HYDROLOGIC ASSESSMENT OF SMALL DAMS IN POTOHAR AREA: CASE STUDY OF JAMMERGAL DAM

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ABSTRACT

The Potohar Plateau covers an area of 2.2 million hectares. The topography of the area is undulating generally sloping from North East to South West. The annual rainfall ranges from 450 mm in southwest to 1750 mm in northeast with 70% rainfall in the monsoon months. Most of rainwater runs off the Plateau unutilized. Small Dams Organization have constructed a number of small dams in the area. The catchment yield for these dams was assessed by using a simple relationship between rainfall (P) and runoff volume (Q) as $Q = 0.00922\ (P+21.3)^{1.6}$. However no detailed hydrological assessment of catchment yield was carried for establishing the water potential of these small dams. This study was conducted to analyze hydrologic assessment of Jammergal dam in terms of underlying rainfall-runoff relationships and probable inflows for better design of future small dam projects in Potohar area. Data was collected for rainfall and resulting runoff for Jammergal dam and three other neighboring small dams in Potohar region. The data showed wide variation and scatter and the traditional formula for estimating runoff did not match with the measured runoff. A number of formulae were evaluated for establishing relationship between measured rainfall and runoff. The applicability of the derived relationships was evaluated by applying the models to the neighboring small dams. Models were also evaluated by using the regional data (combined data of four small dams).

No single formula was found to perfectly describe the measured runoff at all dam particularly at large rainfall values. The Empirical formula $[Q=0.046(P-10)^{1.354}]$ and Exponential formula $[Q=0.0446\ P^{1.35}]$ were found to better describe the rainfall-runoff relationship. Since these models did not specifically take into account the basin parameters i.e. vegetation, soil type, size, shape and slopes etc, the resulting runoff may be under or over estimated by 10 to 50%. The relationships derived from the data of Jammergal dam when tested to data of neighboring small dams did not provide a perfect fit. Similarly the relationship derived from regional data did not perfectly describe the runoff for individual dams. The relationships provide fair results and can be applied with confidence particularly in the absence of other better models.

Frequency analysis for the Jammergal Dam indicate that the reservoir has almost 98% probability of getting completely filled in any year to its present live capacity of 930 AF. As much as 500 AF of additional water can be harnessed at Jammergal dam by raising the dam structure by 3.5 ft at 65% probability of filling (T = 1.55 years). At 50% and 25% probability levels, the additional water potential is 700 AF and 1200 AF respectively.

INTRODUCTION

Potohar plateau has an area of 2.2 Mha. The topography of the area is undulating generally sloping from North East to South West. The annual rainfall ranges from 450 mm in south-west to 1750 mm in north-east with 70% rainfall occurring during the monsoon months of June to

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September. Storm water channels originate from the Potohar plateau as hill torrents and ultimately reach Indus and Jhelum Rivers. Most of water runs off the Plateau unutilized. The streams, because of steeper bed slopes, are mostly flashy rising suddenly with the rainfall and subsiding quickly afterwards. There is a scarcity of water in the Potohar area in general and people at some places have to walk long distances to bring water for drinking. The soils are good and there is considerable scope of irrigated agriculture provided the crops get water at the right time. Because of the plateau's ridge and trough topography there is significant potential to construct water retention structures / small dams in the area.

The Potohar Plateau has great agricultural and social significance. Total cultivated area of Potohar Plateau is around 1 Mha of which approximately 0.015 Mha is irrigated at present from small dams and rest is rain fed. The rainfed area is not developed due to low productivity of soils, erratic and delayed rainfall over a year, losses of rain water due to rapid runoff, etc. The topography of barani areas having steep ground slopes cause water to flow over the surface with high velocities, which results in erosion of the fertile lands/soil. Apart from damaging the land and the erosion of soil the water thus does not get a chance to soak down and build up groundwater reservoir, which could be tapped for growing crops. To conserve the rainwater for agriculture, the most appropriate solution is to construct small dams and build up reservoirs in the area. These storage reservoirs can eliminate the hazards caused by delayed and erratic rains at the time of crop sowing and maturity when a little delay in rain can adversely affect the crop yield.

Thirty one Nos. small dams have already been constructed in the Potohar area by Small Dams Organization of the Punjab Irrigation Dept. (SDO, 1994) with a total live storage capacity of 86,212 Acre-feet (AF). The water from these small dams is being used to irrigate 35,769 acres in the Potohar plateau. Jammergal dam is one of several small dams located in the southern part of the Potohar plateau The Jammergal dam was constructed in 1992 and is in operation for the last 8 years. The runoff generated from the occasional rainfall in the catchment area is stored in the reservoir of Jammergal dam. The stored water is released subsequently for crop use in the command area. A regular supply is made from the reservoir through irrigation channel to the command area of the dam. With the passage of time and availability of modern crop inputs and the agricultural system has resulted in intensification of the agriculture in the area. The existing capacity of the dam is unable to meet the irrigation requirement of the crops as most of the stored water is consumed up in Rabi season and no water is available for release during sowing of Kharif crops.

The project hydrologic design for Jammergal dam was purely based on empiricism and thumb rules because of lack of adequate hydrologic data (SDO, 1992). No detailed hydrologic assessment of catchment yield was available before the design of the Jammergal dam. The record of hydrological data showed that the reservoir water overflowed through un-gated chute type spillway for 13 times in last 8 years (1992 to 1999) since the **completion of the dam. At this stage, this valuable overflow water cannot be stored in the dam beyond the designed live storage capacity (930 AF) of the reservoir. Such events are not unusual and indicate additional water resources potential that could be harnessed.** This indicates a need for hydrologic assessment of rainfall runoff relationships in Potohar area for better design of future small dam projects in the area. In essence the soil characteristics i.e. topography, surface retention, infiltration, porosity, bulk density, hydraulic conductivity effect the runoff generated by rainfall in the catchment area. The historic data of Jammergal and other neighboring dams could be used for updating hydrologic behavior in Potohar area. It is also necessary to understand that how far the hydrologic assessment for any area can be transposed to neighboring areas with confidence.

The dam's spillway has operated almost each year to pass runoff during the flood seasons. The Dam Safety Organization of WAPDA recommended raising of the Jammergal Dam by 3.5 ft (DSO, 2000). In the light of the proposed raise by Dam Safety Organization, a detailed study to assess the probability of the filling of the dam is inevitable.

OBJECTIVES

The major objective of this study was the hydrologic assessment of Jammergal dam. The following tasks were set for this study.

1. To determine underlying rainfall runoff relationships for Jammergal dam.
2. To assess applicability of derived rainfall runoff relationships to other neighboring dams in the Potohar area.
3. To compare the rainfall runoff relationship for Jammergal dam with the regional rainfall runoff relationship for the area.
4. To assess the water yield of the Jammergal dam at different probability levels.

The hydrological analysis was made on the basis of the historic data available for Jammergal dam for the period 1992 to 1999. Yield probability analysis was conducted on the basis of 30 years rainfall data recorded at Jhelum meteorological station. The determination and evaluation of rainfall runoff relationships was based on the hydrologic data (rainfall and runoff) respect of Jammergal dam, Tainpura-I dam, Tainpura-II dam and Garat dam, all located in Potohar area near Jehlum city. The study was oriented towards runoff volumes only.

The results of study can be useful in many ways. As this study is based on historic hydrological data collected for Jammergal dam, the results will be useful for planning better operational and remodeling plan for the Jammergal dam. These results may be applicable for other small dams lying in other area with similar hydrological and catchment parameters. The results may be useful for planning and designing for rehabilitation, remodeling or construction of new small storage reservoirs / dams in Potohar area of Punjab.

THE STUDY AREA

The study used hydrologic data of four small dams located in Potohar area. These include Jammergal Dam, Tanpura-1 Dam, Tanpura-2 Dam and Grat Dam. The salient features are briefly given in Table 1.

Table 1. Salient features of selected small dams.

Description	Jammergal	Tanpura-1	Tanpura-2	Grat
Location	6 miles NE of Rasool	4 miles NE of Dina	4 miles NE of Dina	10 miles W of Dina
Dam length (ft)	460	960	360	360
Gross capacity (AF)	2432	7300	1736	2227
Dead storage (AF)	1502	1575	1103	538
Live storage (AF)	930	5725	633	1690
Normal pond area (Ac)	125	150	45	103
Catchment area (sq.mi)	5.86	13.08	3.60	5.41
Operational since:	1992	1996	1996	1983

REVIEW OF LITERATURE

General

The runoff is that part of precipitation which reaches the streams in the form of channel flow. The flow from the basin area must satisfy the demand of evaporation, interception, infiltration, surface storage, surface detention and channel detention. The occurrence of runoff is possible when the rate of rainfall exceeds the rate at which water may infiltrate into the soil. After infiltration, water begins to fill the depression. Once the depressions are filled, overland flow may occur. The overland flow takes the form of sheet flow. Although overland flow or superficial runoff may be referred to as sheet flow, the concept of thick uniform sheet of water moving down a slope is unrealistic. Precipitation may deliver water uniformly to the slope, but will runoff over the slope as sub-divided flow (Anderson and Burt, 1990). The overland flow quickly forms into rills, rivulets and surface channels.

Runoff due to rainfall can be estimated by a number of methods/ formulae. Runoff developed from a catchment area depends upon the total precipitation, rainfall intensity, storm duration, vegetative cover, soil moisture content, antecedent moisture condition, soil density, permeability (Hawkins, 1973). Of the many factors influencing rainfall-runoff process, only few of these factors remain constant for storm to storm. It is therefore, obvious that no single relationship can be established to predict the runoff from all storms.

The planning and management of water resource systems are dependent upon information relating to the spatial and temporal distributions of hydrologic phenomena. Hydrologic data bases are seldom large enough to provide enough and precise information and, as a result, planning and management decisions are subject to hydrologic uncertainty in addition to uncertainties of a non-hydrologic nature.

The technical evaluation of rainfall-runoff models has mostly been in terms of how well the models describe historic hydrologic events and thereby measure, or so it is hoped, the degree of our understanding of hydrologic processes (Haans, 1992). Taking all aspects of hydrological investigations, there are three types of model structure that are classically identified. Rainfall runoff relationship may be described as probabilistic or deterministic models, parametric or non-parametric (black box) models, and lumped or distributed models. The selection of suitable models depends upon the project objectives, and availability of data, time, and personal resources.

Rainfall Runoff Relationship

Sur et al., (1999) analyzed the hydrological parameters relating to the catchment area of small earthen dams in lower Shiwaliks of Northern India. The average rainfall (June-September) at these sites varied from 939 ± 242 mm at Ballowal Sounkhri and Takarla, and 926 ± 219 mm at Karoran during 1986-1995. The monsoon rainfall runoff relationships at different locations in Kandi-area were better represented by a straight line with a high correlation coefficient (r). Following relationships were obtained:

Ballowal Sounkhri: $Q = 0.203\ P - 167.0$ $(r = 0.95)$ **(1a)**

Takarla: $Q = 0.380\ P - 81.8$ $(r = 0.96)$ **(1b)**

Karoran: $Q = 0.412\ P - 105.2$ $(r = 0.94)$ **(1c)**

where Q = Runoff (mm), P = Total monsoon rainfall (mm). More than 80% of the annual rainfall occurred during the monsoon season at all locations. The maximum weekly and monthly rainfall was as high as 26% and 89% of the average monsoon rainfall recorded respectively.

Small Dam Organization (SDO, 1989) used the following empirical formula to calculate the runoff generated by the rainfall for hydrological design of small dams in Potohar area of Pakistan.

$$Q = C_1 [P + C_2]^{C3} \quad \textbf{(2)}$$

where Q = Monthly runoff (mm), P = Monthly rainfall (mm), and C_1, C_2 and C_3 are constants. The traditional equation used by the Small Dams Organization for various dams is as below:

$$Q = 0.00922 (P + 21.30)^{1.60} \quad \textbf{(3)}$$

The runoff parameters used for the Potohar region have not been evaluated and need careful study to achieve confidence for use at various locations in the region. The precipitation often used for the analysis was for any nearest location and not the dam site.

Parker (Punmia and Lal, 1979; Raghunath, 1991) considered the runoff as a certain percentage of storm rainfall after satisfying the initial catchment losses. Recorded runoff was plotted vs. precipitation and the curve was fitted to the data, possibly a straight line rendering the equation as.

$$Q = K (P – b) \quad \textbf{(4)}$$

where Q = Direct runoff (mm), P = Rainfall (mm), b = Threshold precipitation (mm), and K = Runoff coefficient

Raghunath (1991) introduced an exponential formula in the form of a a power function to calculate the runoff as:

$$Q = a P^N \quad \textbf{(5)}$$

where Q = Monthly runoff (mm), P = Monthly rainfall (mm), and a and N = Constant

Shaw (1988) showed that rainfall runoff relationship depends upon the catchment and climatic condition of the area. Variation of rainfall in any month of the year, and in most places of the country, is considerable and rainfall runoff relationship is built up on the occurrence of wet or dry months. Mutreja (1986) showed that runoff in a region depends upon the rainfall input, physical, vegetative and climatic characteristics of the region. The watershed characteristics are generally evaluated by its area, slope, geology, geomorphology and basin dynamics.

Awan (1981) described that the runoff generated from the forest and grazed land in Potohar region is equal to half the capacity of Tarbela reservoir, which can be stored and utilized for green revolution. A large number of efforts have been made in the past to control the runoff volume in the Potohar area of Punjab, but generally proved unsuccessful because of empirical planning and design due to lack of hydrological as well as meteorological data. There are some small dams that are not utilized fully and others have small design storage. Scientifically planned hydrometeorological network is very essential for design of dams. A long-term plan needs to be undertaken to develop hydrological parameters in proper form.

METHODOLOGY

Data was collected in terms of rainfall and runoff for Jhelum, Jammergal Dam, Tanpura-I Dam, Tanpura-II Dam, and Grat Dam from the Jhelum based office of the Small Dams Organization (SDO) of Punjab Irrigation and Power Department. The available data for Jammergal dam was used for developing rainfall-runoff relationship for Potohar area. Different equations/models were evaluated to develop rainfall runoff relationship. Models were fitted to monthly and yearly data. The selected models were applied to the data available for other dams in the Potohar area. These models/equations were also evaluated for combined data of Jammergal, Tainpura-I, Tainpura-II and Garat dams. Comparison was made between the measured runoff (Q_m) and runoff computed (Q_c) on the basis of different models.

Rainfall Data

Daily rainfall data was collected for Jammergal dam (1992-99), Tanpura-I & II dams (1996-99) and Grat dam (1983-99) and monthly, yearly, average monthly and average yearly rainfall was derived. Yearly rainfall data was also obtained for Jehlum (1969-99).

Runoff Data / Reservoir Inflow

The reservoir inflow following any rainfall event was determined from record of reservoir levels, irrigation releases, and spillway discharges. Thus runoff entering into the dam on any day following a rainfall event was determined as:

$$Q_m = RV_a - RV_b + IR_{\Delta t} + QS_{\Delta t} - ESL_{\Delta t} \qquad \textbf{(6)}$$

where Q_m = Measured volume of runoff inflow (L^3), RV_a = Reservoir volume after the inflow (L^3), RV_b = Reservoir volume before start of rainfall (L^3), $IR_{\Delta t}$ = Irrigation releases during time Δt, (L^3), $QS_{\Delta t}$ = Outflow over the spillway during time Δt, (L^3), $ESL_{\Delta t}$ = Evaporation and seepage losses through dam structure during Δt, (L^3). The RV_a and RV_b were determined from the reservoir's elevation versus storage capacity curves from the recorded reservoir levels. The $QS_{\Delta t}$ was determined from measured spillway discharge hydrograph. The inflow data was converted into depth units (mm) accordingly to the catchment area of the dam (uniform depth Q_m over the catchment area).

Runoff by Using Traditional Formula

During the design of Jammergal dam the runoff volumes were determined by using monthly rainfall data for Jhelum city by using traditional formula, i.e. Eq. (3). For this study the monthly runoff volumes at Jammergal dam were calculated by using traditional formula **for the period Jan-92 to Dec. 99** by the following two approaches i.e.

(i) By using rainfall data of Jhelum city (referred as $Q_{T\text{-}JM}$); and

(ii) by using rainfall data of Jammergal dam site (referred as $Q_{T\text{-}JG}$).

The calculated discharges ($Q_{T\text{-}JM}$ and $Q_{T\text{-}JG}$) were compared with the runoff measured at Jammergal (Q_m). Root mean square error (RMSE) was determined for the calculated runoff volumes. The RMSE is defined as:

$$RMSE = \sqrt{\Sigma\,(Q_m - Q_c)^2 \div N} \qquad \textbf{(7)}$$

where Q_m = Measured inflow (mm), Q_c = Computed inflow (mm) $Q_{T\text{-}JM}$ or $Q_{T\text{-}JG}$, and N = No. of data pairs

Rainfall Runoff Models

Following black box rainfall runoff models were evaluated for the measured rainfall and runoff data using a non-linear curve fitting program or spreadsheet package. The goodness of fit of any model was determined from the coefficient of determination (r^2).

Empirical Formula:	Q	=	$C_1 (P - C_2)^{C3}$	**(8)**
Parker's Formula:	Q	=	$K \times (P - b)$	**(9)**
Linear Formula:	Q	=	$K_1 \times P$	**(10)**
Exponential Formula:	Q	=	$a P^N$	**(11)**

where Q = Runoff (mm), P = Rainfall (mm), and C_1, C_2, C_3, *K*, *b*, K_1, *a*, *N* are constants; the constants C_2 and *b* represent threshold precipitation below which no runoff is generated. The model constants were determined by applying the model to measured monthly and yearly rainfall runoff data of Jammergal dam and also to combined data of Jammergal, Tainpura-I, Tainpura-II and Garat dams.

Evaluation of Local Models to Regional Areas

The models derived from Jammergal dam data were evaluated for applicability in other Potohar areas. For this the runoff was calculated for Tainpura-I, Tainpura-II and Garat dams using measured rainfall data at these dams. The runoff computed by these models (Q_c) was compared with the measured runoff (Q_m) at these dam sites. The goodness of fit was determined from the root mean square error (RMSE).

Evaluation of Regional Models to Local Areas

The models derived from regional data were applied to all dams individually. The goodness of fit between measured and computed runoff was determined from the root mean square error (RMSE).

Assessment of Water Yield

To water yield was determined for Jammergal dam at different probability levels by carrying Gumbel frequency analysis. The rainfall data for Jammergal dam was available for the period 1992 to 1999 only whereas the rainfall data for Jhelum was available for time period of 30 years (1969-99).The yearly runoff data for Jammergal dam of the period 1992-99 was correlated with yearly rainfall at Jehlum; the simple exponential model of Eq. (11) was used to fit to the data. Then this representation was used to extend the runoff data of Jammergal dam for the 30 years period 1969 to 1999 based on the rainfall at Jhelum for the same period.

The yearly runoff for Jammergal dam synthesized for the period 1969-1999 was used to perform the frequency analysis. The data was sorted in descending order and the frequency of occurrence or the return period, T, for any rainfall value was calculated by Weibull plotting position method as:

$$T = \frac{n + 1}{m} \qquad \textbf{(12)}$$

where T = Return period (years), n = No. of data points (= 30), m = Order number (descending). The inflow at Jammergal dam was plotted on Gumbel probability paper against the return period. A stragith line was drawn through the data points. The straight line was extrapolated for the evaluation of inflows for larger return periods. From Gumbel probability paper, the values of inflow for different return periods were noted. The percent probability of exceedence ($p, 0 \le p \le 100$) was determined as $p = 1/T \times 100$. A graph between the inflow and percent probability was prepared which provided the values of inflow at different probability level.

RESULTS AND DISCUSSION

Historic Rainfall and Runoff

The historic average monthly and yearly rainfall, P, (mm), runoff, Q, (mm), and runoff ratio, RR, (%) (RR = Q/P×100) at Jammergal, Tainpura-I, Tainpura-II and Garat dams is given in Table 2. The detailed daily and monthly record for various dams is given by Tariq (2000).

Jammergal Dam

Monthly rainfall varied from 10 mm in November 1995 to 496 mm in July 1995 during the record period of 1992 to 1999. Rainfall occurred in 65 months out of 96 months during the 8 years record at Jammergal dam while 31 months remained dry. The average monthly rainfall varied from 8 mm in November to 174 mm in July. About 60% rainfall occurred during 3 monsoon months (July to September). The months of November and December have minimum rainfall. The maximum yearly rainfall of 975 mm occurred during the year of 1997 and minimum rainfall of 384 mm occurred in 1993. The average yearly rainfall during the eight years record was found as 687 mm. The historic monthly average and annual rainfall at Jammergal dam is shown in Figs. 1 and 2.

Monthly runoff varied from 1.02 mm against 60 mm rainfall in March 1998 to 177.3 mm against 249 mm rainfall in August 1992. Runoff occurred in 49 months out of 65 wet months at Jammergal dam while no runoff was generated during 16 months having small rainfall. The average monthly runoff varied from 0.4 mm in November to 61 mm in August. Runoff averaged as 76% during 3 monsoon months (July to September). The maximum yearly runoff of 307 mm occurred during the year 1992 and minimum runoff of 55 mm occurred in 1993. The average yearly runoff during the eight years record was found as 153.4 mm. The historic monthly average and annual runoff at Jammergal dam is shown in Figs. 1 and 2. The figures also show rainfall-runoff-ratio defined as ratio of historic measured runoff Q_m and rainfall P (Runoff ratio = Q_m/P).

Tainpura-I and Tanpura-II Dams

The two dams are located very close and thus experience same rainfall. The historic monthly rainfall at Tainpura-I and Tanpura-II dams varied from 6 mm in November 1997 to 427 mm in August 1997 during the record period 1996 to 1999. Monthly rainfall occurred in 35 months out of 48 months. The average monthly rainfall varies from 2 mm in November to 220 mm in August. About 50% of the total rainfall occurred during the month of July and August. The maximum annual rainfall of 1028 mm occurred in 1997 and the lowest value of 632 mm was found in the year 1998. The average yearly rainfall depth is 784 mm.

The runoff at two dams was found to be slightly different. The monthly runoff at Tanpura-I dam varied from 1.15 mm against 25.5 mm rainfall in April 1996 to 157.8 mm against 427 mm rainfall in August 1997. Runoff occurred in 24 months out of 35 wet months while no runoff was generated during 11 months having small rainfall. The average monthly runoff varied from 1.39 mm in March to 61 mm in August. The maximum yearly runoff of 223 mm occurred during the year 1997 and minimum runoff of 93 mm occurred in 1996. The average yearly runoff during the eight years record was found as 149.8 mm.

The monthly runoff at Tanpura-II dam varied from 0.64 mm against 25.5 mm rainfall in April 1996 to 168.2 mm against 427 mm rainfall in August 1997. Runoff occurred in 24 months out of 35 wet months while no runoff was generated during 11 months having small rainfall. The average monthly runoff varied from 1.36 mm in March to 75.0 mm in August. The maximum yearly runoff of 222 mm occurred during the year 1997 and minimum runoff of 66 mm occurred in 1996. The average yearly runoff during the eight years record was found as 154.8 mm.

Table 2. Monthly rainfall, P (mm), runoff, Q (mm) and rainfall runoff ratio RR (%).

Month	Jammergal dam			Tanpura-I dam			Tanpura-II dam			Grat dam		
	P	Q	RR	P	Q	RR	P	Q	RR	P	Q	RR
Jan	57	4.6	8	52	9.1	18	52	10.9	21	29	3.1	11
Feb	53	9.9	19	88	26.3	30	88	28.0	32	45	8.4	18
Mar	46	8.9	19	31	1.4	5	31	1.4	4	43	6.7	15
Apr	32	1.5	5	36	2.2	6	36	2.1	6	33	6.2	19
May	21	1.7	8	18	0.0	0	18	0.0	0	18	2.9	17
Jun	27	4.9	18	66	3.4	5	66	2.6	4	27	3.7	14
Jul	174	47.0	27	169	34.1	20	169	27.5	16	196	53.9	27
Aug	174	61.1	35	220	60.8	28	220	75.0	34	172	51.9	30
Sep	57	9.2	16	60	10.1	17	60	6.0	10	59	22.3	38
Oct	28	3.1	11	40	2.4	6	40	1.4	4	13	0.9	7
Nov	8	0.4	5	2	0.0	0	2	0.0	0	5	0.2	4
Dec	10	1.0	11	3	0.0	0	3	0.0	0	16	3.8	23
Total	**687**	**153**	**22**	**784**	**150**	**19**	**784**	**155**	**20**	**656**	**164**	**25**

Garat Dam

Monthly rainfall varied at Grat dam from 1.3 mm in March 1996 to 492 mm in July 1995 during the record period of 1983 to 1999. Rainfall occurred in 156 months out of 204 months during the 17 years record at Grat dam while 48 months remained dry. The average monthly rainfall varied from 5 mm in November to 196 mm in July. About 65% rainfall occurred during 3 monsoon months (July to September). The months of October to December have minimum rainfall. The maximum yearly rainfall of 1291 mm occurred during the year of 1983 and minimum rainfall of 291 mm occurred in 1987. The average yearly rainfall during the record period was found as 656 mm.

The monthly runoff at Grat dam varied from 1.1 mm against 6.4 mm rainfall in January 1989 to 136.3 mm against 492 mm rainfall in July 1995. Runoff occurred in 112 months out of 165 wet months while no runoff was generated during 44 months having small rainfall. The average monthly runoff varied from 0.2 mm in November to 53.9 mm in July. The maximum yearly runoff of 302 mm occurred during the year 1983 and minimum runoff of 43 mm occurred in 1991. The average yearly runoff during the eight years record was found as 164.0 mm.

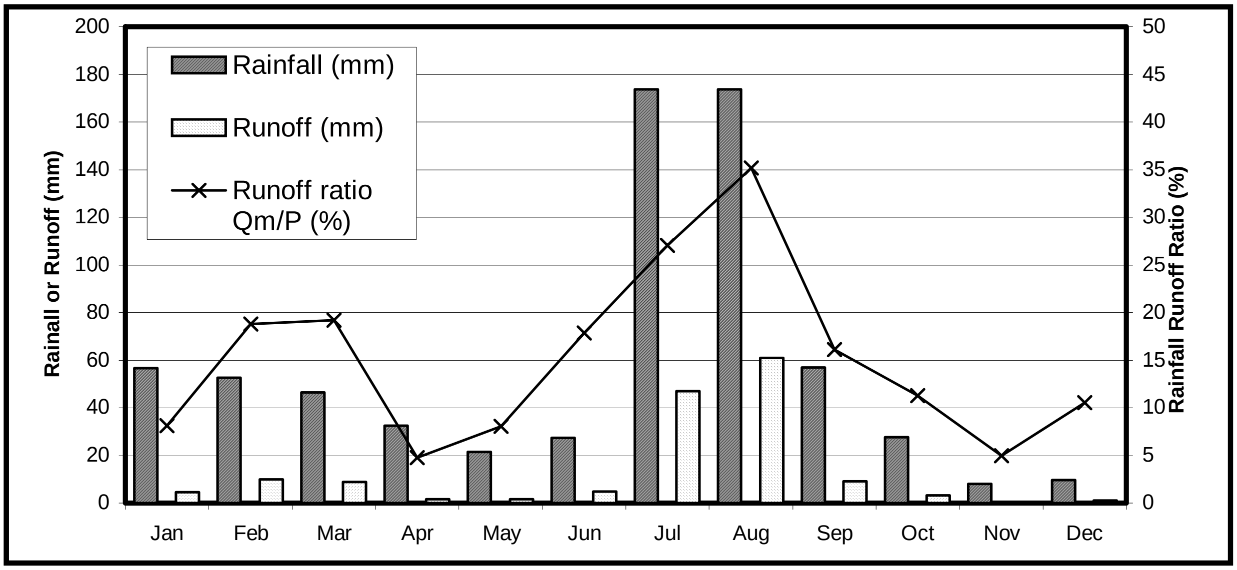

Figure 1. Average monthly rainfall, runoff, and runoff ratio at Jammergal dam.

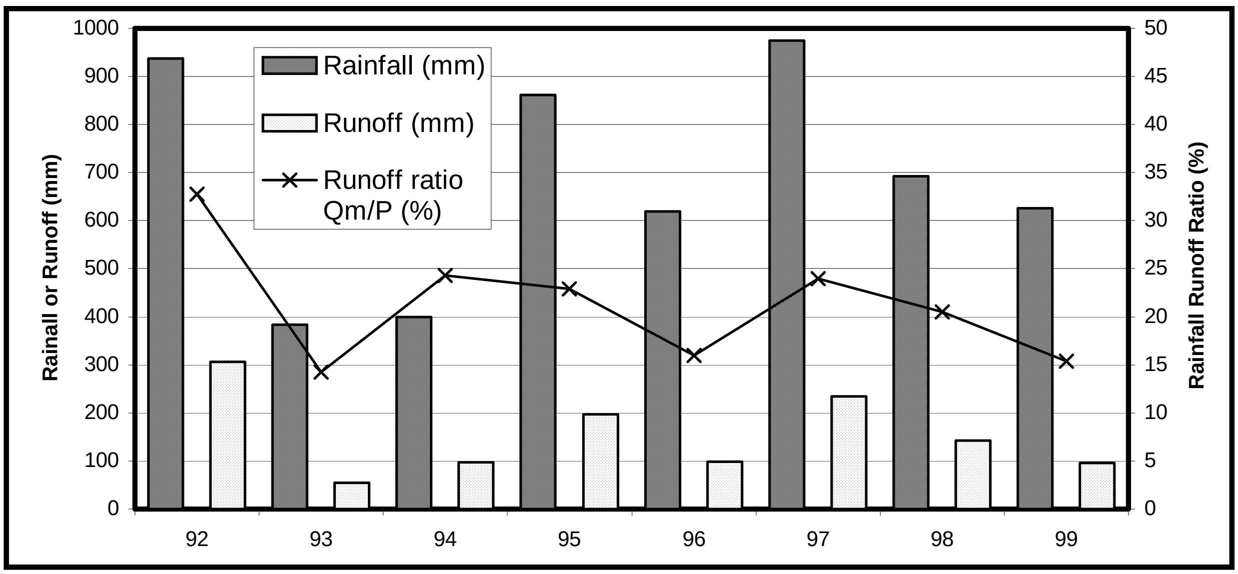

Figure 2: Yearly rainfall, runoff, and runoff ratio at Jammergal dam.

Runoff Calculated By Using Traditional Formula

The runoff computed by using traditional formula (Eq. 3) from the monthly rainfall at Jammergal dam ($Q_{T\text{-}JG}$) and Jhelum ($Q_{T\text{-}JM}$) are compared with runoff measured at Jammergal dam (Q_M) in Fig. 3. The runoff computed by using the rainfall at Jehlum overestimates the runoff at Jammergal Dam. The difference of runoff measured at Jammergal Dam and the runoff calculated by using traditional formula and the rainfall at Jammergal is small for $P \leq 100$ mm and at large P, the deviation is large. The runoff determined using rainfall data of Jammergal dam i.e. $Q_{T\text{-}JG}$ provides better results with RMSE of 13.93 mm than runoff determined by using rainfall data of Jhelum Station i.e. $Q_{T\text{-}JM}$ with RMSE of 28.55 mm. This may be explained by the poor correlation (r^2 = 0.38) in rainfall at the two locations (spaced 32 miles apart), as the rainfall at Jammergal Dam is generally 40 to 90% of the rainfall at Jehlum (Fig. 4). Thus runoff determined by using site specific rainfall data provide better results than rainfall of any other distant located place.

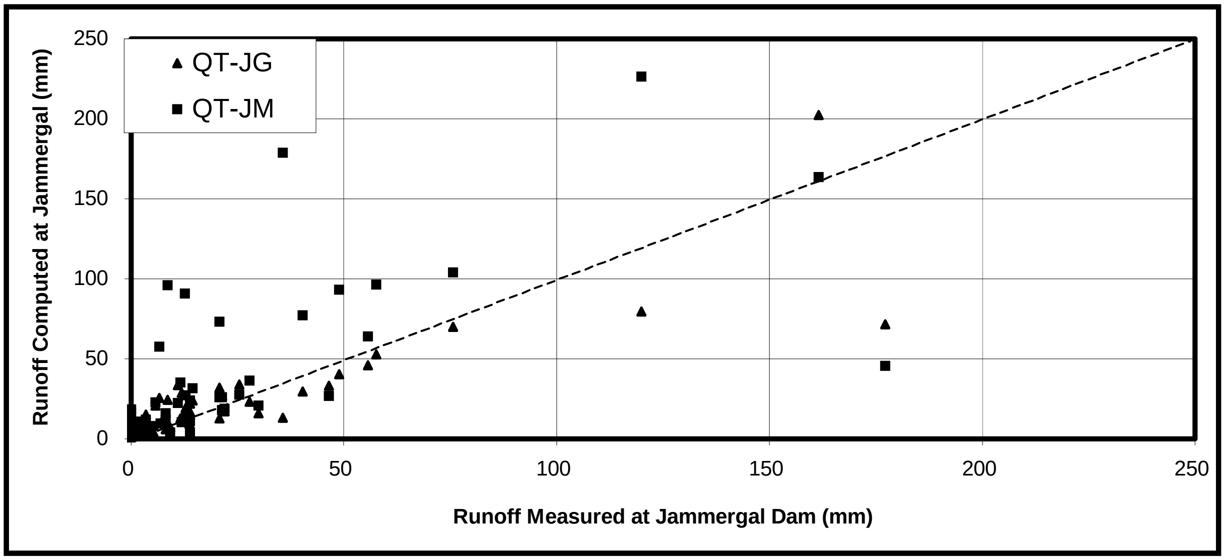

Figure 3. Comparison of runoff calculated by traditional formula at Jammergal Dam with measured runoff.

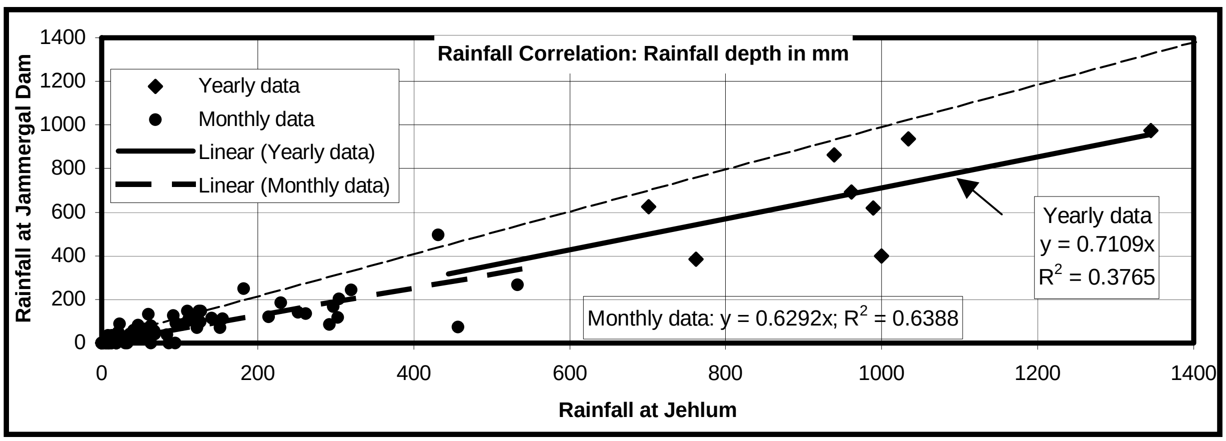

Figure 4. Correlation of monthly and yearly rainfall at Jammergal Dam and Jehlum.

Rainfall Runoff Relationships

The models were fitted to monthly and yearly data for Jammergal dam. The models were also fitted on regional data of four small dams lying in the same Potohar region. Rainfall runoff models were developed for measured rainfall runoff data using a non-linear program. The model coefficients obtained and the highest coefficient of determination (r^2) is as under.

Models Fitted on Monthly Rainfall Runoff Data of Jammergal Dam

The models derived from monthly rainfall runoff data of Jammergal dam are given below. The model fit is compared together with the measured data in Fig. 5.

Empirical:	Q	=	$0.046\ (P - 10.0\ )^{1.354}$	($r^2 = 0.7741$)	**(13a)**
Parker:	Q	=	$0.372\ (P - 33.72)$	($r^2 = 0.7698$)	**(13b)**
Linear:	Q	=	$0.294\ P$	($r^2 = 0.7053$)	**(13c)**
Exponential:	Q	=	$0.0446\ P^{1.349}$	($r^2 = 0.7780$)	**(13d)**

Models Fitted on Regional Monthly Rainfall Runoff Data of Four Small Dams

The models derived from monthly rainfall runoff data of four small dams are described below. The model fit is compared together with the measured data in Fig. 6.

Empirical:	Q	=	$0.265 (P - 13.97)^{1.055}$	$(r^2 = 0.7780)$	**(14a)**
Parker:	Q	=	0.3259 (P - 27.40)	$(r^2 = 0.8060)$	**(14b)**
Linear:	Q	=	0.277 P	$(r^2 = 0.7709)$	**(14c)**
Exponential:	Q	=	$0.0725 P^{1.243}$	$(r^2 = 0.7999)$	**(14d)**

Models Fitted on Yearly Rainfall Runoff Data of Jammergal Dam

The models derived from yearly rainfall runoff data of Jammergal dam are described below. The model fit is compared together with the measured data in Fig. 7.

Empirical:	Q	=	$1.8936 \times 10^{-7} (P + 454.8)^{2.90}$	$(r^2 = 0.8625)$	**(15a)**
Parker:	Q	=	0.34117 (P – 237.32)	$(r^2 = 0.8154)$	**(15b)**
Linear:	Q	=	0.2335 P	$(r^2 = 0.7266)$	**(15c)**
Exponential:	Q	=	$0.001263 P^{1.7807}$	$(r^2 = 0.8512)$	**(15d)**

Models Fitted on Regional Yearly Rainfall Runoff Data of Foue Smalll Dam

The models derived from yearly rainfall runoff data of Jammergal dam are described below. The model fit is compared together with the measured data in Fig. 8.

Empirical:	Q	=	$0.2175 (P - 69.73)^{1.024}$	$(r^2 = 0.6902)$	**(16a)**
Parker:	Q	=	0.2592 (P – 82.4)	$(r^2 = 0.6902)$	**(16b)**
Linear:	Q	=	0.2315 P	$(r^2 = 0.6815)$	**(16c)**
Exponential:	Q	=	$0.0915 P^{1.1385}$	$(r^2 = 0.6897)$	**(16d)**

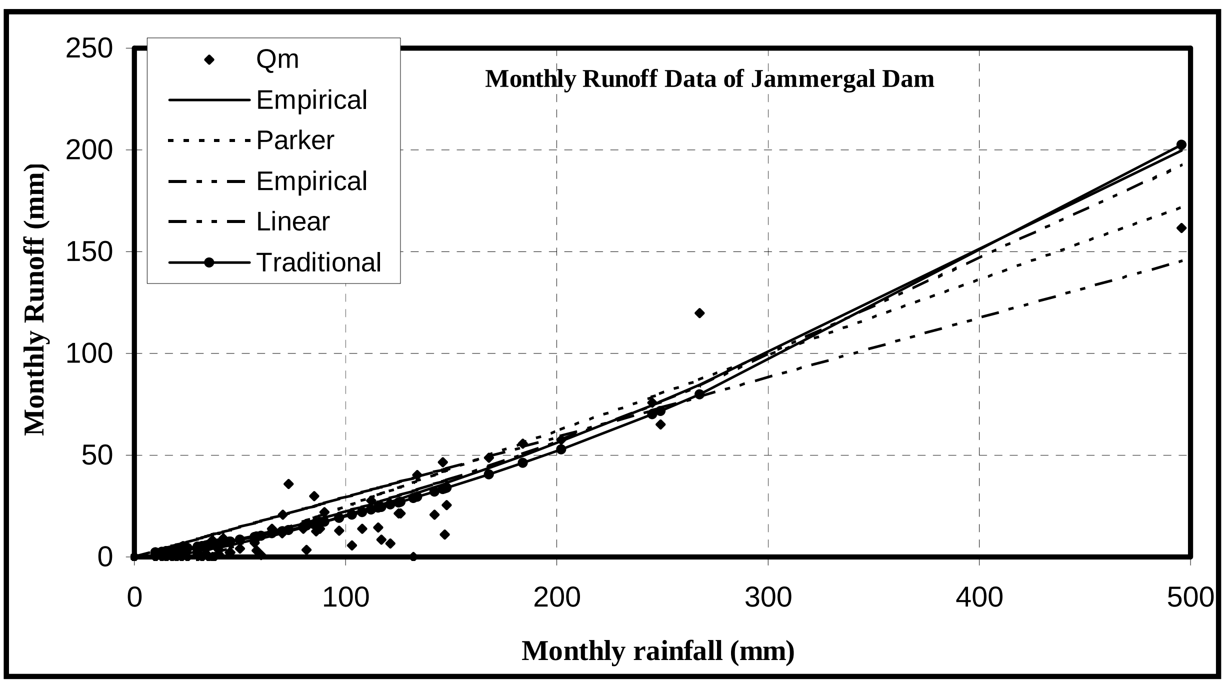

Figure 5. Model fit to monthly data of Jammergal Dam.

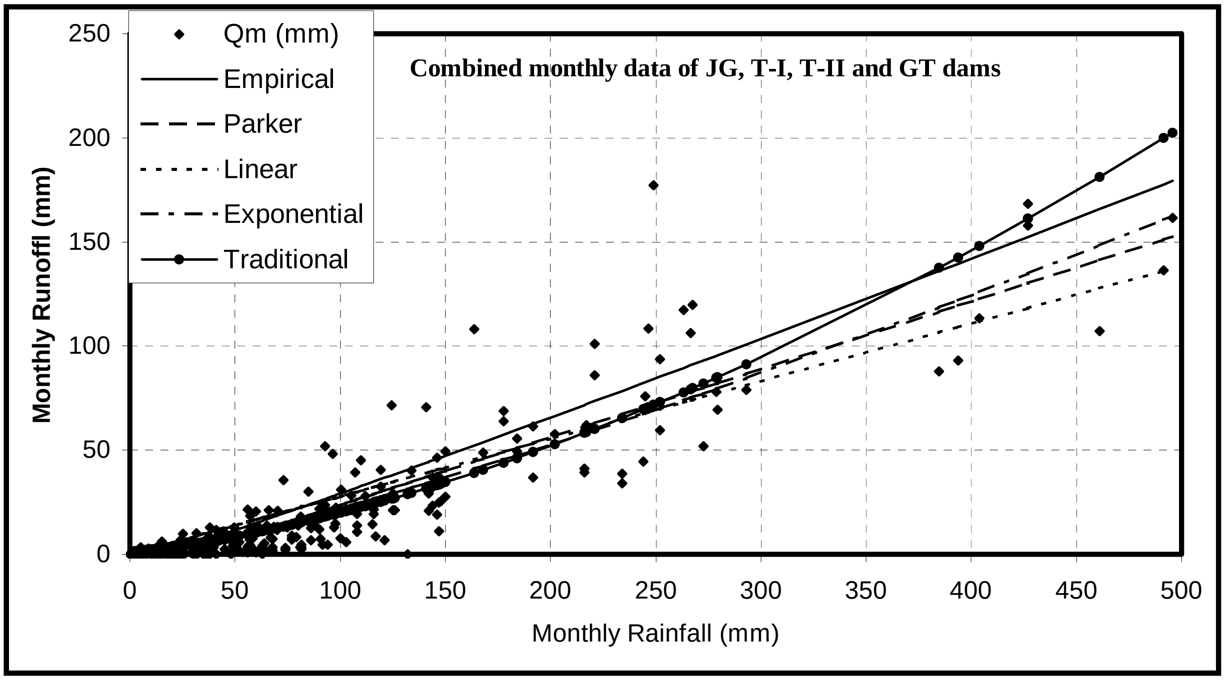

Figure 6. Model fit to combined monthly data of four small dams.

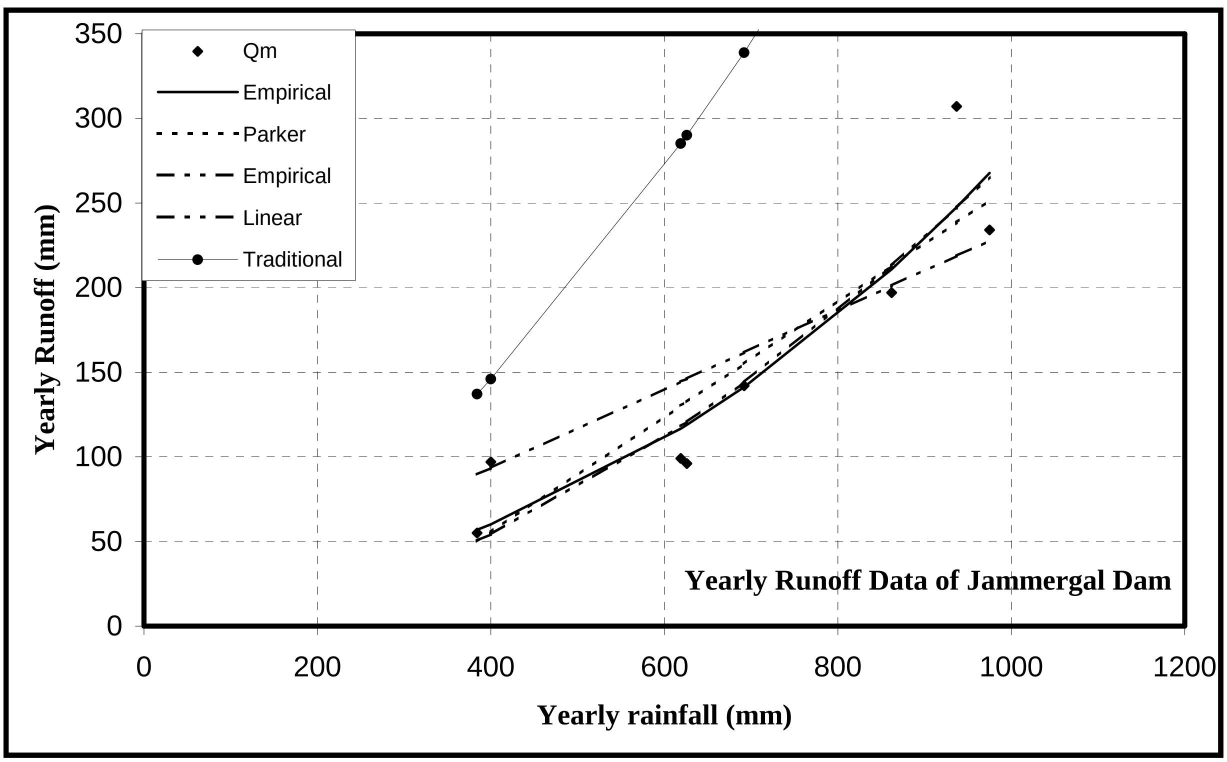

Figure 7. Model fit to yearly data of Jammergal Dam.

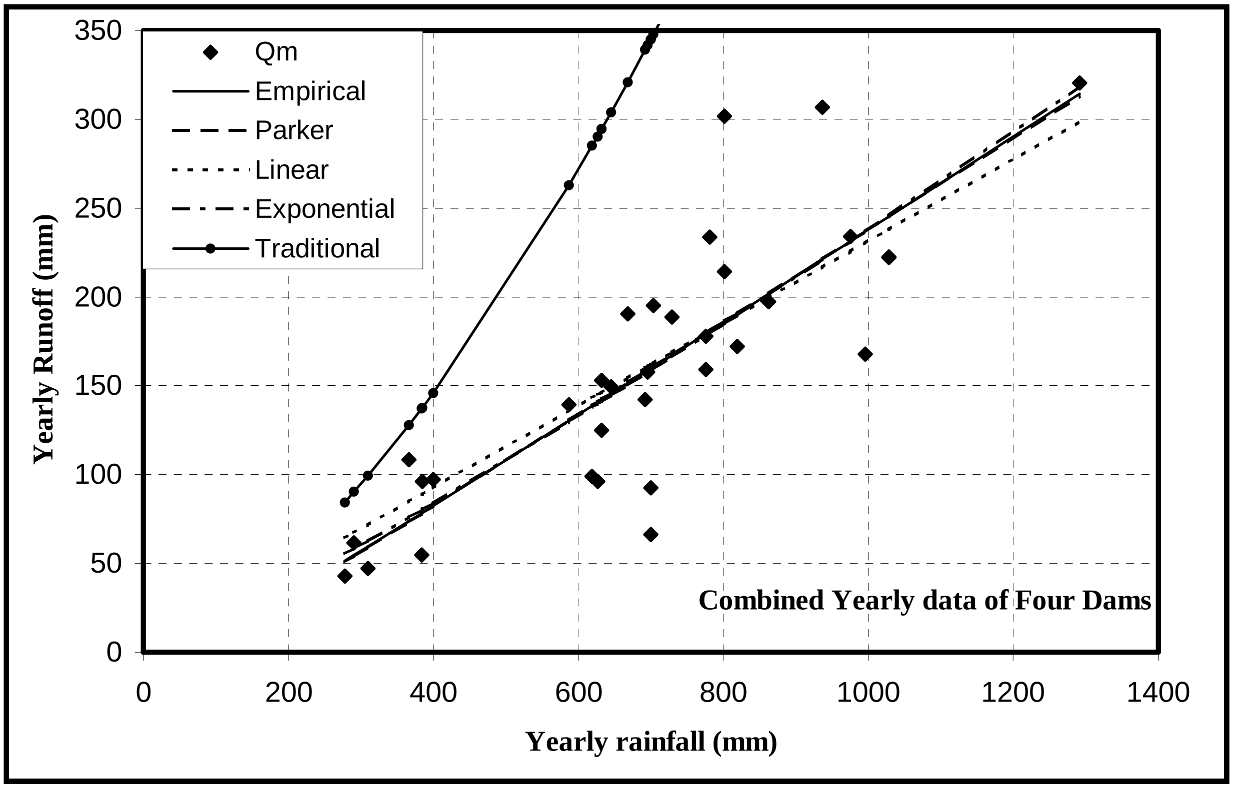

Figure 8. Model fit to combined yearly data of four small dams.

Discussion

The rainfall-runoff relationship for any catchment area depends upon many factors, which generally vary with time. Thus neither of the models gives any perfect fit. The data is very erratic and no simple relation seems to provide representative relationship under all conditions. The spread of the data of all dams when combined together becomes much wider than data for Jammergal dam only. However, the coefficient of determination (r^2) for the two data set for any models are quite close. From the study of the coefficients of determination (r^2), it is seen that the empirical model and the exponential model generally provide better representation than the other models with $r^2 \approx 0.77$. These models even provide better representation for the case of yearly data for Jammergal dam as shown in Fig. 7 with $r^2 \approx 0.86$.

The empirical formula was used for hydrologic assessment during design of Jammergal dam. However, the coefficients used were considerably different than results of this study. A wide difference in values of these coefficients suggests that great care must be exercised in the choice of the model and its coefficients. However the results of empirical formula with traditional coefficients were very close with the revised coefficients for monthly rainfall data, but differed considerably for the yearly data. In general it can be seen that the traditional coefficients of the empirical formula yield as good results as for revised coefficients.

Applicability of Local Monthly Models to Different Area

The models derived for monthly Jammergal dam data (Eqs. 13a to 13d) were tested for applicability to other areas in the neighborhood of Jammergal Dam for Tainpura-I Dam (Fig. 9), Tainpura-II Dam and Garat Dam (Fig. 10). The RMSE for various models is given in Table 3. It has been seen that none of these models yield perfect agreement to measured runoff data. The empirical formula (Eq. 13a) and the exponential formula (Eq. 13d) still provide better representation than other models as these models has smaller RMSE (33 and 34 mm) than other formulae. It is seen that large contribution to such errors are caused by rare events. As sustainable hydrologic assessment of small dams usually do not depend upon such rare and extraordinary events, therefore such errors become less important even for their not so small value, e.g. 33 ± mm. If these rare events are excluded, then the RMSE decreases to as 20± mm. This indicates that catchment yield model derived from data of any place can be used for neighboring areas as well with small average errors.

Table 3. Root mean square error for local monthly models applied to regional areas.

Sr.No.	Name of Dam	Empirical	Parker	Linear	Exponential
1	Tainpura-I	19.70	36.35	38.85	22.69
2	Tainpura-II	34.09	46.11	50.82	36.52
3	Garat	45.74	47.94	35.53	43.44
Average root mean square error		33.18	43.47	41.73	34.22

Applicability of Regional Models To Local Scale

The models derived from regional data of Jammergal, Tainpura-I, Tainpura-II and Garat dams together (Eqs. 14a to 14d) were tested for applicability to individual dam sites. The results are shown by Tariq (2000). The RMSE is given in Table 4. The data indicates a wide scatter in runoff values for similar rainfall amounts. The fit of the curves indicate much larger error for the case of rare / high frequency events. The RMSE is even higher than for the case of applying local scale model to regional areas. This indicates that a high confidence cannot be placed on the usefulness of these formulae for hydrologic assessment of small dams. The empirical formula and exponential formula generally show better fit to data and also has smaller RMSE than other formula. This result is consistent with the observation in the last section.

Table 4: Root mean square error for regional models applied to local areas.

Sr.No.	Name of Dam	Empirical	Parker	Linear	Exponential
1	Jammergal	49.74	52.11	53.99	48.99
2	Tainpura-I	41.60	37.21	41.85	31.35
3	Tainpura-II	45.19	44.54	50.68	40.43
4	Garat	41.05	40.20	34.86	37.35
Average root mean square error		44.40	43.52	45.35	39.53

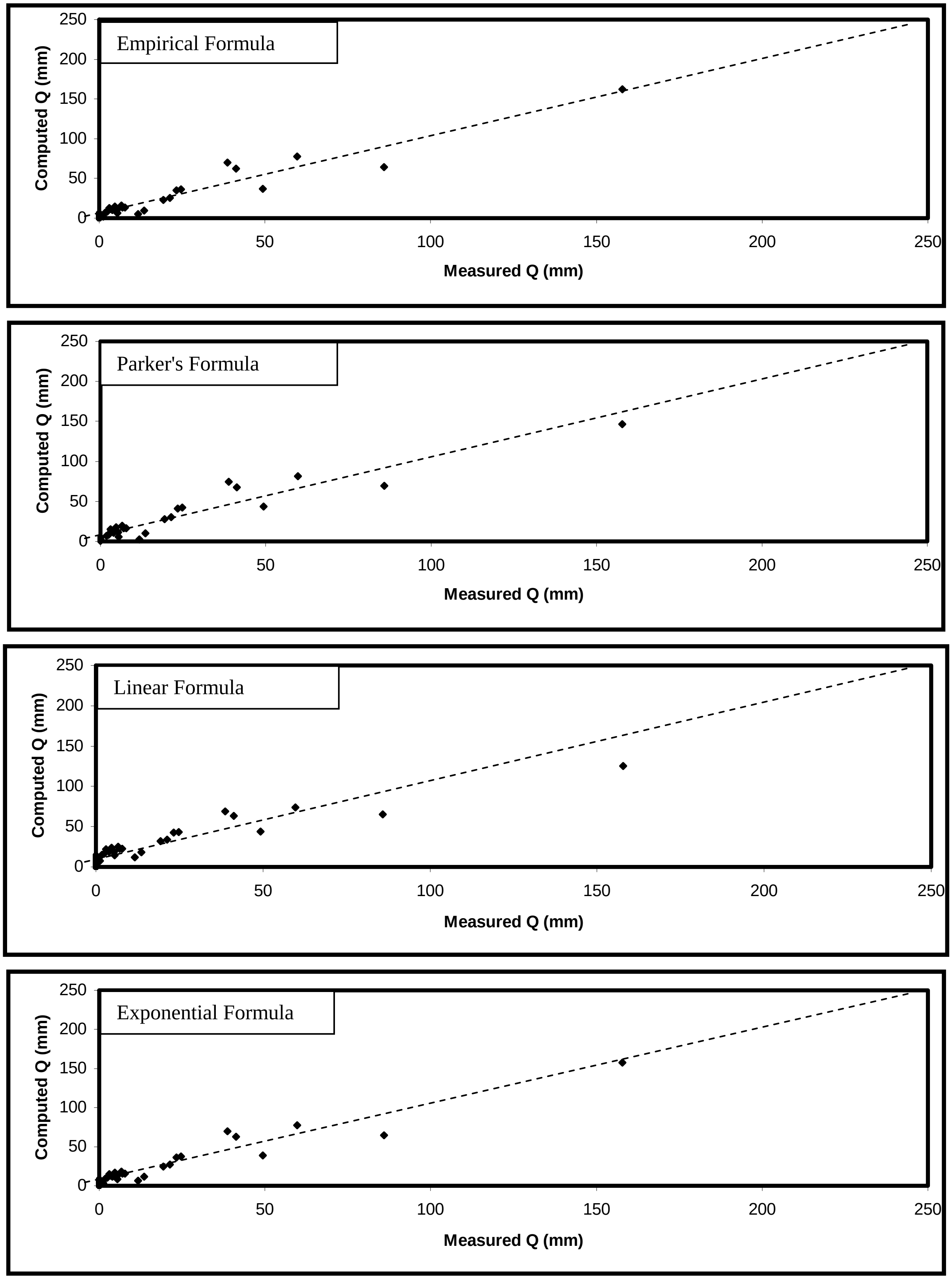

Figure 9. Application of runoff models derived from Jammergal Dam data to Tanpura-1 Dam.

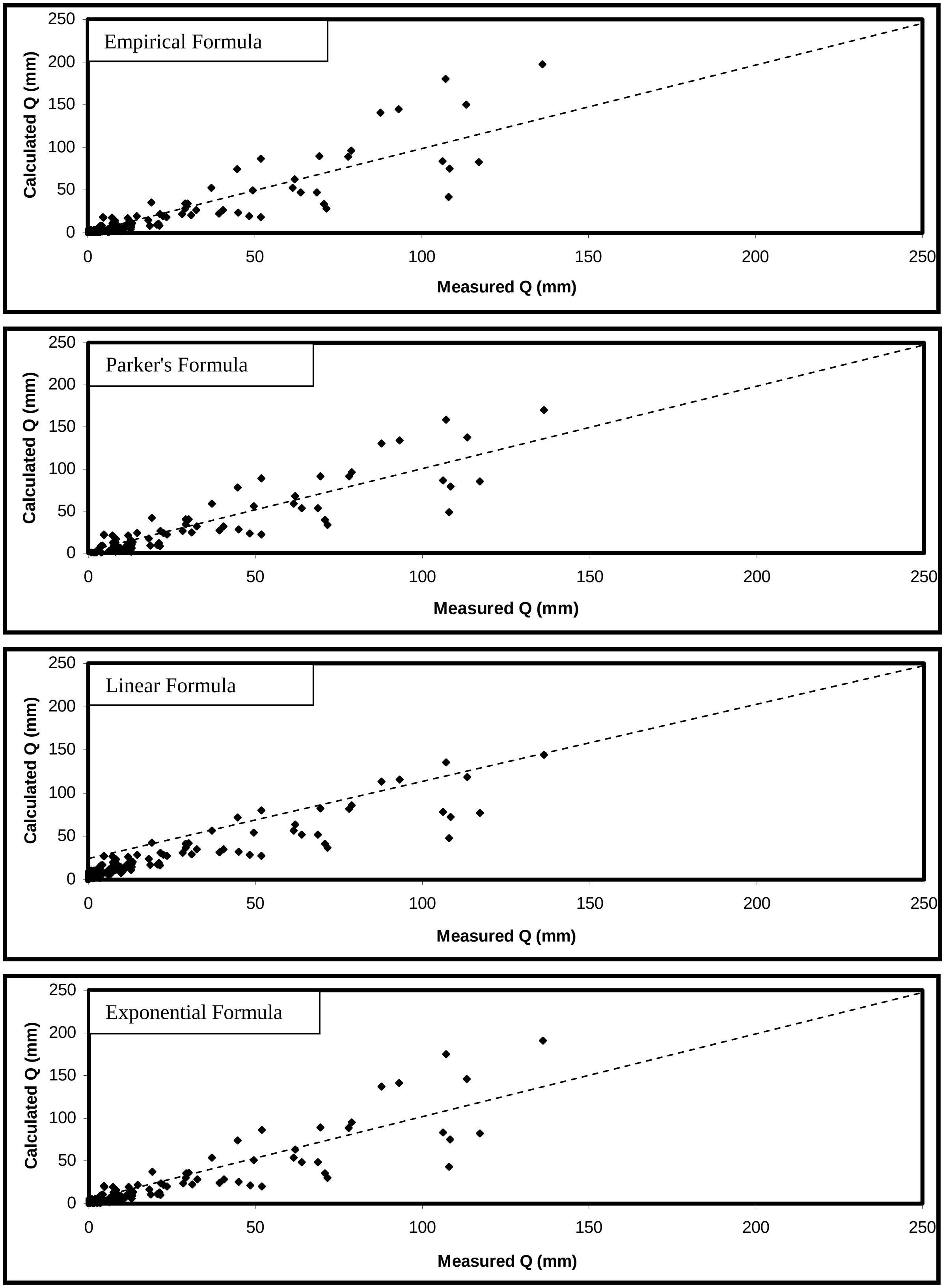

Figure 10. Application of runoff models derived from Jammergal Dam data to Grat Dam.

Assessment Of Water Yield

The water yield for Jammergal dam at different return period and probability levels was determined by Gumbel frequency analysis.

Correlation

The yearly runoff at Jammergal dam was correlated with yearly rainfall at Jhelum for the period 1992 to 1999 and found as (Q = Runoff at Jammergal dam, mm; P = Rainfall at Jehlum, mm):

$$Q = 0.0027636\ P^{1.58768} \qquad \textbf{(17)}$$

Frequency Analysis

The inflows were synthesized for Jammergal dam by using Eq. (17) for the period 1969-1999. The derived return period, T, (in years) and probability of exceedence, p (%) are shown in Figs. 11 and 12. The live storage capacity of the Jammergal dam is 930 AF (76 mm). The average dam system losses (evaporation, seepage etc) are estimated as 540 AF per year. The historic annual irrigation releases from the Jammergal dam varied from 50 to 1215 AF with an average of 540 AF. The present live storage capacity of the Jammergal dam corresponds to return period of 1.02 years (p = 98%). This is also evident from the fact that the dam has over spilled 13 times during the last 8 years. The present capacity of the Jammergal dam is highly conservative and it becomes evident that the dam could have provided much higher water resources in the area. This also signifies that frequency analysis must be carried for every dam site for ascertaining the optimal storage potential.

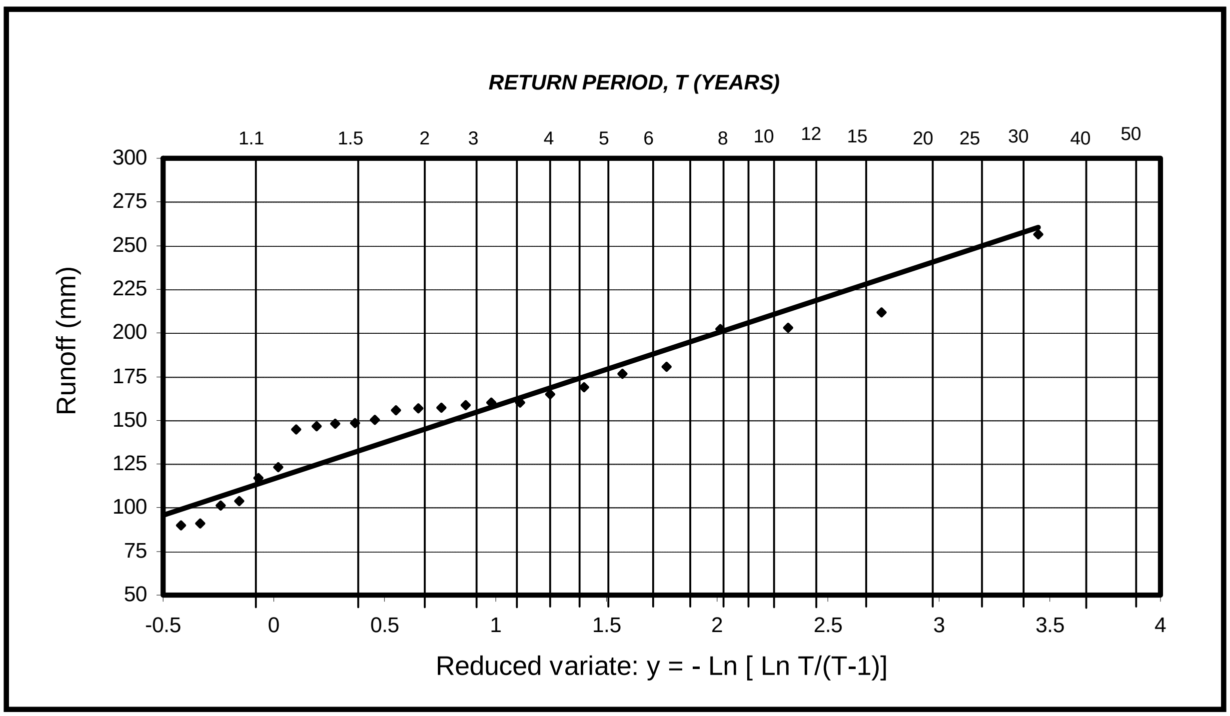

Figure 11. Return period vs. annual runoff at Jammergal Dam.

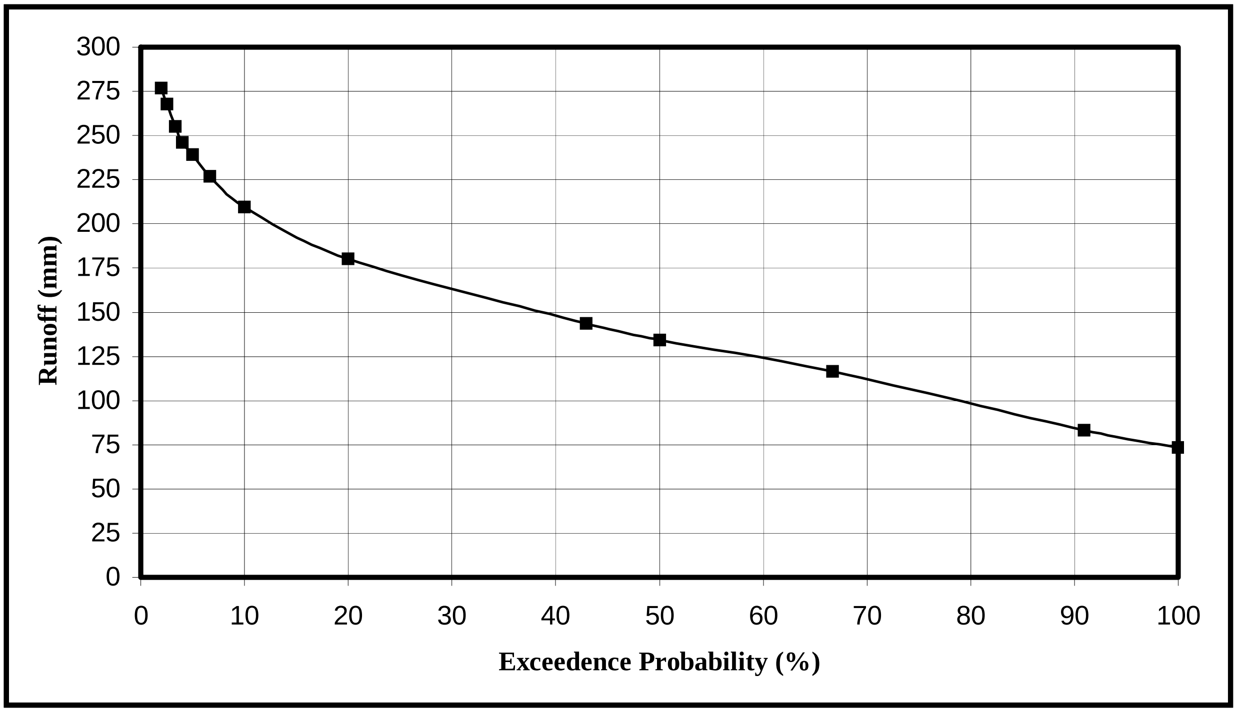

Figure 12. Exceedence probability for runoff inflows into Jammergal Dam.

The yearly runoff and net usable water for various probability levels as determined from Fig. 12 are given in Table 5. At 25% and 50% probability, the gross inflows into Jammergal dam are estimated as 2128 and 1636 AF, respectively. Excluding the system losses the net available inflow into the Jammergal dam for 25% and 50% probability level is 1588 and 1096 AF respectively. The Jammergal dam is considered to be raised by 3.5 ft increasing present live storage capacity by 500 AF to total of 1430 AF. The probability of getting reservoir full after 3.5 ft. raising (capacity = 1430 AF, 116 mm) is about 65% (Return period T = 1.55 years) which means reservoir will be filled completely in general for two years out of every three yeas. Thus raising of dam has a sound hydrologic basis and this will make additional 500 AF of water available for agricultural use resulting in almost doubling the current supplies. During years of non-filling of reservoir, scientific water management techniques may be used to optimize water supplies in the command area.

Table .5. Assessment of additional water storage potential for Jammergal Dam.

Probability (%)	Yearly inflow		Average dam system losses		Net available inflow	
	mm	AF	mm	AF	mm	AF
25	173	2128	44	540	129	1588
50	133	1636	44	540	89	1096
60	123	1513	44	540	79	973
70	109	1341	44	540	65	801
80	97	1193	44	540	53	653
90	87	1070	44	540	43	530
100	74	910	44	540	30	370

CONCLUSIONS & RECOMMENDATIONS

CONCLUSIONS

This study was conducted to evaluate hydrologic assessment of small dams in Potohar areas. Following conclusions are drawn:

1. Rainfall-runoff relationship for Jammergal dam is highly varied from month to month and season to season.
2. All the models tested (i. Empirical, ii. Parker, iii. Linear iv. Exponential,) based on local or regional, and monthly or yearly data provide similar level of accuracy.
3. The empirical formula is fairly applicable for hydrologic assessment of Jammergal dam and other neighboring dams with presently used coefficients or the revised coefficients for monthly data provided rainfall data of the particular site is used instead of any distant located site.
4. The rainfall runoff relationships derived from data of Jammergal dam may be applied advantageously to neighboring small dams in comparison to the relationship derived from the combined regional data.
5. Jammergal dam has a hydrologic probability of 98% (return period T = 1.02 years) for getting completely filled in any year for present live storage capacity of 930 AF.
6. The hydrologic assessment support that Jammergal dam can be raised by 3.5 ft. to new live storage capacity of 1430 AF with probability of 65% (return period T = 1.55 years) for getting completely filled in any year. At probability level of 25% (T = 4 years) and 50%

(T = 2 years), the reservoir's live storage capacity can be increased to 2128 AF and 1636 AF, respectively. This can provide additional 700 and 1200 AF of water for irrigation releases. During years of non-filling of reservoir, scientific water management techniques may be used to optimize water supplies in the command area.

RECOMMENDATIONS

1. Black box models are reliable only for the range for which these relationships are derived. For accurate hydrologic assessment, extensive parametric catchment modeling may be undertaken at one of small dams to accurately establish rainfall runoff relationship in Potohar area.
2. In the absence of detailed parametric catchment models, the empirical formula with revised coefficients may be used for hydrologic assessment of small dam in southern and southeastern parts of the Potohar area.
3. The capacity of Jammergal dam may be increased by 500 AF by raising dam structure by 3.5 feet.

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