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A Comprehensive Study on Rainfall Frequency Analysis for Sustainable Water Resource Management in District Khushab, Pakistan

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ABSTRACT

This paper addresses the critical role of rainfall frequency analysis in sustainable water resource management and infrastructure development, particularly in the context of a dynamically changing climate. Focused on the District Khushab region in Pakistan, the study delves into the methodologies and advancements associated with rainfall frequency analysis, emphasizing concepts like return period, probability distribution, and various frequency analysis methods. The research underscores the imperative to comprehend the evolving complexities of rainfall patterns for mitigating flood risks, designing resilient water management systems, and preparing communities for extreme weather events. The integration of climate change considerations further enhances the utility of rainfall frequency analysis, providing essential insights for researchers and practitioners to anticipate and adapt to future hydrological challenges. The literature review explores historical approaches to frequency analysis, emphasizing the development of regional techniques and the utilization of the index flood procedure to pool statistics from diverse sites.

In the methodology section, data collection from various rainfall stations in the project area is detailed, with a thorough analysis and verification process. Limitations of available data for certain stations lead to the selection of relevant rainfall stations with sufficient data for further analysis. Results from frequency analysis, based on the correlation of Joharabad rainfall data with nearby stations (Mianwali and Sargodha) and actual rainfall data, highlight the reliability of correlated rainfall data for hydrological modeling. The paper concludes by underscoring the necessity for a minimum of 30 years of rainfall data for accurate and realistic assessments in the frequency analysis, and the adopted results will contribute to computing peak flood discharges for hill torrents, aiding in effective water resource management in the project area.

KEYWORDS: Pakistan Meteorological Department (PMD), Rainfall Frequency Analysis, Average Annual Rainfall, Correlation of Joharabad Rainfall Data

1. INTRODUCTION

The accurate assessment of rainfall patterns is paramount for sustainable water resource management and the development of resilient infrastructure in the face of a changing climate. Rainfall frequency analysis, a critical component of hydrological studies, employs statistical methods to characterize the probability of different rainfall events occurring over specific time durations. This paper delves into the advancements and methodologies associated with rainfall frequency analysis, exploring concepts such as return period, probability distribution, and

frequency analysis methods. As climate patterns continue to evolve, understanding the complexities of rainfall becomes imperative for mitigating flood risks, designing efficient water management systems, and preparing communities for extreme weather events. The integration of climate change considerations further enhances the utility of rainfall frequency analysis, enabling researchers and practitioners to anticipate and adapt to future hydrological challenges. This paper aims to provide a comprehensive overview of the current state of rainfall frequency analysis, emphasizing its significance in fostering sustainable practices and resilient infrastructure within the realm of water resource management.

2. LITRETURE REVIEW

Early frequency analysis studies derived estimates from at-site data and created isopluvial maps from these site-specific esti- mates using interpolation procedures and judgment. Since record lengths are often relatively short at gage sites (e.g., it is difficult to estimate accurately a 100-year event from, say, 50 years of data), regional techniques have been developed to increase accuracy. Regional frequency analysis "trades space for time" by using data from nearby or similar sites to derive estimates for any given site in a homogeneous region (Stedinger et al. 1993). A common method for pooling summary statistics from different sites is the index flood procedure. The term "index flood" comes from early studies (Dalrymple 1960) that used flood data when implementing the procedure. The main assumption of an index flood procedure is that the sites in a homogeneous region have an identical fre- quency distribution apart from a site-specific scaling factor, the *indexod*. The index flood is usually the mean of the site- specific data (Hosking and Wallis 1997).

3. METHEDOLOGY OF RAINFALL FREQUENCY ANALYSIS

3.1 Data Collection

The project area lies in District Khushab, where a rainfall station was established at Joharabad by the Pakistan Meteorological Department (PMD) in 2007. There are also other rainfall stations which lie near project area, established by different government departments. we have acquired the available rainfall data of these stations; status of data collection is given in Table 1.

Table 1: Available rainfall data

Station	***Data Type***	**Duration**	**Source**
Joharabad	Daily Rainfall	2007 - 2021	Pakistan Meteorological Department (PMD)
Mianwali	Daily Rainfall	1962-2007	Pakistan Meteorological Department (PMD)
Sargodha	1-Daily Maximum	1977-2019	Pakistan Meteorological Department (PMD)
Nowshehra	Daily Rainfall & Temperature	1998 -2021	Horticultural Research Station (HRS)
Wan	Daily Rainfall	2011 –21	Executive Engineer, Khushab Canal Division, Irrigation Department
Gunjial	Daily Rainfall	2011 –21	Executive Engineer, Khushab Canal Division, Irrigation Department
Mitha Tiwana	Daily Rainfall	2011 –21	Executive Engineer, Khushab Canal Division, Irrigation Department
Khushab	Daily Rainfall	2011 –21	Executive Engineer, Khushab Canal Division, Irrigation Department

3.2 Data Analysis/Verification

We have analyzed the available data of all rainfall stations in detail. The rainfall data of rainfall stations collected from the office of Executive Engineer, Khushab Canal Division is available for limited no. of years i.e., 2011-21. Yearly rainfall distribution of Wan, Gunjial, Mitha Tiwana and Khushab stations were plotted in MS excel to check the consistency of the data and are shown in Figure 1 to 4.

It is evident from above graphs that average monthly rainfall in March is higher than monsoon period i.e., June-September which is not realistic. As the project area lie in arid zone and average monsoon precipitation is higher as compared to other remaining months of the year therefore this data is not reliable to be used in hydrological analysis.

To carry out the frequency analysis for any rainfall station, daily rainfall data for at least 30 years is required to have a authenticate and accurate results[1]. Rainfall data of Wan, Gunjial, Mitha Tiwana and Khushab stations is available for limited no. of years i.e., 2011-21 as described above therefore, is not sufficient to be used for frequency analysis.

Similarly, rainfall data of Nowshera station collected from Horticultural Research Station (HRS), Nowshera is available for limited number of months i.e., June-September of each year for the period 1988-2000 & 2006-21, for the period 2001-05, rainfall data of entire years is missing, therefore the rainfall data for this is also not suitable to be used in hydrological studies. Hence these stations were discarded.

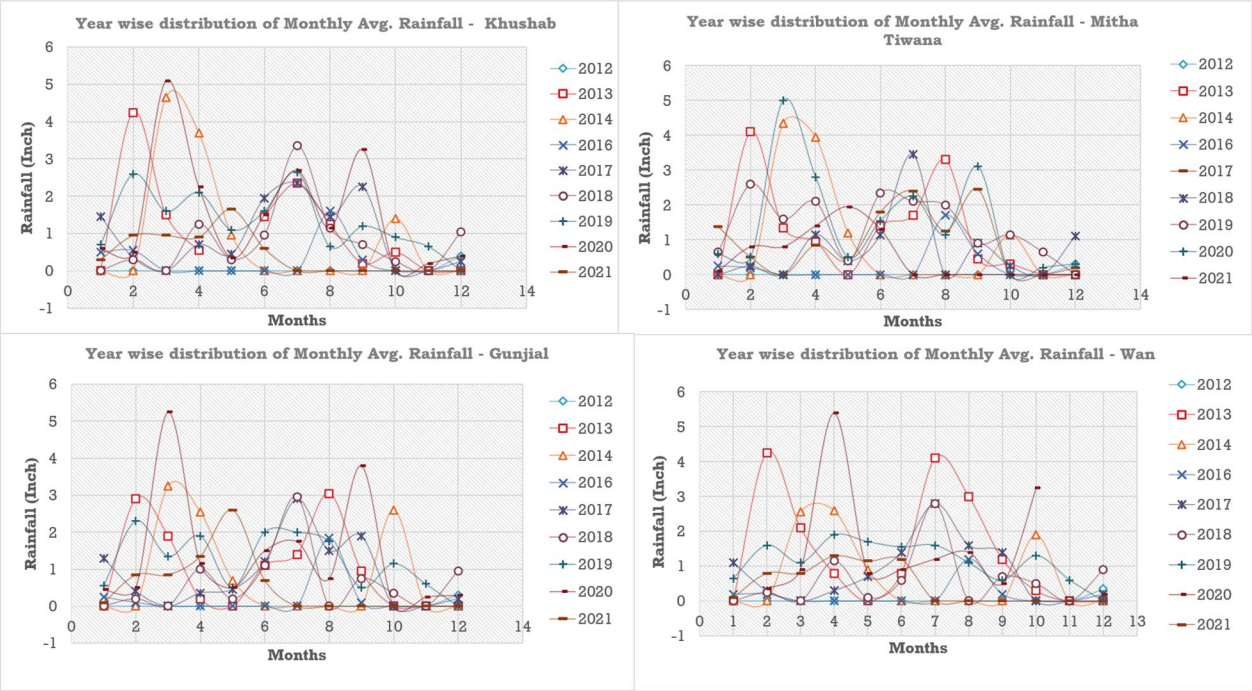

Figure 1 (A, B, C & D): Yearly rainfall distribution of Khushab, Mitha Tiwana, Gunjial, and Wan stations Respectively.

3.3 Selected Rainfall Stations

The most relevant PMD rainfall station is Joharabad however, the rainfall station of Joharabad station is available for the period 2007-20 which is not sufficient for frequency analysis. Therefore, we have checked two other PMD rainfall stations in the vicinity of project area i.e., Mianwali and Sargodha. Based on the criteria mentioned in previous sub section, for frequency analysis, rainfall data for Mianwali and Sargodha stations are sufficient to be used, but these stations are distant as compared to Joharabad station

Rainfall data for extended years is available for Mianwali and Sargodha stations that affect the hill torrents of Mohar A & B schemes respectively. Based on the analysis of rainfall data of Mianwali & Sargodha, the rainfall data of Joharabad is also analysed and suitable correlations have been developed for the hydrological studies. One daily maximum rainfall of Mianwali. Sargodha and Joharabad stations for the available years is shown in Table 2, 3 & 4 respectively.

Table 2: One daily maximum rainfall of Mianwali

Year	1-Daily Max. (mm)	Year	1-Daily Max. (mm)	Year	1-Daily Max. (mm)
1962	46.99	1984	88	2003	93
1963	40.64	1985	31	2004	30

Year	1-Daily Max. (mm)	Year	1-Daily Max. (mm)	Year	1-Daily Max. (mm)
1964	71.12	1986	56.5	2005	78
1965	79.25	1987	68	2006	63
1966	34.54	1988	90	2007	90
1967	82.3	1989	149	2008	79
1968	32.26	1990	60	2009	85
1969	36.07	1991	60	2010	190
1970	34.8	1992	98	2011	85
1971	42.42	1993	105	2012	99
1972	35.81	1994	92	2013	129
1974	34.54	1995	120	2014	94
1975	86.61	1996	70	2015	204
1976	176.53	1997	47	2016	90
1978	54.36	1998	52	2017	116
1980	90	1999	99	2018	43
1981	117	2000	47	2019	62
1982	60.8	2001	26	2020	102
1983	82	2002	69		

Table 3: One daily maximum rainfall of Sargodha

Year	1-Daily Max. (mm)	Year	1-Daily Max.	Year	1-Daily Max. (mm)
1977	62.0	1992	55.2	2007	125.0
1978	85.3	1993	36.0	2008	61
1979	79.0	1994	76.6	2009	45
1980	87.0	1995	38.1	2010	87
1981	29.4	1996	66.1	2011	64
1982	135.0	1997	176.7	2012	69
1983	62.5	1998	46.0	2013	40
1984	90.0	1999	48.9	2014	37
1985	62.0	2000	108.0	2015	47
1986	40.0	2001	68.0	2016	37
1987	54.5	2002	117.6	2017	47
1988	71.1	2003	76.0	2018	83
1989	73.5	2004	29.0	2019	41
1990	58.8	2005	65.0		
1991	68.5	2006	68.0		

Table 4: One daily maximum rainfall of Joharabad

Year	1-Daily Max. (mm)	Year	1-Daily Max. (mm)	Year	1-Daily Max. (mm)
2007	65	2012	61	2017	49
2008	93	2013	70.1	2018	110
2009	95	2014	64.2	2019	44
2010	85	2015	50	2020	166
2011	95	2016	63.6		

3.4 Correlation of Joharabad Rainfall Data with other PMD Stations

We have worked out on different approaches to find out the correlation between rainfall stations (Mianwali and Joharabad) & (Sargodha and Joharabad) to estimate the rainfall data for missing years of Joharabad

3.4.1 Linear Relation

This is the simplest method to find linear relation between two data sets. The data of Mianwali and Joharabad stations were plotted on the same graph for the available years i.e., 2007-19. The peak historic 1-daily maximum rainfall event In Joharabad happened in the month of September, 2020, in which Khushab and nearby areas were badly hit by the floods originating from hill torrents, this peak event was excluded from the analysis as it was outlier event (Outlier is the value which is far above or below the extents of the data being analyzed, hence not taken in the analysis). The graph shows the uniform relationship between the two data sets. 1-daily maximum rainfall for Joharabad was found approx. 30 % less than Mianwali. The graph has been shown in Figure 5. Similarly, the data of Sargodha and Joharabad stations were plotted for the available years i.e., 2007-19 and is shown in Figure 6. The graph shows almost similar pattern, rainfall at Sargodha station is approximately 20% lesser as compared to Joharabad station

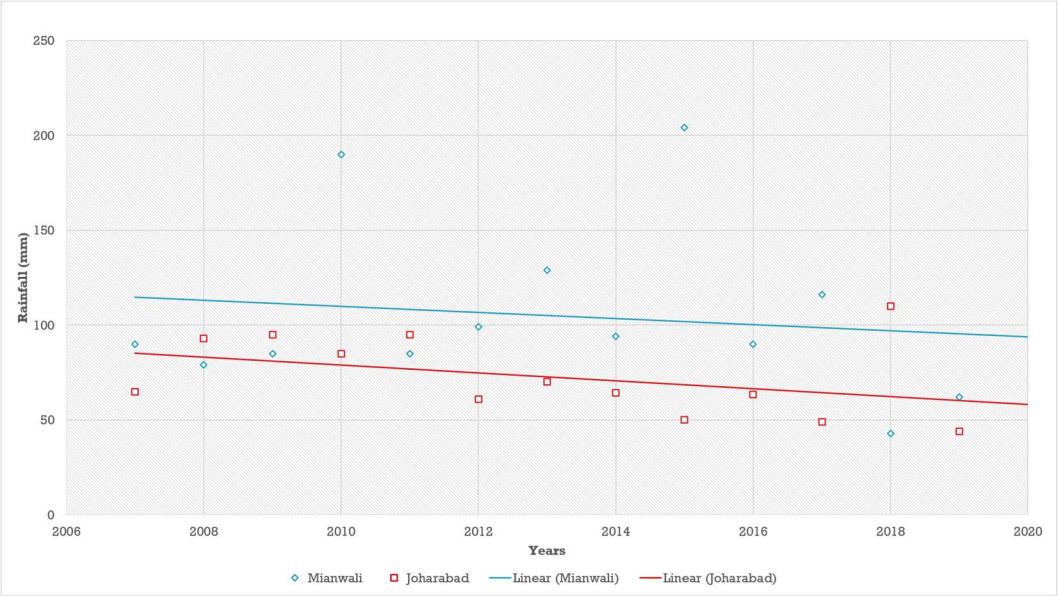

Figure 2: Comparison of Mianwali-Joharabad Rainfall Station

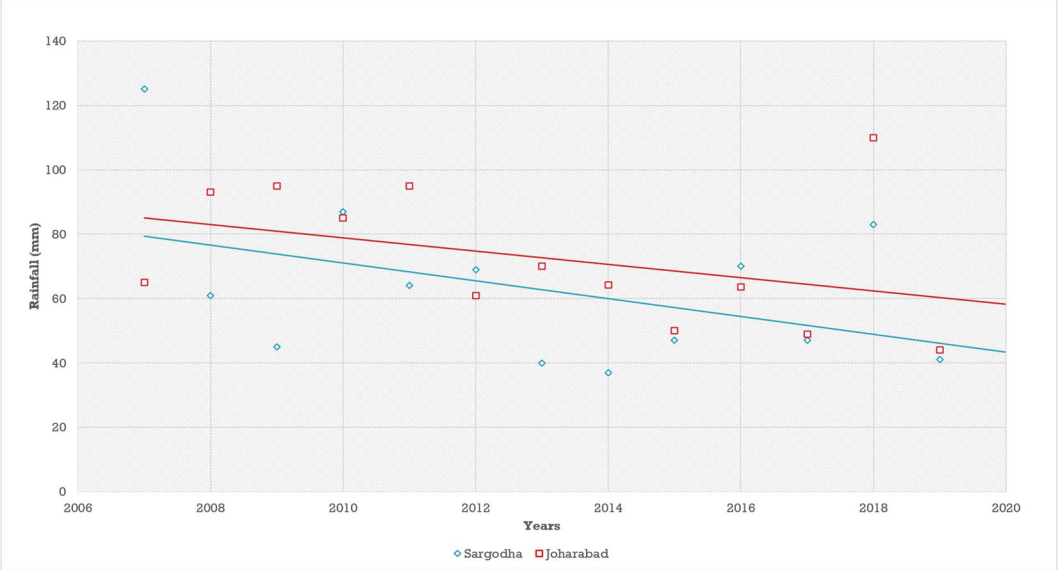

Figure 3: Comparison of Sargodha-Joharabad Rainfall Station

3.4.2 Pearson Correlation

This method is a measure of linear correlation between two sets of data. It is the ratio between the covariance of two variables and the product of their standard deviations.
Pearson correlation coefficient formula is shown below

$$r = \frac{\sum (x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum (x_i - \bar{x})^2 \sum (y_i - \bar{y})^2}}$$

r = correlation coefficient

x_i = values of the x-variable in a sample

$\bar{x}$ = mean of the values of the x-variable

y_i = values of the y-variable in a sample

$\bar{y}$ = mean of the values of the y-variable

This method is also integrated in MS Excel for correlation of two data sets. After inputting all the rainfall data of both Mianwali and Joharabad for common period of available rainfall data i.e., 2007-19, the correlation coefficient between these two data sets comes out to be -0.31, which means that the rainfall of Joharabad is approximately 31 percent less than that of Mianwali.

Similarly, another correlation coefficient has been developed by inputting rainfall data of common period 2007-19 for Sargodha and Joharabad, the correlation coefficient between these two data sets comes out to be +0.25 which mean that rainfall of Joharabad is 25 % on higher side as compared to Sargodha.

3.4.3 Average Annual Rainfall

For the sake of confirmation of the used approaches, a map showing average annual rainfall for entire Pakistan is shown in Figure 10. It shows that the average annual rainfall for Mianwali is almost 600 mm whereas for Joharabad it is 550 mm approximately. Average annual rainfall for Sargodha is almost 500 mm, hence the rainfall of Joharabad is less than Mianwali but greater than Sargodha which authenticates the results of two approaches discussed in previous section.

3.4.4 Updated Rainfall of Joharabad Station

The rainfall data of Joharabad station for missing years has been estimated based on above analysis i.e., linear relations, Pearson correlation and validation from average annual rainfall map. The data sets of updated Joharabad rainfall data based on Pearson correlation coefficient both with Mianwali and Sargodha station i.e., -0.31 and +0.26 respectively are shown in Table 5 & 6 below.

Table 6: 1-Daily Maximum Rainfall of Joharabad after Correlation with Mianwali

Year	1-Daily Max. (mm)	Year	1-Daily Max. (mm)	Year	1-Daily Max. (mm)
1977	45.4	1992	40.4	2006	49.8
1978	62.5	1993	26.4	2007	91.6
1980	57.9	1994	56.1	2008	44.7
1981	63.7	1995	27.9	2009	33.0

1982	21.5	1996	48.4	2010	63.7
1983	45.8	1997	129.4	2011	46.9
1984	65.9	1998	33.7	2012	50.5
1985	45.4	1999	35.8	2013	29.3
1986	29.3	2000	79.1	2014	27.1
1987	39.9	2001	49.8	2015	34.4
1988	52.1	2002	86.1	2016	51.3
1989	53.8	2003	55.7	2017	34.4
1990	43.1	2004	21.2	2018	60.8
1991	50.2	2005	47.6	2019	30.0

Table 7: 1-Daily Maximum Rainfall of Joharabad after Correlation with Sargodha

Year	1-Daily Max. (mm)	Year	1-Daily Max. (mm)	Year	1-Daily Max. (mm)
1962	32.28	1984	60.45	2003	63.89
1963	27.92	1985	21.30	2004	20.61
1964	48.86	1986	38.81	2005	53.58
1965	54.44	1987	46.71	2006	43.28
1966	23.73	1988	61.83	2007	61.83
1967	56.54	1989	102.36	2008	54.27
1968	22.16	1990	41.22	2009	58.39
1969	24.78	1991	41.22	2010	130.52
1970	23.91	1992	67.12	2011	58.39
1971	29.14	1993	71.79	2012	68.01
1972	24.60	1994	63.20	2013	88.62
1974	61.07	1995	82.43	2014	64.57
1975	23.73	1996	48.09	2015	140.14
1976	59.50	1997	32.29	2016	61.83
1978	121.27	1998	35.72	2017	79.69
1980	74.68	1999	68.01	2018	29.54
1981	37.34	2000	32.29	2019	42.59
1982	28.27	2001	17.86		
1983	61.83	2002	47.40		

4. RESULTS AND DISCUSSION

4.1 Frequency Analysis

We performed the frequency analysis for Joharabad stations to compute the rainfall for different return periods based on:

- Correlation of Joharabad with Mianwali
- Correlation of Joharabad with Sargodha
- Actual Rainfall Data of Joharabad (2007-20)

The method used for frequency analysis is General Extreme Value – 1 which is the common method used in frequency analysis.

4.1.1 Frequency Analysis based on Mianwali Correlation

The results of frequency analysis of Joharabad after correlation with Mianwali has been shown in Table 8.

Table 8: Frequency Analysis of Joharabad (Mianwali Correlation)

Sr. No	Return Period (Years)	Rainfall (mm)
1	5	75
2	10	91
3	25	112
4	40	123
5	50	128
6	100	143

4.1.2 Frequency Analysis based on Sargodha Correlation

The results of frequency analysis of Joharabad after correlation with Mianwali has been shown in Table 9 below.

Table 9: Frequency Analysis of Joharabad (Sargodha Correlation)

Sr. No	Return Period (Years)	Rainfall (mm)
1	5	69
2	10	84
3	25	103
4	40	112
5	50	116
6	100	130

4.1.3 Frequency Analysis of Actual Rainfall Data of Joharabad (2007-20)

We have also performed the frequency analysis for actual available data of rainfall i.e., 2007-20 to check the variance of results from the correlated one. It has been found that most of rainfall peak events have occurred in recent years i.e., 2010, 2011, 2014, 2016 and 2020. Due to this fact, results of frequency analysis show higher rainfall as compared to the correlated one as shown in Table 10

Table 10: Frequency Analysis Comparison of Joharabad (Based on actual rainfall 2007-20)

Sr. No	Return Period (Years)	Rainfall (mm)
1	5	106
2	10	129
3	25	158
4	40	173
5	50	180
6	100	201

4.1.4 Comparison of Frequency Analysis Results

Comparison summary for frequency analysis of Joharabad station based on correlation with Mianwali & Sargodha and actual rainfall data for period 2007-21 is shown in Table 11 below.

Table 11: Comparison of Frequency Analysis Results

Sr. No	Return Period (Years)	Rainfall (After correlation with Mianwali) (mm)	Rainfall After correlation with Sargodha) (mm)	Rainfall based on Actual Data (2007-20)
1	5	75	69	106
2	10	91	84	129
3	25	112	103	158
4	40	123	112	173
5	50	128	116	180
6	100	143	130	201

5. CONCLUSION

These results shows that the correlation developed by using data of both Mianwali and Sargodha stations have almost similar results for frequency analysis of Joharabad station.

Frequency analysis results based on actual rainfall data (2007-20) results clearly depict that due to repeated rainfall events of higher intensities in past 14 years in Joharabad, computed rainfall at different return periods is on higher side as compared to the one computed by the correlated data from Mianwali and Sargodha rainfall stations.

Based on above discussion, it is concluded that the frequency analysis of Joharabad station based on correlated rainfall data is more reliable as compared to rainfall data available for limited number of years 2007-20 as later indicates that the project area is currently experiencing wet years. As described earlier that at least a rainfall data of last 30 years or more is required to carry out frequency analysis as it includes both dry and wet years providing more actual and realistic results. Hence the results of frequency analysis for Joharabad station shown in Table 12 are selected to be used for the computation of peak flood discharges for hill torrents.

Results of adopted frequency analysis will be used in preparation of hydrological models to

compute the peak flood discharges of all hill torrents of project area.

Table 12: Adopted Frequency Analysis of Joharabad (Mianwali Correlation)

Sr. No	Return Period (Years)	Rainfall (mm)
1	5	75
2	10	91
3	25	112
4	40	123
5	50	128
6	100	143

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