has been elected as it has been widely used in many countries [7]. Matalas and Wallis [8] compared the quantile estimates by P (3) using MOM and MLM. Bucket and Oliver [6] recommend

MLM for P(3). Haligram and Lele [14] had analyzed flood flows from 16 streams in India using P (3).

LP (3) has been selected as it has been recommended by the Water Resources Council of U.S.A [7]. Askhar and Bobee [3] developed confidence intervals for P (3) and LP (3). Arrora and Singh [2] compared different methods of parameter estimation of LP (3) by monte carlo simulation. In general, P (3) fits annual floods data better than LP(3) but latter is recommended for flexibility [1]. One of the important problems related to the use of LP(3) is the variability in  $C_s$ . Infact, as  $C_s \rightarrow 0$ .  $LP(3) \rightarrow LN(2)$ .

Data is collected from the office of Chief Engineer, Sukkur barrage, at Sukkur. Histogram is presented in Fig.1. Histogram and frequency curve are presented in Fig. II 95% Confidence Intervals for quantiles estimated by P(3) and LP (3) distribution using MLM along with observed and estimated floods are given in Fig. III and Fig. IV, respectively and plot of P (3) and LP (3), by MLM, together is shown in Fig. V. Mean, Median, Mode  $S > D$ ,  $C_s$ ,  $C_k$ , S.E's, Sample L-moments, 1st Quartile ( $Q_1$ ), 3rd Quartile ( $Q_3$ ), etc, are presented in Table-1. SPSS, Excel, Minitab and Data plot software were used for Statistical analysis.

**Step 3:** Computation of design flood estimates

For  $T=5$ ,  $K_T = 0.703$ ,  $X_5 = 768.953$

For  $T=50$ ,  $K_T = 2.694$ ,  $X_{50} = 1182.166$

For  $T=100$ ,  $K_T = 3.265$ ,  $X_{100} = 1300.87$

Table.VI Values of the standard normal variate

T (Years)	2	5	10	20	50	100
$u_T$	0	0.842	1.282	1.645	2.054	3.326

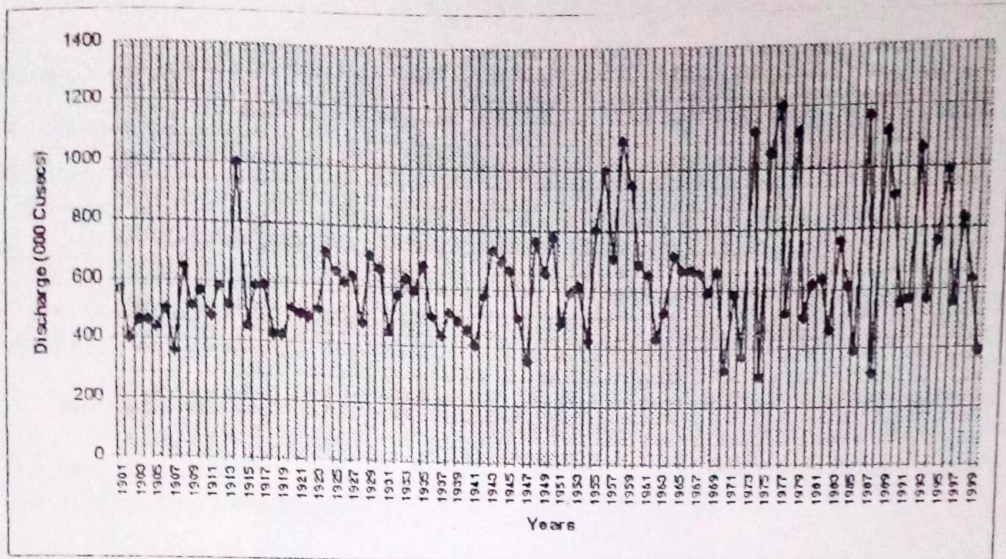


Fig.I. Histogram Of Peak Floods Discharge At Sukkur Barrage (1901 – 1999)

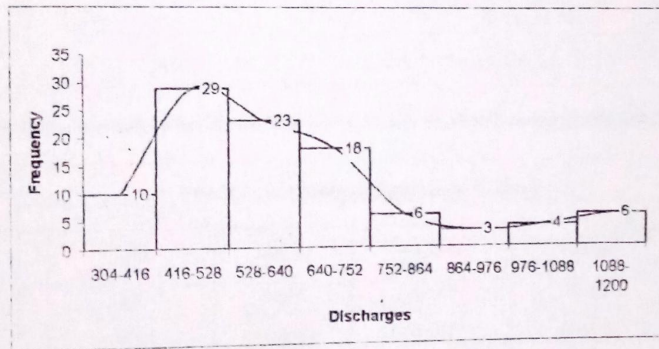


Fig.II. Histogram & Frequency Curve of floods peaks at Sukkur barrage (1901-1999)

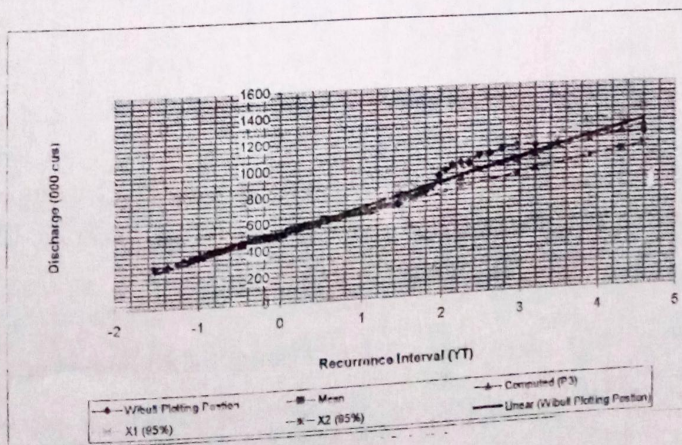


Fig.III. Plot of P (3) Distribution Curve by MLM Methods, of Floods Peak of Indus River at Sukkur Barrage

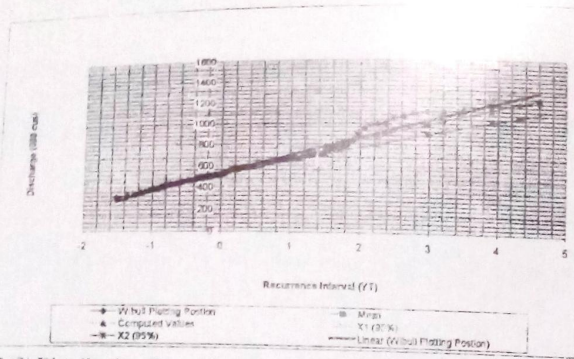


Fig. IV. Plot of LP (3) Distribution Curve, by MLM, of Flood Peaks of Indus River at Sukkur Barrage

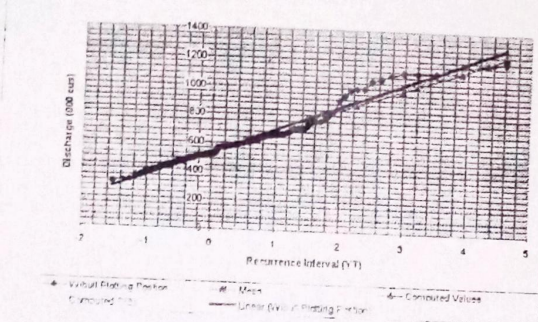


Fig. V. Plot of P (3) and LP(3) Distribution Curve, by MLM of Flood Peaks of Indus River at Sukkur Barrage (1901-1999)

Table -1 Basic statistics (Sukkur) 190-999

N	Mean*	Median*	Mode*	Min	Max
99 (8.5)	622.87 (604.1)	585.0 (582.0)	546.0 (566.7)	306 (306)	1200 (1200)
S. D	Q. D	C. V	S. E	$C_s$	$C_k$
205.7 (184.0)	102.5 (94.1)	0.35 (0.306)	20.8 (19.9)	1.120 (1.26)	3.68 (3.62)
$Q_1^*$	$Q_3^*$	$D_1^*$	$D_9^*$	$T_3$	$T_4$
484.0 (481)	689.0 (669)	407 (423.0)	99.7.0 (810.0)	0.228	0.181

Note: The values in the parenthesis are for 85 year  
 \* indicates value in 000-cusecs

## 2. Methodology

The probability distributions are fitted and the results are tested and compared step-wise as follows:

- i Parameters of each distribution (by three methods of estimation) along with quantile estimates and their S. E's, for different return periods, are calculated.
- ii Various goodness of fit tests.  $C_s$ ,  $C_k$  etc, are used.
- iii Ratios, Differences and Confidence Intervals are also displayed by tables and figures.

Theoretical details are given in [1] and [3]. An example of fitting P (3) by PWM is presented in Appendix.

### Steps:

#### 2.1 Testing the Goodness of Fit

The formulae as well as procedure for conducting  $\chi^2$ -test, S-K test and PPCC are as discussed in [13].

#### 2.2 Role of Skewness, Kurtosis and L-moments Ratios

The procedure adopted is same as in [13] and [1]. These relationships give on idea about the candidate probably distribution to be fitted on any given data..

3. Results and Discussion

(i) Descriptive Statistics (Table -1)

Fig-1 shows that upper flood above 1.1 million cusecs have occurred 6 times and Fig-II shows that high floods above 750 thousand cusecs and between the ranges of (750-860), (860-980), (980-1090) and (1090-1200) thousand cusecs have occurred 6, 3, 4 and 6 times, respectively, from (1901-1999).

Mean > Median > Mode,  $C_s$  is 1.1 and C.V is 0.305. Thus the data is positively skewed (the results are similar to those for Guddu barrage).

The difference between Mean and median is substantial and increases with the sample size.

(ii) Parameter and Quantile Estimates

Table-II shows the values of parameters for P(3) and LP(3), estimated by the three methods. Table - III shows the quantile estimates and their S.E's, for various return periods for both the distributions. The quantile estimates compared in Table - IV A and are discussed as under:

Table-II. Parameters of P (3) and LP (3) Distributions (Sukkur) (in 000's cusecs) 1901-1999

Distribution	Parameter	MOM	MLM	PWM
P (3)	$\alpha$	115.10	115.4	142.79
	B	3.19	3.085	2.11
	$\gamma$	255.81	267.654	321.00
LP (3)	$\alpha$	0.057	0.157	0.158
	B	29.35	382.51	380.0
	$\gamma$	-4.71	0.430	0.33

Table-III Quantile estimates and their S.E's (In parantheses) by P (3) and LP (3) (Sukkur) 1901-1999

Return Period T	Exceedence Probability P	Quantic Magnitude (000) cusecs)					
		Pearson (3)			Log-Pearson (3)		
		MOM	MLM	PWM	MOM	MLM	PWM
5	20	774.708	771.749	768.95	771.915	765.64	762.6
		(31.71)	(30.8)		(31.1)	(29.1)	
10	10	897.249	892.769	989.55	906.049	879.72	887.7
		(42.46)	(40.8)		(42.2)	(40.6)	
20	05	1011.865	1006.169	1022.65	1040.647	988.13	1011.0
		(53.07)	(51.5)		(52.3)	(50.2)	
25	04	1047.643	1041.60	1061.87	1084.655	102.41	1046.0
		(56.44)	(55.1)		(54.8)	(51.3)	
50	02	1156.285	1149.279	1182.17	1224.558	1128.05	1165.0
		(66.82)	(65.3)		(66.7)	(61.1)	
73	013	1218.464	1210.958	1251.75	1309.116	1189.64	1224.0
		(72.81)	(71.9)		(72.1)	(68.6)	
100	01	1262.098	1254.263	1300.87	1370.511	1233.39	1268.7
		(77.04)	(75.8)		(76.6)	(72.8)	

Table -IV Tests of Goodness of Fit (Sukkur) 1901-1999.

$\chi^2$ -Test		S-K Test		PPCC		RMSE	
$\alpha=5\%$	$\chi^2_{cal}$	$\alpha=5\%$	$D_{cal}$				
	P (3) LP (3)		P (3) LP (3)	P (3)	LP (3)	P (3)	LP (3)
5.99	5.93 5.81	0.136	0.179* 0.172*	0.9846	0.9848	0.0434	0.048

\* Indicates non acceptance of null hypotheses.

Table-IV-A Ratios of Quantile estimates (Sukkur) 1901-1999 for different  $T_r$

Ratio	Distribution/Method	$T_r$					
		10	20	25	50	75	100
$Q_{MOM}/Q_{MLM}$	P (3)	1.05	1.05	1.006	1.006	1.066	1.007
$Q_{MOM}/Q_{MLM}$	LP(3)	1.03	1.05	1.06	1.09	1.10	1.11
$Q_{PWM}/Q_{MLM}$	P (3)	1.01	1.016	1.02	1.03	1.035	1.04
$Q_{PM}/Q_{MLM}$	PL(3)	1.01	1.02	1.024	1.033	1.033	1.03
$Q_{LP(3)}/Q_{P(3)}$	MOM	1.01	1.03	1.04	1.06	1.07	1.09
$Q_{LP(3)}/Q_{P(3)}$	MLM	0.985	0.98	0.98	0.98	0.98	0.98
$Q_{LP(3)}/Q_{P(3)}$	PWM	0.986	0.99	0.985	0.986	0.98	0.976

Table-IV B. Ratio of S.E.'s (Sukkur) 1901-1999 for different  $T_r$

Ratio	Distribution/Method	$T_r$					
		10	20	25	50	75	100
$S.E_{MOM}/S.E_{MLM}$	P (3)	1.04	1.03	1.03	1.03	1.02	1.02
$S.E_{MOM}/S.E_{MLM}$	LP (3)	1.04	1.06	1.07	1.08	1.05	1.05
$S.E(LP-3)/S.E(P-3)$	MOM	0.99	0.99	0.97	0.998	0.99	0.99
$S.E(LP-3)/S.E(P-3)$	MLM	0.995	0.97	0.93	0.94	0.95	0.96

(a) Pearson (3)

MLM gives the smallest quantiles and PWM gives the largest quantiles.

$Q_{MOM} / Q_{MLM}$  varies from 1.006 to 1.05 and  $Q_{PWM} / Q_{MLM}$  varies from 1.01 to 1.04. The ratios are greater for larger  $T_r$ .

(b) Log-Pearson (3)

MLM gives the smallest quantiles while MOM gives the largest quantiles.

The differences between quantile estimates are smaller than for P (3).

$$Q_{MLM} < Q_{PWM} < Q_{MOM}$$

$Q_{PWM} / Q_{MLM}$  varies from 1.01 to 1.03, greater for larger  $T_r$

(c) P (3) . Vs. LP (3)

Q estimated by LP (3) are smaller than Q by P (3) using MLM and PWM, (1 % to 2 %), but are larger using MOM (1 % to 2 %).

Note: 1.25 and 1.23 million cusecs flood I expected at Sukkur barrage during next 100-years using MLM, for P (3) and LP (3), respectively.

**(III) S. E's of Quantile Estimates (Table -III and IV B).**

**(a) Pearson (3)**

S. E's by MOM are larger than by MLM (% to 4%) MOM is less efficient than MLM.

**(b) Log-Pearson (3)**

S.E.'s by MOM are larger than by MLM (4% to 8%), i.e. MLM is more efficient than MOM.

**(c) P (3). Vs . LP (3)**

The difference is up to 1% for MOM and up to 7 % for MLM. The S. E's by LP (3) are smaller than by P (3).

Thus LP (3) is better than P (3) is better tha P (3), specially for MLM.

Fig. III and Fig IV are the plots of P (3) and (3) distribution curves by MLM with confidence bands of 95%. Both the curves show that computed quantiles of P (3) and LP (3) distributions by MLM, give a better fit by passing in a straight line through its mean point ( $T = .33$ ,  $X = 622.87$  000 cusecs) and within the confidence bands of  $X_1$  (95%) and  $X_2$  (95%), but LP (3) is superior than P (3) for MLM Fig. V is the plot for P (3) and LP (3) quantiles and both the curves pass through the straight line at mean point.

**(IV) Teats of Goodness of Fit**

Both the distributions are rejected on the basis of S-K test, but are accepted using  $\chi^2$  test, PPCC and RMSE.

LP (3) is better than P (3) on the basis of PPCC and RMSE.

**(V)  $C_s$ ,  $C_k$  and L-moment Ratios:**

Above table shows that both the distributions are acceptable on the basis of  $t_3$   $t_4$  and  $C_s$ . More over,

LP (3) is better than P (3) on the basis of  $C_s$  and  $C_k$ . Note:  $t_3$  and  $C_s$  for LP (3) are calculated using log of actual observations.

**4. Findings**

The data is +ly skewed, i. e. floods of high magnitude have occurred less frequently.

Quantile estimates by MLM are smallest for both the distributions, and are smaller for LP (3) than for P (3).

MLM is more efficient than MOM for P (3). LP (3), specially by MLM.Both the distributions are rejected by  $C_k$  and S-K test but accepted on the basis of  $\chi^2$  - test, PPCC, RMSE,  $C_s$  and L-moment ratios.

LP (3) is better than P (3) by PPCC, RMSE and values of  $C_s$  and  $C_k$ .

1.23 million cusecs flood is expected at Sukkur barrage during next 100 years, by fitting LP (3), using MLM.

Table- V Values of  $C_s$ ,  $C_k$  and L-Moment Ratios (Sukkur) 1901-1999.

	Observed	Suggested for P (3)	App. Ample value for LP (3)
$T_3$	0.228	0.228	0.220
$T_4$	0.181	0.140	0.139
$f_{\bar{x}}$	1.00	1.120	1.100
$C_k$	3.680	4.880	4.815

**5. Suggestion**

It is suggested to fit LP (3) distribution using MLM for prediction of occurrence of individual peak flood on the Indus river t Sukkur barrage. The Predicted flood by LP (3) using MLM I 1.3 million cusecs which I much higher than the 0.9 million cusecs designed capacity of the Sukkur barrage. Thus there is urgent need to take the appropriate measures to save the structure of barrage form occurrences of ny possible damage due to the above predicted flow which can occur t any time as environment changes.

Table (V) Model of P (3) and LP (3) Distribution

Distribution	Barge	Method	Model
P (3)	Sukkur	MOM	$\hat{x}_T = (115.1 \times 3.19) + (255.8) + K_T \sqrt{(115.1)^2 \times 3.19}$
		MLM	$\hat{x}_T = (115.14 \times 3.09) + (267.6) + K_T \sqrt{(115.14)^2 \times 3.09}$
		PWM	$\hat{x}_T = (142.8 \times 2.11) + (321.0) + K_T \sqrt{(142.8)^2 \times 2.11}$
LP (3)	Sukkur	MOM	$\hat{x}_T = \exp [ (0.057 \times 29 \times 35) + (-4.71) + K_T \sqrt{(0.057)^2 \times 29 \times 35}]$
		MLM	$\hat{x}_T = \exp [ (0.157 \times 382.5) + (0.43) + K_T \sqrt{(0.157)^2 \times 382.5}]$
		PWM	$\hat{x}_T = \exp [ (0.158 \times 380.0) + (0.33) + K_T \sqrt{(0.158)^2 \times 380.0}]$

Appendix

An Example of Fitting P (3) Distribution by PWM to Annual Peak Flood Discharges Data at Sukkur Barrage (1901-1999)

a. Station Description

River: Indus  
 Barrage: Sukkur  
 Period of records: 99 years  
 Data: See Fig-1

a. Computational Procedure

Step 1:  $l_1 = 622.879$ ,  $l_2 = 100.302$ ,  $C_s = 1.120$ ,  $C_y = 0.330$ ,  $t_3 = 0.28$  and  $t = 0.177$

Step 2: Parameters estimation by PWM method

Since  $t_3 = 0.228$  is less than  $1/3$

$$t_m = 3 \pi t_3^2$$

$$= 3 (22/7) (0.228)^2 = 0.490$$

$$B = \frac{(1 + 0.2906 t_m)}{(t_m + 0.1882 t_m^2 + 0.0442 t_m^3)}$$

$$= \frac{(+ 0.2906 \times 0.490)}{(0.490 + 0.1882 (0.490)^2 + 0.0442 (0.490)^3)}$$

= 2.114

$$\hat{\alpha} = \sqrt{\pi} l_2 \frac{\Gamma(\hat{B})}{\Gamma(\hat{B} + 1/2)}$$

$$\Gamma(\hat{B}) = \Gamma(2.114) = 1.055$$

$$\Gamma(\hat{B} + 1/2) = \Gamma(1.055 + 1/2) = \Gamma(2.614) = .444$$

$$\hat{\alpha} = \sqrt{\pi} (110.302) \times \frac{1.055}{1.444}$$

$$\alpha = 142.799$$

$$\hat{\gamma} = l_1 - \hat{\alpha} \hat{\beta}$$

$$= 622.879 - (14.799)(1.055) = 321.002$$

The fitted quantiles by P (3) are obtained by

$$\hat{x}_T = \hat{\alpha} \hat{\beta} + \hat{\gamma} + K_T \sqrt{\hat{\alpha}^2 \hat{\beta}}$$

where

$$K_T = \frac{2}{C_s} \left[ \left\{ \frac{C_s}{6} \left( \mu - \frac{C_s}{6} \right) + 1 \right\} - 1 \right] C_s > 0$$

and  $\mu$  is given in Table VI

**Step 3: Computation of design flood estimate**

$$\text{For } T = 5, K_T = 0.703, \hat{x} = 768.953$$

$$\text{For } T = 50, K_T = 2.694, \hat{x}_{50} = 1182.166$$

$$\text{For } T = 100, K_T = 3.265, \hat{x}_{100} = 1300.87$$

Table-VI Values of the standard normal variate

T (Year)	2	5	10	20	50	100
$\mu_T$	0	0.842	1.282	1.645	2.054	3.326

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### MANUSCRIPT

Three legible copies of the paper, double spaced, typed or its diskette may be submitted. All pages of the manuscript must be numbered consecutively including those carrying references, tables, figures and captions to the illustrations. Both the drawing and photographs are to be numbered as figures in a common sequence and each must be referred in the text. A separate list of typed captions should be attached. **Title Page:** the title page should be in this order, from the top, (a) RUNNING TITLE: it should be no longer than 60 characters, including spaces. (b) TITLE OF THE ARTICLE: It should be brief and specific. If a paper forms part of series, this should be given in consecutive parts with roman numbers. (c) FULL NAME AND ADDRESS: names of authors and addresses must be given, indicating the name, address, Fax No, telephone number and e-mail address of the corresponding author.

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Jafri, S.I. H., N.T. Narejo and S.A. Shaikh, (2003) Toxic effects of hexavalent Chromium on fingerlings of a commercial carp, *Labeo rohita* (Teleostei). Pak. J. Zool. 35 (1) : 15 -19.

#### Papers in Proceedings/Symposia:

Mirza, M.R. and N.A. Bhatti, (1999) Biodiversity of the fresh water fishes of Pakistan and Azad Kashmir. Proc. Sem. " Aquatic biodiversity of Pakistan, (Q.B.Kazmi and M. A. Kazmi, eds.) MRCRC, University of Karachi, pp. 177-184.

**Books:** Barton, D.H.R. (1979) Comprehensive Organic Chemistry, Vol. IV, 2<sup>nd</sup> Edition, Pergamon Press, Oxford, England, pp. 405-408.

**Thesis:** Zafar, M. (1992) Fundamental and Applied Marine Ecology, Ph.D. Thesis, Free University, Brussels, Belgium. P. 250.

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