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# Estimation of runoff generating capacity of a small watershed

**Abhishek Ranjan and Dr. DM Denis**

**Abstract**
Water is the basic requirement for existence of all forms of life on the earth. Water is abundantly available on the globe as it covers nearly three quarters of the earth surface. More than 97% of the earth's water is found in the seas and oceans, which is salty and unfit for drinking and irrigation. Another 2% is locked up in the Polar Regions in the form of ice and the remaining 1% a meager fraction is trapped in under-ground reservoirs and remains meager fraction that forms the world's main source of water supply. That work is entitled with Estimation of runoff generating capacity of a small watershed." is undertaken with the following objectives are: To compute runoff coefficient for the selected watershed, To predict monthly runoff at different percent probability levels and to predict annual runoff at different percent probability levels. This study done on Nagwan Watershed of Damodar Barakar Catchment (Jharkhand, India). The monthly and the annual runoff at different percent probability levels were determined by using Weibull's method. July month has the highest average runoff followed by September and August while October has the lowest value of average runoff. July has higher value of runoff coefficient than June due to higher antecedent moisture present in soil and the annual runoff coefficient for the watershed is 0.38. September month has the highest value (0.47) of runoff coefficient while June has the lowest value (0.18). At 50% probability level, the monthly runoff in September is maximum (= 81.4 mm) followed by August (79.7 mm), July (66.5 mm) and June (18.1 mm) while it is minimum in October (8.7 mm) and the expected annual runoff value is 325.4 mm. Whereas at 75% probability level, the expected monthly runoff is maximum in August (= 43.9 mm) followed by September (39.8 mm) and July (30.3mm) while there is no chance of any runoff in October and expected annual runoff is 209.6 mm.

**Keywords:** Hingwadi choorna, bhavana, pharmaceuticals, particle, size reduction, preparation

## Introduction

Water is the basic requirement for existence of all forms of life on the earth. Water is abundantly available on the globe as it covers nearly three quarters of the earth surface. More then 97% of the earth's water is found in the seas and oceans, which is salty and unfit for drinking and irrigation. Another 2% is locked up in the Polar Regions in the form of ice. Of the remaining 1% a meager fraction is trapped in under-ground reservoirs and remains meager fraction that forms the world's main source of water supply.

A watershed is a geographical area that catches the rainwater and drains it to a common point known as outlet. The watershed characteristics such as length, width, area, shape, drainage pattern, soil type, vegetation cover, land use, and hydrologic conditions significantly affect the rainfall-runoff process.

A part of the precipitation that infiltrates into the soil moves laterally through upper crusts of the soil and returns to the surface at some location away from the point of entry into the soil. This component of runoff is known variously as interflow. Depending upon the time delay between the infiltration and the outflow, the interflow is sometimes classified into prompt interflow, i.e. the interflow with the least time lag and delayed interflow. Another route for the infiltrated water is to undergo deep percolation and reach the groundwater storage in the soil. Based on time delay between rainfall and runoff, the runoff is classified into two categories: direct runoff and base flow. Direct runoff is that part of the runoff which enters the stream immediately after the rainfall. It includes surface runoff, prompt interflow and rainfall on the surface of the stream. Base flow is the delayed flow that reaches outlet essentially as groundwater flow.

The runoff water may be harvested and can be used for various productive purposes such as domestic water supply, supplemental irrigation to the crops, livestock drinking and also for fish farming. Knowing the above importance, the present project work entitled

"Estimation of runoff generating capacity of a small watershed." is undertaken with the following objectives.

**Objectives**

1. To compute runoff coefficient for the selected watershed.
2. To predict monthly runoff at different percent probability levels.
3. To predict annual runoff at different percent probability levels.

**Review of Literature**

The various reviews collected from the available literature are presented below briefly:

Inglis and Disooza (1929) [6] developed regional formula between annual runoff (R) in cm and annual rainfall (P) in cm for different regions of India, given as:

1. For Ghat regions of western India,

$$R = 0.85\ P - 30.5$$

2. For Deccan Plateau,

$$R = \frac{1}{254}\ (P - 17.8)$$

Khosla (1960) analyzed the rainfall, runoff and temperature data for various catchments in India and USA to derive empirical relations between rainfall and runoff. The time period was taken as a month. The relationship for monthly runoff is:

$$\mathbf{R_m = P_m - L_m}$$
$$\mathbf{L_m = 0.48\ T_m \text{ for } T_m > 4.5^0\ C}$$

Where,

$R_m$ = monthly runoff, cm
$P_m$ = monthly rainfall, cm
$L_m$ = monthly losses, cm
$T_m$ = mean monthly temperature of catchments, $^0$C.

Hardeha *et al.* (1989) [5] developed rainfall- runoff relationship for small watersheds to ascertain efficient design or right extent of over-design for soil and water conservation measures. In their study an attempt was made to correlate runoff and storm rainfall for their varying slopes with a grass cover. Runoff as percentage in rainfall, straight line relationship and curve numbers for hilly cropped and pasture watersheds were compared. It was found that curve number could better represent the effectiveness of runoff producing characteristics of small watershed.

Mathan (1996) [10] studied runoff and soil loss from watersheds under different conservation practices. The nature of the soil in relation to the amount of runoff water loss, sediment loss during every fall event was studied in two watersheds at Kodaikanal, Tamilnadu viz. Forest shoal watershed (W2) and banana cultivated watershed (W1). The result revealed that in both the watersheds the total runoff was not only dependent on the rainfall but also on the previous moisture status of the soil, soil conservation measures and vegetal cover. The sediment loss variations were due to aggregate stability and other erosion related properties, such as clay content and dithionite iron.

Satapathy (1997) developed prediction models of runoff for hilly watersheds. Nine small watersheds with area ranging from 0.52 ha to 3.8 ha were identified to develop simple linear rainfall-runoff models for hilly watersheds. The regression equations displayed only a moderate degree of correlation. The models however, can be tailored to specific conditions and be used as first approximation of storm runoff in watersheds.

Pawar (2001) estimated surface runoff for Ahar river catchment and Udaisagar catchment by using SCS curve number method. It was observed that the surface runoff contribution from Ahar river catchment was more than that from Udaisagar catchment. He also concluded that annual surface runoff from the catchment is dependent not only on the total amount of rainfall but also on the amount of daily rainfall events and rainfall distribution.

Singh (2007) developed and tested a simple physically based distributed rainfall-runoff model for storm runoff simulation in humid forested basins. It was found that relationship between rainfall and runoff was good for the basins.

Kumar (2008) [8] developed rainfall-runoff relationship for a small watershed. It was found that the annual rainfall-runoff relationships were found to be 3rd order polynomial equation with the correlation coefficient as 0.90. The obtained equation was-

$$\mathbf{Y = -\ 1E\text{-}05X^3 + 0.030X^2 - 29.88X + 9883}$$
$$\mathbf{R^2 = 0.90}$$

The value of runoff coefficient of Karso watershed was evaluated as 0.490 which is slightly higher than the old value (0.483) reported in the past record and hence there is no any significant change in the runoff coefficient value.

**Materials and Methods**

The whole presentation is divided into four sub-sections. The first sub-section deals with selection of watershed, second subsection contains data collection, the third deals computation of runoff coefficient, and the last subsection deals with analysis of runoff data and method to predict monthly and annual runoff at different percent probability levels.

**Selection of Watershed**

In the present study Nagwan Watershed of Damodar Barakar Catchment (Jharkhand, India) is selected.

**Nagwan Watershed**

The information on characteristics of the selected watershed was collected from Engineering Department of Damodar Valley Corporation, Hazaribagh (Jharkhand, India). The Nagwan Watershed which lies in Damodar Barakar catchments is situated at 85º24'E longitude and 24º3'N latitude. The gauging station of Watershed is Nagwan. The watershed which is rectangular in shape is extended over a total area of 9246 ha or 92.46 km$^2$. The watershed receives an average annual rainfall of 1300 mm and more than 80% of the rainfall is received during the monsoon season (June to October).

**Land use/Land Cover**

The land use of watershed includes paddy cultivation, upland cultivation, wood and grass combination land, waste or fallow land, habitation and head surface (farm striates, roads etc.). Thus, the watershed has mixed land use.

**Table 1:** Land use/land cover for Nagwan watershed

| Sl. No. | Land use/land cover | Area (km$^2$) |
|---|---|---|
| 1. | Paddy cultivation | 39.96 |
| 2. | Upland cultivation | 16.32 |
| 3. | Wood and grass Combination land | 17.27 |
| 4. | Waste or fallow land | 10.38 |
| 5. | Habitation | 8.03 |
| 6. | Hard surface | 0.5 |
| Total area | | 92.46 |

**Soils**

The dominant soil group of the area falls under loamy sand of red colour, which is derived from granite ferruginous genesis. The soil is well drained. The soil profile depth is more than 100cm in the majority of areas of watershed. The soil depth is relatively low in heavily gullied areas.

**Collection of Rainfall-Runoff Data Set**

The rainfall-runoff data sets of selected watershed were collected from Engineering Department of Damodar Valley Corporation, Hazaribagh (Jharkhand, India). The monthly rainfall & runoff data were collected for twenty years duration i.e. from 1996 to 2015.

**Determination of runoff coefficient**

The abstractions during rainfall are normally accounted by means of runoff coefficients. The most common definition of a runoff coefficient is the ratio of peak rate of direct runoff to the average intensity of rainfall of a storm and this value is difficult to determine from observed data. A runoff coefficient can also be defined to be ratio of runoff depth (or volume) to rainfall depth (or volume) over a given time period. These coefficients are most commonly applied to storm rainfall and runoff, but also are used for monthly or annual rainfall and stream flow data (Chow, 1987) [2]. The runoff coefficient is expressed as:

$$\mathbf{C = R_o/R_f} \qquad \text{...... (1.1)}$$

Where, C = runoff coefficient (dimensionless)
$R_o$ = runoff
$R_f$ = rainfall

**Analysis of runoff data**

From the collected rainfall-runoff data, average monthly and average annual runoffs were computed first. Then, the monthly and annual runoffs in terms of corresponding% of rainfall were computed. Further, the monthly and the annual runoff at different percent probability levels were determined using Weibull's method.

**Weibull's method**

This is a simple empirical technique for analysis of series of data for probability distribution at different levels. The probability of an event equal to or exceeded is given by the following formula:

$$\mathbf{P = m/(n+1)} \qquad \text{… (1.2)}$$

Where, P = Probability (fraction)
m = order number
n = length of records

**Different steps involved in the analysis are**

1. Tabulation of data
2. Arrangement of data in descending order
3. Assigning order number, m, to data; i.e. m = 1 for the highest magnitude and every successive data in the descending order is assigned 2, 3, 4,... and so on till the last event for which m = n
4. Determination of probability, P, by using Weibull's equation
5. Plotting values of P on x-axis and the runoff amount on y-axis on arithmetic paper
6. Determination of magnitude of runoff at different probability levels.

**Results and Discussion**

**Average monthly and annual runoff**

The computed values of average monthly and average annual runoff based on 20 years (1996-2015) data are presented in Table 2. From this table, it is seen that the average monthly runoff for June, July, August, September and October are 39.4, 109.5, 100.7, 109.3, 20.3, and 383.2 respectively. Hence, it is obvious that July month has the highest average runoff followed by September and August. October has the lowest value of average runoff. It is also clear from Table 2 that average annual runoff for the selected watershed is 383.2 mm. Further, the annual variations of monthly and annual runoff values are shown in Fig. 1 to Fig. 6. These figures indicate that there is no any definite pattern of variation.

**Runoff coefficient**

The values of average monthly and average annual runoff coefficient of the watershed based on 20 years (1996-2015) data were computed and are presented in Tables 3 to Tables 8. From Table 3, it is clear that average rainfall in June month is 189.7 mm and average runoff is 39.4 mm resulting into runoff coefficient as 0.18. It means on an average 18% of rainfall converts into runoff. Similarly, average rainfall in July month is 289.7 mm while average runoff is 109.5 mm producing runoff coefficient as 0.35 (Table 4). The reason behind higher value of runoff coefficient in July than that in June is that the soil remains in dry condition in the preceding month (May) of June while it becomes in moist condition in June resulting into lower infiltration of the soil for July.

Similarly, average runoff coefficients for August, September and October are computed to be 0.40, 0.47 and 0.24 respectively (Tables 5 - 7). It is obvious that September month has the highest runoff coefficient (0.47) followed by August (0.40) and July (0.35). October has the lowest value of runoff coefficient.

Average annual rainfall for the selected watershed is found to be 999.9 mm (approx. 1000 mm) while average annual runoff is 383.2 mm producing an average annual runoff coefficient value of 0.38 (Table 8). Hence, on an average, 38% of rainfall is converted into runoff on annual basis.

Figure 7 compares the values of average monthly and average annual runoff coefficient. It is clear from this figure that September month has the highest value (0.47) of runoff coefficient while June has the lowest value (0.18).However, the annual runoff coefficient is 0.38.

**Expected values of monthly and annual runoff at different probability levels**

The computed values of probability and recurrence interval of monthly and annual runoff using Weibull's method. The plots of expected monthly runoff in June, July, August, September and October are shown in Figures 8 to Fig.12 respectively while the similar plot for annual runoff is shown in Fig. 13.

The equations of relationship between expected runoff and probability are shown on the plots along with coefficient of determination ($R^2$) value. It is clear from these figures that the relationships are very satisfactory. Using these equations, the expected monthly and annual runoff at different probability levels were computed and are presented in Table 4.8. From this table, it is clear that at 50% probability level, the monthly runoff in September is maximum (= 81.4 mm) followed by

August (79.7 mm),
July (66.5 mm) and June (18.1 mm) while it is minimum in October (8.7 mm). At this probability level, the expected annual runoff value is 325.4 mm. At 75% probability level, the expected monthly runoff is maximum in August (= 43.9 mm) followed by September (39.8 mm) and July (30.3 mm) while there is no chance of any runoff in October (Table 9). At this probability level, expected annual runoff is 209.6 mm.

**Table 2:** Computation of average monthly and average annual runoff based on 20 years data

| S.N. | year | Runoff in June (mm) | Runoff in July (mm) | Runoff in August (mm) | Runoff in Sept. (mm) | Runoff in Oct. (mm) | Annual Runoff (mm) |
|---|---|---|---|---|---|---|---|
| 1 | 1996 | 21.0 | 219.0 | 152.0 | 88.0 | 49.0 | 529.0 |
| 2 | 1991 | 25.0 | 76.0 | 112.0 | 135.0 | 3.0 | 351.0 |
| 3 | 1992 | 50.0 | 57.0 | 96.0 | 28.0 | 26.0 | 257.0 |
| 4 | 1993 | 16.0 | 62.0 | 50.0 | 237.0 | 15.0 | 380.0 |
| 5 | 1994 | 117.0 | 228.0 | 120.0 | 30.0 | 105.0 | 600.0 |
| 6 | 1995 | 13.0 | 76.0 | 119.0 | 326.0 | 22.0 | 589.0 |
| 7 | 1996 | 138.0 | 60.0 | 150.0 | 58.0 | 14.0 | 420.0 |
| 8 | 1997 | 34.0 | 154.0 | 136.0 | 135.0 | 6.0 | 465.0 |
| 9 | 1998 | 13.0 | 48.0 | 42.0 | 78.0 | 17.0 | 198.0 |
| 10 | 1999 | 32.0 | 145.0 | 87.0 | 26.0 | 20.0 | 310.0 |
| 11 | 2000 | 8.0 | 83.0 | 50.0 | 135.0 | 0.0 | 276.0 |
| 12 | 2001 | 30.0 | 64.0 | 85.0 | 53.0 | 0.0 | 262.0 |
| 13 | 2002 | 15.0 | 84.0 | 60.0 | 82.0 | 53.0 | 294.0 |
| 14 | 2003 | 23.0 | 32.0 | 34.0 | 49.0 | 38.0 | 176.0 |
| 15 | 2004 | 10.0 | 24.0 | 22.0 | 77.0 | 28.0 | 161.0 |
| 16 | 2005 | 0.0 | 30.0 | 62.0 | 37.0 | 9.0 | 138.0 |
| 17 | 2006 | 85.0 | 75.0 | 48.0 | 103.0 | 0.0 | 311.0 |
| 18 | 2007 | 16.8 | 299.5 | 251.4 | 187.4 | 0.0 | 755.0 |
| 19 | 2008 | 130.2 | 334.3 | 258.7 | 109.1 | 0.0 | 853.4 |
| 20 | 2015 | 10.5 | 39.1 | 78.0 | 211.6 | 0.0 | 339.2 |
| Average | | 39.4 | 109.5 | 100.7 | 109.3 | 20.3 | 383.2 |

**Table 3:** Computation of runoff coefficient for June

| S.N. | Year | Rainfall in June (mm) | Runoff in June (mm) | Runoff coefficient | Runoff (% of Rainfall) |
|---|---|---|---|---|---|
| 1 | 1996 | 217.0 | 21.0 | 0.10 | 9.68 |
| 2 | 1991 | 199.0 | 25.0 | 0.13 | 12.56 |
| 3 | 1992 | 185.0 | 50.0 | 0.27 | 27.03 |
| 4 | 1993 | 81.0 | 16.0 | 0.20 | 19.75 |
| 5 | 1994 | 252.0 | 117.0 | 0.46 | 46.43 |
| 6 | 1995 | 99.0 | 13.0 | 0.13 | 13.13 |
| 7 | 1996 | 329.0 | 138.0 | 0.42 | 41.95 |
| 8 | 1997 | 163.0 | 34.0 | 0.21 | 20.86 |
| 9 | 1998 | 78.0 | 13.0 | 0.17 | 16.67 |
| 10 | 1999 | 392.0 | 32.0 | 0.08 | 8.16 |
| 11 | 2000 | 146.0 | 8.0 | 0.05 | 5.48 |
| 12 | 2001 | 343.0 | 30.0 | 0.09 | 8.75 |
| 13 | 2002 | 115.0 | 15.0 | 0.13 | 13.04 |
| 14 | 2003 | 184.0 | 23.0 | 0.13 | 12.50 |
| 15 | 2004 | 134.0 | 10.0 | 0.07 | 7.46 |
| 16 | 2005 | 67.0 | 0.0 | 0.00 | 0.00 |
| 17 | 2006 | 196.0 | 85.0 | 0.43 | 43.37 |
| 18 | 2007 | 114.9 | 16.8 | 0.15 | 14.64 |
| 19 | 2008 | 407.9 | 130.2 | 0.32 | 31.93 |
| 20 | 2015 | 92.0 | 10.5 | 0.11 | 11.43 |
| Average | | 189.7 | 39.4 | 0.18 | 18.24 |

**Table 4:** Computation of runoff coefficient for July

| S.N. | Year | Rainfall in July (mm) | Runoff in July (mm) | Runoff coefficient | Runoff (% of Rainfall) |
|---|---|---|---|---|---|
| 1 | 1996 | 473.0 | 219.0 | 0.46 | 46.30 |
| 2 | 1991 | 295.0 | 76.0 | 0.26 | 25.76 |
| 3 | 1992 | 164.0 | 57.0 | 0.35 | 34.76 |
| 4 | 1993 | 184.0 | 62.0 | 0.34 | 33.70 |
| 5 | 1994 | 494.0 | 228.0 | 0.46 | 46.15 |
| 6 | 1995 | 179.0 | 76.0 | 0.42 | 42.46 |
| 7 | 1996 | 197.0 | 60.0 | 0.30 | 30.46 |
| 8 | 1997 | 411.0 | 154.0 | 0.37 | 37.47 |
| 9 | 1998 | 152.0 | 48.0 | 0.32 | 31.58 |
| 10 | 1999 | 444.0 | 145.0 | 0.33 | 32.66 |

| | | | | | |
|---|---|---|---|---|---|
| 11 | 2000 | 390.0 | 83.0 | 0.21 | 21.28 |
| 12 | 2001 | 243.0 | 64.0 | 0.26 | 26.34 |
| 13 | 2002 | 290.0 | 84.0 | 0.29 | 28.97 |
| 14 | 2003 | 120.0 | 32.0 | 0.27 | 26.67 |
| 15 | 2004 | 122.0 | 24.0 | 0.20 | 19.67 |
| 16 | 2005 | 216.0 | 30.0 | 0.14 | 13.89 |
| 17 | 2006 | 457.0 | 75.0 | 0.16 | 16.41 |
| 18 | 2007 | 490.9 | 299.5 | 0.61 | 61.01 |
| 19 | 2008 | 355.3 | 334.3 | 0.94 | 94.09 |
| 20 | 2015 | 116.0 | 39.1 | 0.34 | 33.74 |
| Average | | 289.7 | 109.5 | 0.35 | 35.17 |

**Table 5:** Computation of runoff coefficient for August

| S.N. | Year | Rainfall in August (mm) | Runoff in August (mm) | Runoff coefficient | Runoff (% of Rainfall) |
|---|---|---|---|---|---|
| 1 | 1996 | 224.0 | 152.0 | 0.68 | 67.86 |
| 2 | 1991 | 344.0 | 112.0 | 0.33 | 32.56 |
| 3 | 1992 | 266.0 | 96.0 | 0.36 | 36.09 |
| 4 | 1993 | 152.0 | 50.0 | 0.33 | 32.89 |
| 5 | 1994 | 233.0 | 120.0 | 0.52 | 51.50 |
| 6 | 1995 | 192.0 | 119.0 | 0.62 | 61.98 |
| 7 | 1996 | 390.0 | 150.0 | 0.38 | 38.46 |
| 8 | 1997 | 394.0 | 136.0 | 0.35 | 34.52 |
| 9 | 1998 | 180.0 | 42.0 | 0.23 | 23.33 |
| 10 | 1999 | 338.0 | 87.0 | 0.26 | 25.74 |
| 11 | 2000 | 204.0 | 50.0 | 0.25 | 24.51 |
| 12 | 2001 | 204.0 | 85.0 | 0.42 | 41.67 |
| 13 | 2002 | 125.0 | 60.0 | 0.48 | 48.00 |
| 14 | 2003 | 118.0 | 34.0 | 0.29 | 28.81 |
| 15 | 2004 | 252.0 | 22.0 | 0.09 | 8.73 |
| 16 | 2005 | 248.0 | 62.0 | 0.25 | 25.00 |
| 17 | 2006 | 232.0 | 48.0 | 0.21 | 20.69 |
| 18 | 2007 | 507.1 | 251.4 | 0.50 | 49.57 |
| 19 | 2008 | 286.8 | 258.7 | 0.90 | 90.20 |
| 20 | 2015 | 145.0 | 78.0 | 0.54 | 53.79 |
| Average | | 251.7 | 100.7 | 0.40 | 39.80 |

**Table 6:** Computation of runoff coefficient for September

| S.N. | Year | Rainfall in Sept. (mm) | Runoff in Sept. (mm) | Runoff coefficient | Runoff (% of Rainfall) |
|---|---|---|---|---|---|
| 1 | 1996 | 196.0 | 88.0 | 0.45 | 44.90 |
| 2 | 1991 | 386.0 | 135.0 | 0.35 | 34.97 |
| 3 | 1992 | 48.0 | 28.0 | 0.58 | 58.33 |
| 4 | 1993 | 369.0 | 237.0 | 0.64 | 64.23 |
| 5 | 1994 | 69.0 | 30.0 | 0.43 | 43.48 |
| 6 | 1995 | 410.0 | 326.0 | 0.80 | 79.51 |
| 7 | 1996 | 109.0 | 58.0 | 0.53 | 53.21 |
| 8 | 1997 | 251.0 | 135.0 | 0.54 | 53.78 |
| 9 | 1998 | 230.0 | 78.0 | 0.34 | 33.91 |
| 10 | 1999 | 232.0 | 26.0 | 0.11 | 11.21 |
| 11 | 2000 | 340.0 | 135.0 | 0.40 | 39.71 |
| 12 | 2001 | 137.0 | 53.0 | 0.39 | 38.69 |
| 13 | 2002 | 154.0 | 82.0 | 0.53 | 53.25 |
| 14 | 2003 | 320.0 | 49.0 | 0.15 | 15.31 |
| 15 | 2004 | 264.0 | 77.0 | 0.29 | 29.17 |
| 16 | 2005 | 171.0 | 37.0 | 0.22 | 21.64 |
| 17 | 2006 | 259.0 | 103.0 | 0.40 | 39.77 |
| 18 | 2007 | 259.9 | 187.4 | 0.72 | 72.08 |
| 19 | 2008 | 154.0 | 109.1 | 0.71 | 70.87 |
| 20 | 2015 | 283.7 | 211.6 | 0.75 | 74.58 |
| Average | | 232.1 | 109.3 | 0.47 | 46.63 |

**Table 7:** Computation of runoff coefficient for October

| S.N. | Year | Rainfall in October (mm) | Runoff in October (mm) | Runoff coefficient | Runoff (% of Rainfall) |
|---|---|---|---|---|---|
| 1 | 1996 | 65.0 | 49.0 | 0.75 | 75.38 |
| 2 | 1991 | 17.0 | 3.0 | 0.18 | 17.65 |
| 3 | 1992 | 40.0 | 26.0 | 0.65 | 65.00 |
| 4 | 1993 | 32.0 | 15.0 | 0.47 | 46.88 |

| | | | | | |
|---|---|---|---|---|---|
| 5 | 1994 | 188.0 | 105.0 | 0.56 | 55.85 |
| 6 | 1995 | 55.0 | 22.0 | 0.40 | 40.00 |
| 7 | 1996 | 50.0 | 14.0 | 0.28 | 28.00 |
| 8 | 1997 | 15.0 | 6.0 | 0.40 | 40.00 |
| 9 | 1998 | 94.0 | 17.0 | 0.18 | 18.09 |
| 10 | 1999 | 92.0 | 20.0 | 0.22 | 21.74 |
| 11 | 2000 | 0.0 | 0.0 | 0.00 | 0.00 |
| 12 | 2001 | 0.0 | 0.0 | 0.00 | 0.00 |
| 13 | 2002 | 131.0 | 53.0 | 0.40 | 40.46 |
| 14 | 2003 | 98.0 | 38.0 | 0.39 | 38.78 |
| 15 | 2004 | 50.0 | 28.0 | 0.00 | 56.00 |
| 16 | 2005 | 26.0 | 9.0 | 0.00 | 34.62 |
| 17 | 2006 | 0.0 | 0.0 | 0.00 | 0.00 |
| 18 | 2007 | 0.0 | 0.0 | 0.00 | 0.00 |
| 19 | 2008 | 0.0 | 0.0 | 0.00 | 0.00 |
| 20 | 2015 | 0.0 | 0.0 | 0.00 | 0.00 |
| Average | | 47.7 | 20.3 | 0.24 | 28.92 |

**Table 8:** Computation of annual runoff coefficient

| S.N. | Year | Annual Rainfall (mm) | Annual Runoff (mm) | Runoff coefficient | Runoff (% of Rainfall) |
|---|---|---|---|---|---|
| 1 | 1996 | 1175.0 | 529.0 | 0.45 | 45.02 |
| 2 | 1991 | 1241.0 | 351.0 | 0.28 | 28.28 |
| 3 | 1992 | 665.0 | 257.0 | 0.39 | 38.65 |
| 4 | 1993 | 818.0 | 380.0 | 0.46 | 46.45 |
| 5 | 1994 | 1236.0 | 600.0 | 0.49 | 48.54 |
| 6 | 1995 | 902.0 | 589.0 | 0.65 | 65.30 |
| 7 | 1996 | 1038.0 | 420.0 | 0.40 | 40.46 |
| 8 | 1997 | 1234.0 | 465.0 | 0.38 | 37.68 |
| 9 | 1998 | 734.0 | 198.0 | 0.27 | 26.98 |
| 10 | 1999 | 1498.0 | 310.0 | 0.21 | 20.69 |
| 11 | 2000 | 1080.0 | 276.0 | 0.26 | 25.56 |
| 12 | 2001 | 927.0 | 262.0 | 0.28 | 28.26 |
| 13 | 2002 | 815.0 | 294.0 | 0.36 | 36.07 |
| 14 | 2003 | 840.0 | 176.0 | 0.21 | 20.95 |
| 15 | 2004 | 822.0 | 161.0 | 0.20 | 19.59 |
| 16 | 2005 | 728.0 | 138.0 | 0.19 | 18.96 |
| 17 | 2006 | 1144.0 | 311.0 | 0.27 | 27.19 |
| 18 | 2007 | 1372.8 | 755.0 | 0.55 | 55.00 |
| 19 | 2008 | 1183.0 | 853.4 | 0.72 | 72.14 |
| 20 | 2015 | 544.6 | 339.2 | 0.62 | 62.28 |
| Average | | 999.9 | 383.2 | 0.38 | 38.20 |

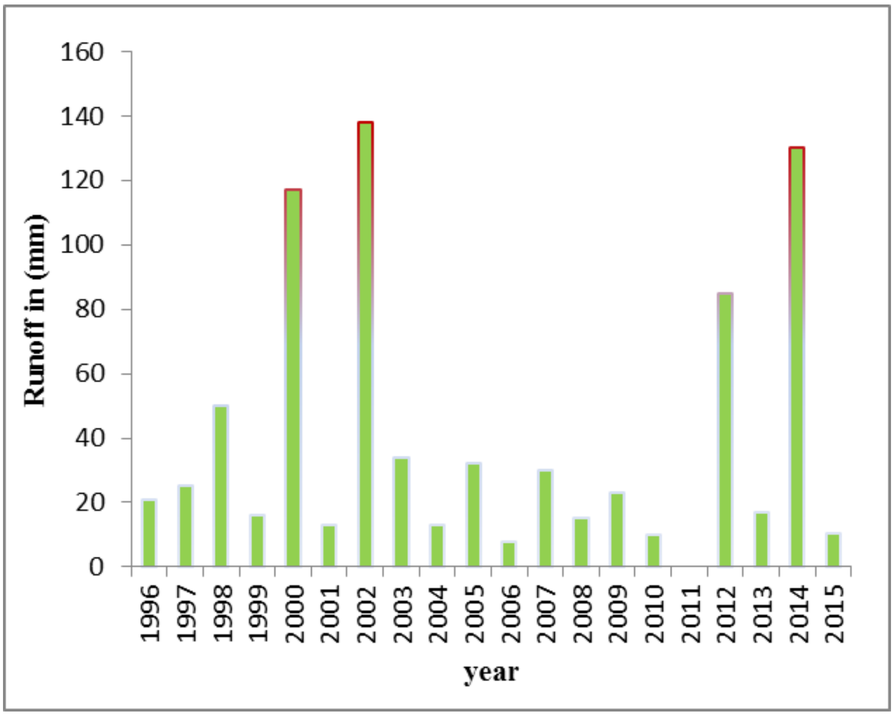

**Fig 1:** Annual variation of monthly runoff in June

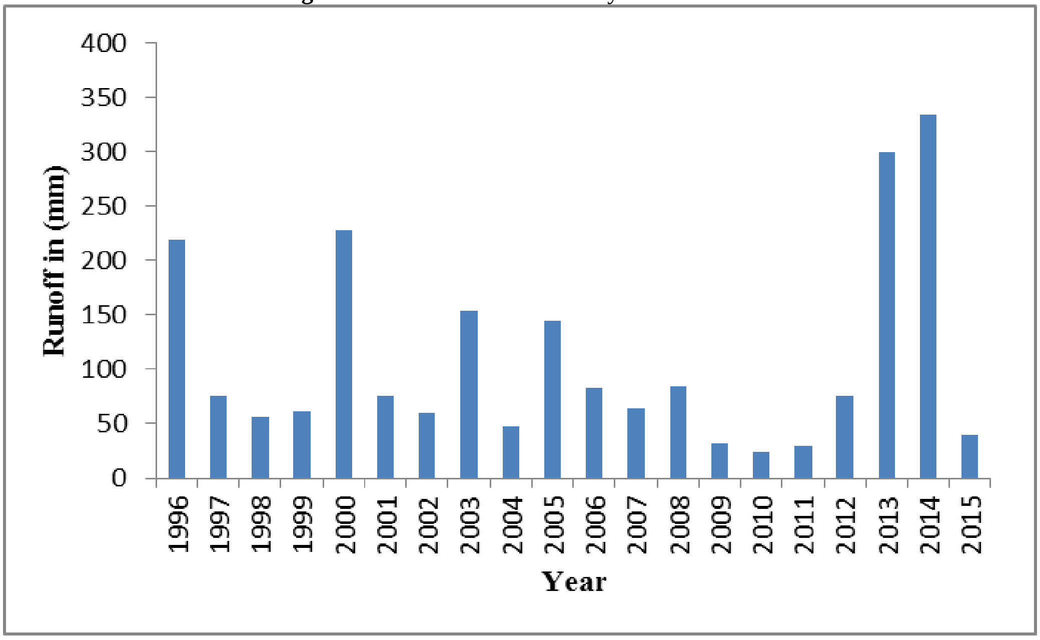


**Fig 2:** Annual variation of monthly runoff in July

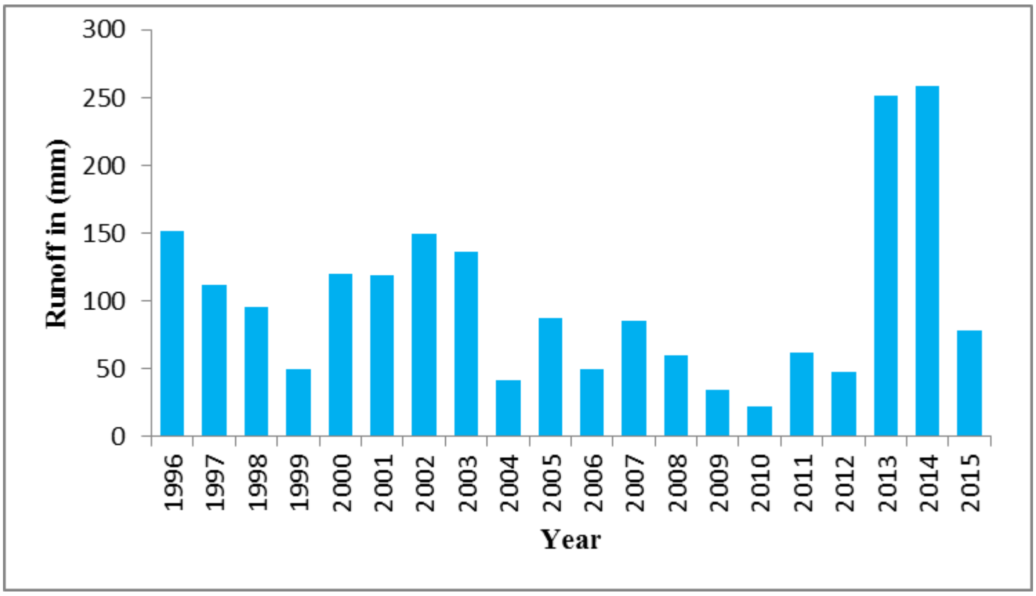


**Fig 3:** Annual variation of monthly runoff in August

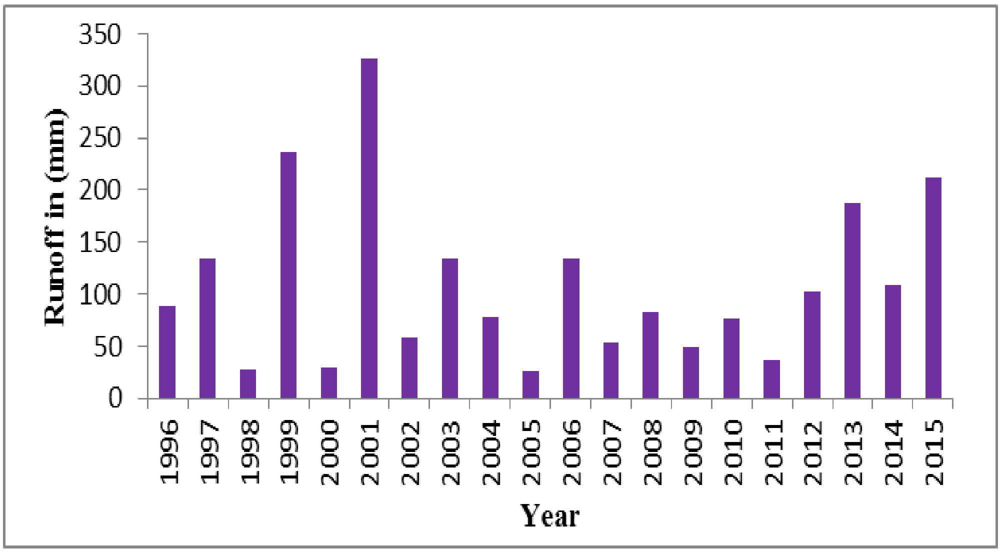


**Fig 4:** Annual variation of monthly runoff in September

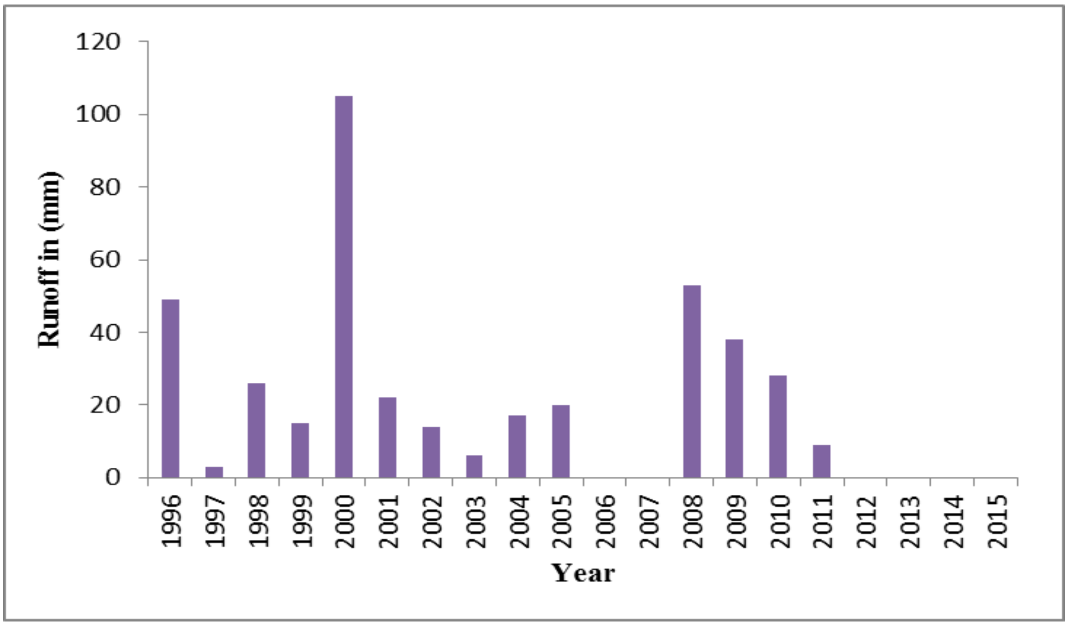


**Fig 5:** Annual variation of monthly runoff in October

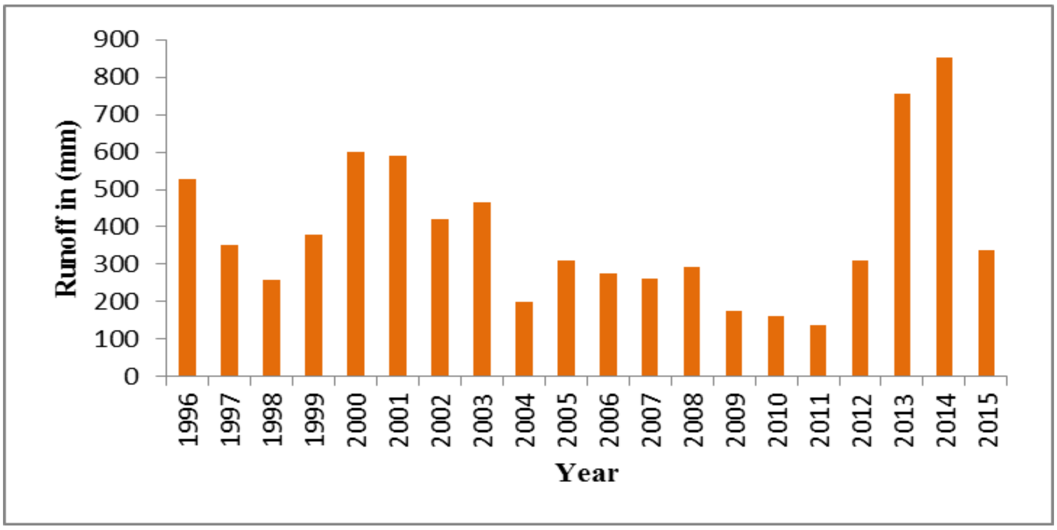


**Fig 6:** Annual variation of annual runoff

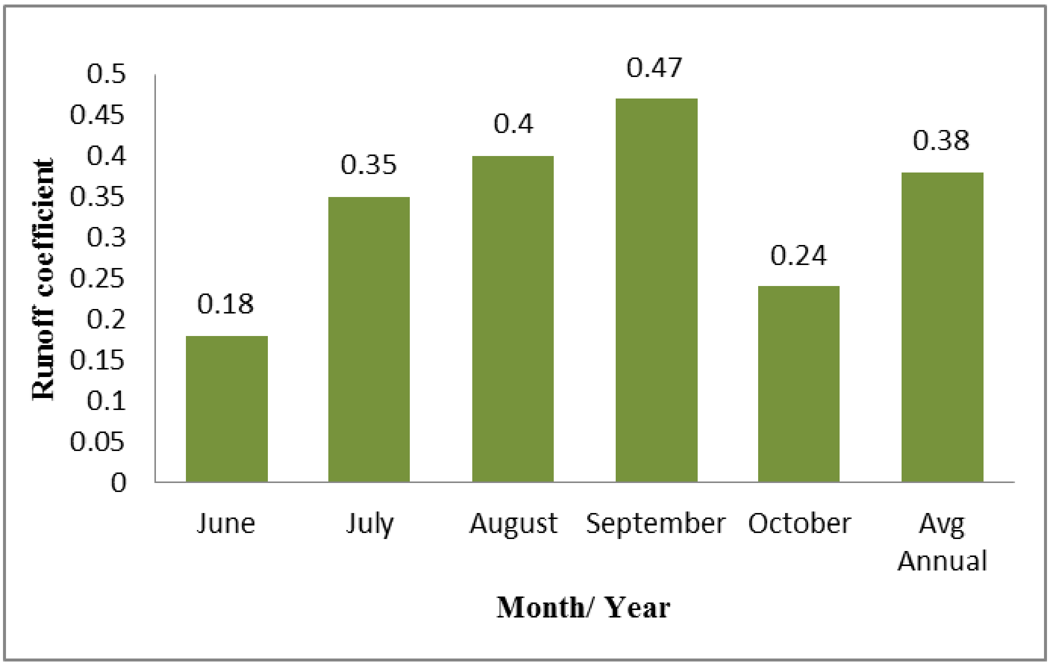


**Fig 7:** Average monthly and annual runoff coefficients

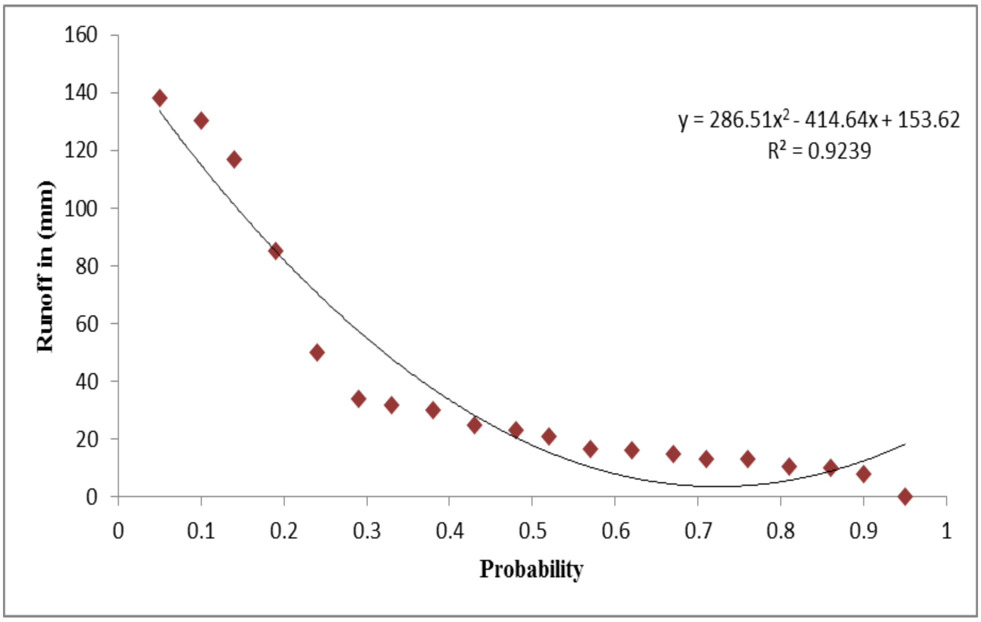


**Fig 8:** Plot of expected runoff in June versus probability.

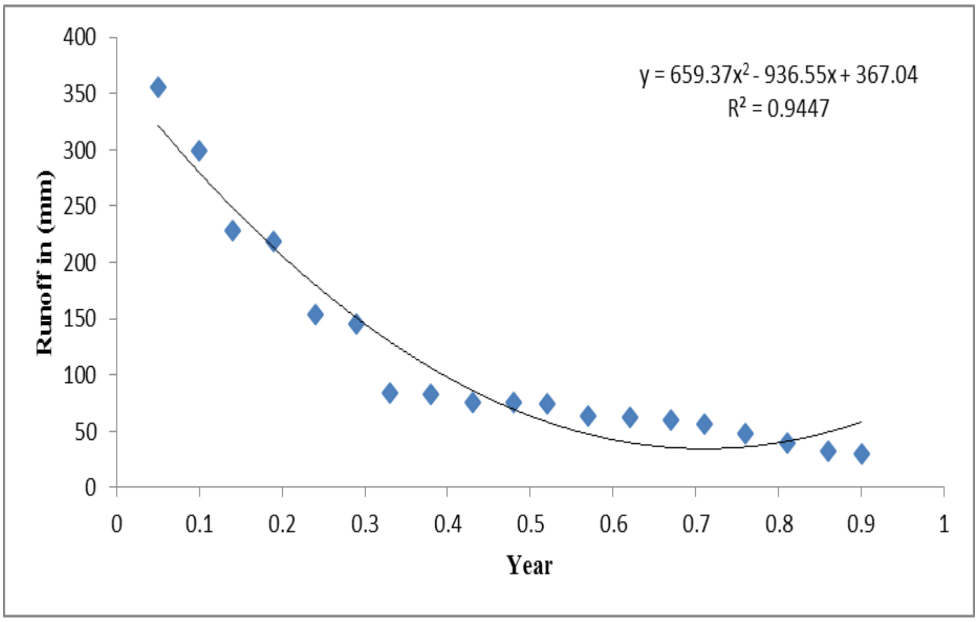


**Fig 9:** Plot of expected runoff in July versus probability

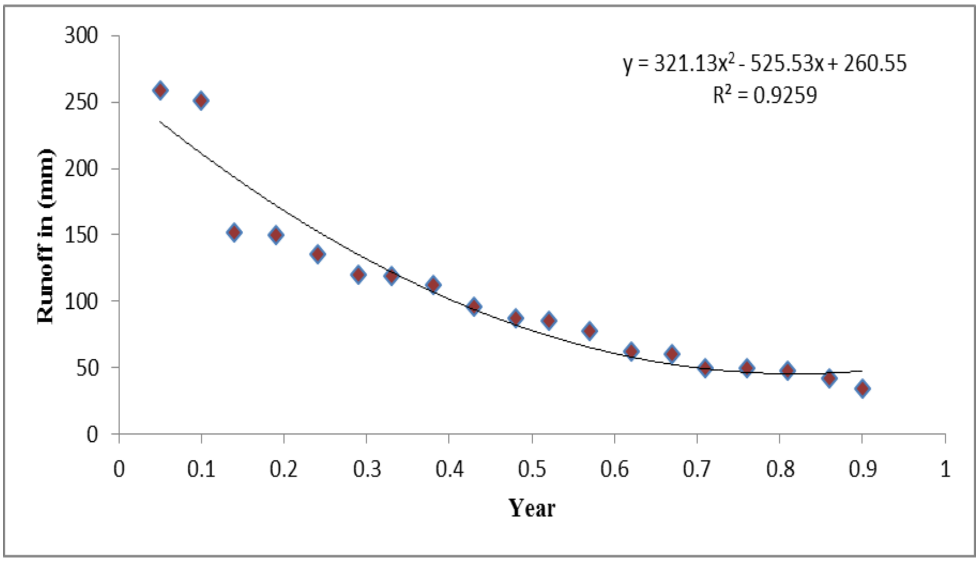


**Fig 10:** Plot of expected runoff in August versus probability

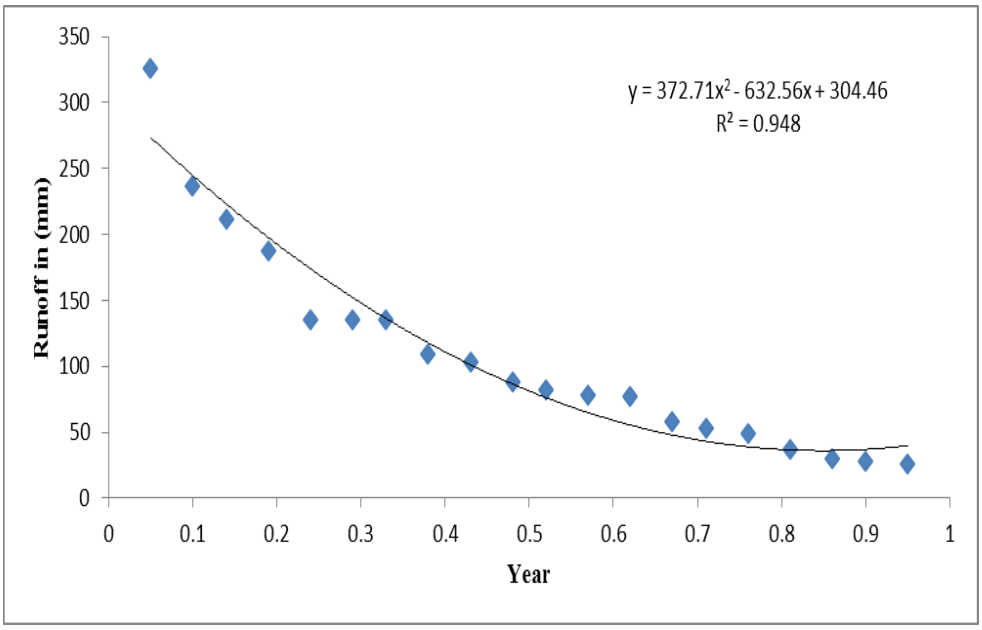


**Fig 11:** Plot of expected runoff in september versus probability

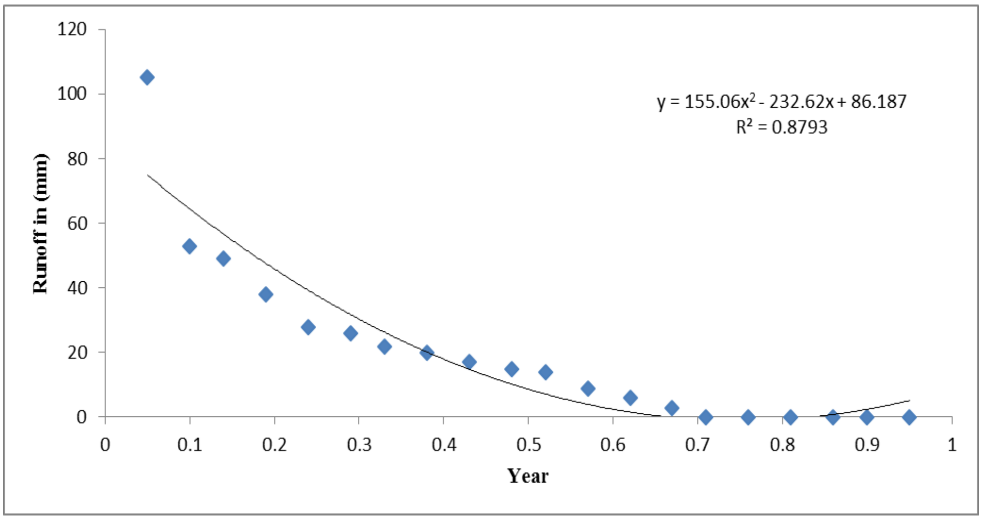


**Fig 12:** Plot of expected runoff in October versus probability

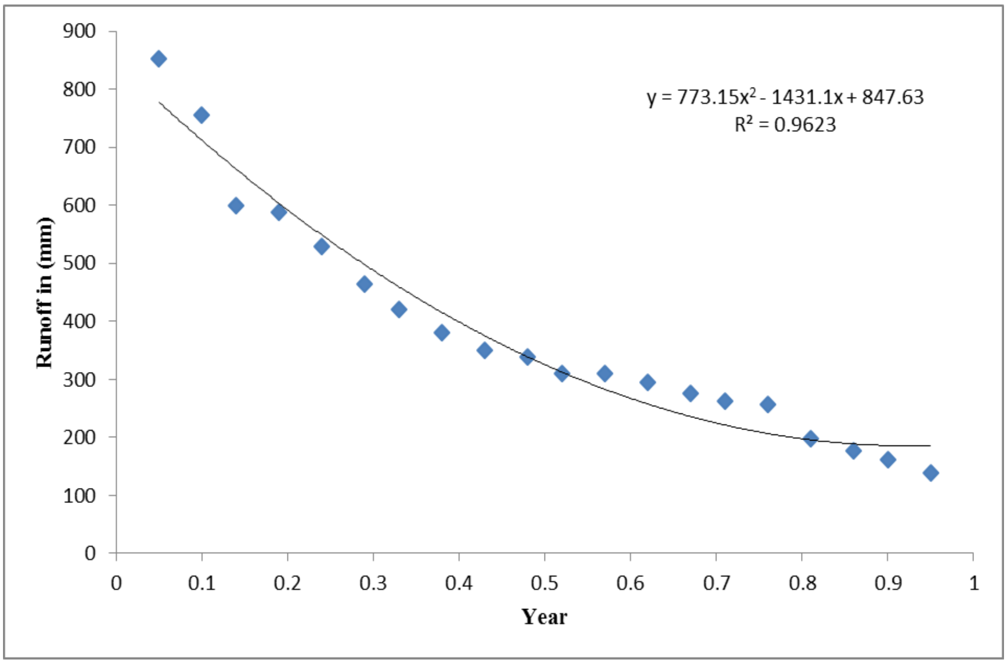


**Fig 13:** Plot of expected annual runoff versus probability

**Table 9:** Expected values of monthly and annual runoff at different probability levels

| Probability level | Runoff in June (mm) | Runoff in July (mm) | Runoff in Aug. (mm) | Runoff in Sept. (mm) | Runoff in Oct. (mm) | Annual Runoff (mm) |
|---|---|---|---|---|---|---|
| 0.50 | 18.1 | 66.5 | 79.7 | 81.4 | 8.7 | 325.4 |
| 0.60 | 8.1 | 43.2 | 61.2 | 59.2 | 2.5 | 267.6 |
| 0.75 | 3.8 | 30.3 | 43.9 | 39.8 | 0.0 | 209.6 |
| 0.90 | 12.2 | 43.7 | 39.1 | 36.9 | 0.0 | 186.2 |
| 0.95 | 17.9 | 54.0 | 40.3 | 39.6 | 0.0 | 186.1 |

**Summary and Conclusion**

The quantitative estimates of runoff volume and rates play an important role in the design of soil and water conservation measures and water harvesting structures. The runoff water may be harvested and can be used for various productive purposes such as domestic water supply, supplemental irrigation to the crops, livestock drinking and also for fish farming. Knowing the importance of the runoff, the present project work entitled “Analysis of runoff generating capacity of a small watershed” was undertaken with the main objectives to compute runoff coefficient for the selected Nagwan watershed and to predict monthly and annual runoff at different percent probability levels.

The rainfall-runoff data sets of selected watershed were collected from Engineering Department of Damodar Valley Corporation, Hazaribagh (Jharkhand, India) for the period of twenty years duration i.e. from 1996 to 2015.

To fulfill the objectives of the present study, the collected runoff data were analyzed on monthly and annual basis. Further, the probability and recurrence intervals for monthly and annual runoff were computed using Weibull’s method. Then, the expected monthly and annual runoff at different probability levels for the selected watershed were determined.

**Based on the above study, following conclusions are draw**

1. The average monthly runoff for June, July, August, September and October are39.4, 109.5,100.7, 109.3,20.3, and 383.2 respectively while average annual runoff for the selected watershed is 383.2 mm.
2. July month has the highest average runoff followed by September and August while October has the lowest value of average runoff.
3. Average runoff coefficients for June, July, August, September and October are computed to be 0.18, 0.35, 0.40, 0.47 and 0.24 respectively
4. September month has the highest value (0.47) of runoff coefficient while June has the lowest value (0.18).
5. July has higher value of runoff coefficient than June due to higher antecedent moisture present in soil.
6. The annual runoff coefficient for the watershed is 0.38.
7. At 50% probability level, the monthly runoff in September is maximum (= 81.4 mm) followed by August (79.7 mm), July (66.5 mm) and June (18.1 mm) while it is minimum in October (8.7 mm).
8. At 50% probability level, the expected annual runoff value is 325.4 mm.
9. At 75% probability level, the expected monthly runoff is maximum in August (= 43.9 mm) followed by September (39.8 mm) and July (30.3mm) while there is no chance of any runoff in October.
10. At 75% probability level, expected annual runoff is 209.6 mm.

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