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Rainfall-Runoff Relationship in Ungauged River Basin: A Case Study of Shivganga Catchment in Western Upland Maharashtra, India

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Abstract:- For all hydrologic analyses, a watershed constitutes the spatial unit, and all hydrologic problems are solved in the context of this spatial unit. There are number of indices, which can be defined to illustrate variability of hydrologic behavior such as rainfall, runoff, evaporation, infiltration, peak discharge, unit hydrograph, groundwater table and its fluctuation, movement to name but a few. An estimate of runoff volume from a drainage basin involves precipitation, infiltration, evaporation, transpiration, interception, depression storage, each of which is complex and can interact with the other variables to either enhance or reduce runoff. These variables are variously distributed within a drainage basin. The manner in which these variables interact in time and space makes a direct determination of runoff very difficult. Therefore we estimate runoff by using methods that reflects combined effect of the variables on an individual drainage basin. Because no two drainage basins are exactly alike, no two solutions can be exactly alike. The present chapter incorporates various methods used to estimate runoff in the Shivganga drainage basin. The results obtained by analyzing basin hydrological parameters such as rainfall, evaporation and infiltration have been presented in detail on the basis of field data and the data obtained from various government agencies and institutes.

Keywords:- *Discharge, Evaporation, Interception, Hydrology, Hydrograph, Runoff.*

I. INTRODUCTION

Runoff characteristics are influenced by soil type, slope, vegetation, and many other conditions. Generally, drainage basins behave differently based on these factors and runoff varies greatly between mountain and valley areas. Steep canyon walls and channel slopes rapidly concentrate storm runoff in mountainous areas. Runoff concentrates rapidly in hilly areas. Valley areas are affected by development. In highly developed valley areas, local runoff volumes increase as impervious materials replace the soil. Peak runoff rates for valley areas increase due to the elimination of natural ponding areas and improved hydraulic efficiency. Conveyances, such as streets and storm drain systems carry the water to the ocean more rapidly and do not allow infiltration. The spatial extent and pattern of runoff-contributing areas are affected by climate, soil, and terrain characteristics.

II. STUDY AREA

The drainage basin taken up for the present study is situated in southwestern part of Pune district, Maharashtra. Geographically it extends between 18° 13' north to 18° 24' north latitude and 73°45' east to 73°56' east longitude. Total geographical area of the basin is 131.25 km^2. The climate of the study area is tropical and semi-arid type.

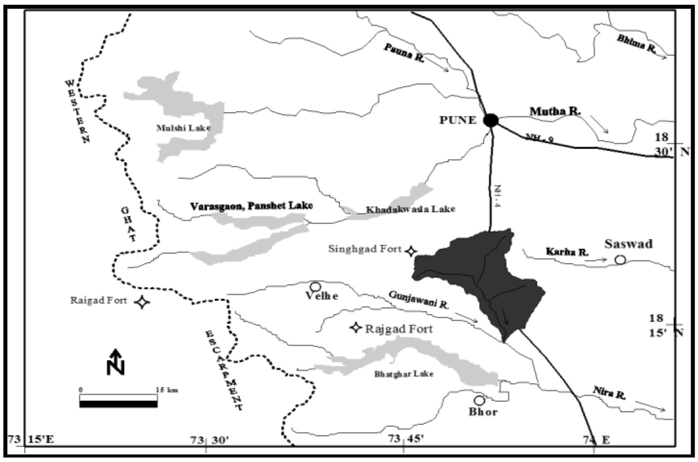

Fig 1:- Location Map of the Study Area

The basin receives about 600 mm of rainfall annually, about 90 percent of rain occurs during June to September. July and August are the rainiest months. This proportion of rainfall decreases towards the eastern part of the basin. July is the rainiest month throughout the basin, and accounts for 25% to 30% of the total annual rainfall. In absence of rainfall data from the Shivganga Basin, the mean areal rainfall figures have been estimated from the surrounding raingauge sites (Velhe, Bhor and Saswad). Since, the areal distance of these sites from the basin centre is 10 to 12km (fig.2).

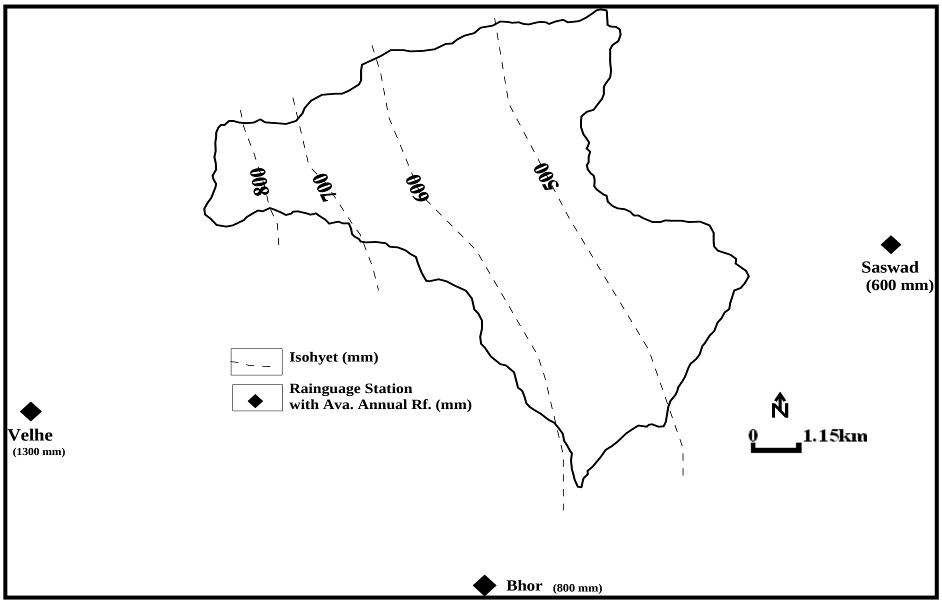

Fig 2:- Isohyetal Mean Areal Rainfall Distribution in Shivganga Basin and Location of Raingauge Stations (Source & modified: IMD, Pune)

Table 1 show annual total and 24 hour peak rainfalls in the respective wet years (1985-1999) for above raingauge stations, whereas table 2 shows the average annual rainfall for three raingauge stations of the surrounding area of the basin. These figures of average annual rainfall have been obtained from India Metrological Department, Pune.

Water Year	Raingauge Station					
	Bhor (South)		Saswad (East)		Velhe (SW)	
	ARF mm)	HRF (mm)	ARF (mm)	HRF (mm)	ARF (mm)	HRF (mm)
1985	856.5	83.0	374.8	33.6	1922.6	143.0
1986	956.8	59.6	399.5	45.0	3389.0	283.0
1987	1506	134	839.2	183.2	1888.0	139.0
1988	897.5	105	1134.3	149.0	2567.0	297.0
1989	787.2	79.0	965.8	100.7	2259.0	230.0
1990	1027.8	87.0	824.5	156.0	2904.0	215.0
1991	1352.7	148.0	475.0	35.0	2437.0	210.0
1992	1136.4	103.0	539.2	36.5	2391.3	178.0
1993	1754.2	401.0	678.5	80.2	2050.0	100.0
1994	1773.5	175.0	734.1	58.0	4131.0	345.0
1995	742.9	62.0	554.7	39.0	1906.0	124.0
1996	1177.1	68.0	854.0	155.0	2403.0	284.0
1997	1401.0	77.0	530.0	53.0	3345.0	184.0
1998	1186.0	81.0	773.0	65.6	2456.0	107.0
1999	1654.0	145.0	589.5	42.8	3324.4	256.0

Table 1:- Annual Total and 24 Hrs Peak Rainfall (mm) of Rain gauge Stations Surrounding to the Shivganga Basin

(Data source: IMD; Based on 15 years of Record,
ARF=Annual Rainfall Total in mm, Water Year =from 01 June to 31 May of Next Year)
HRF= 24 Hours heaviest total rainfall in mm,

Rain gauging Station	Location w. ref. to Basin (Distance in km)	Average Annual Rainfall (mm)
Bhor	South (10)	800
Saswad	East (10)	600
Velhe	Southwest (12)	1300

Table 2:- Average Annual Rainfall of Three Raingauge Stations

(Data source: IMD; Based on 15 years of Record),
See: Fig. 2 for location of stations.

Isohyetal method has been used to estimate rainfall yield of the Shivganga Basin. This method is more appropriate for computing mean areal rainfall in hilly and rugged topographical area (Suresh, 2005). As per IMD recommendations, in a region of average elevation (500 to 1000m ASL) and in hilly areas one raingauge station should be available for the area of 130 to 260 sq. km (Suresh, 2005). Isohyets have been drawn for Shivganga Basin on the basis of rainfall data available from surrounding stations. The mean areal rainfall for study area has been determined by measuring the area of successive Isohyets. Thus the mean areal rainfall values obtained for Shivganga Basin are shown in table 3.

Isohyets (mm)	Area Enclosed (Sq. km)	Rainfall Volume (Cu. M) (Area Enclosed X Mean Areal Rainfall)	Mean Areal Rainfall (mm)
	A	**B**	**C**
800	10.0	8000.0	**= Σ B / Σ A** **= 608.3**
700	36.0	25200.0	
600	40.0	24000.0	
500	45.0	22500.0	
Total	**131.0**	**79700.0**	

Table 3:- Mean Areal Rainfall by Isohyet Method
(Data source: IMD; Based on 15 years of Record)

Average areal rainfall computed from Isohyetal method is **608 mm. Fig. 2** shows the distribution of mean areal rainfall and location of three raingauge sites surrounding the basin. Main stream of the Shivganga River originates in the heavy rainfall zone, whereas Shindewadi and Degaon sub basins heads in the medium to low rainfall zone in the eastern part of the basin. The orographic effect of the Singhgad-Katraj hill range in the western part is responsible for enhancing the higher monsoon rainfall. In addition to this, the geographical location and the east-west orientation of the Shivganga Basin also determines the distribution of rainfall over the entire basin. Thus spatial variation of rainfall is controlled by orographic effect on one side and the east west orientation of basin on the other, which is reflected in the isohyetal pattern of the basin. The isohyetal pattern **(Fig. 2)** displays a marked spatial variation in the basin form west to east. The source areas of Kondhanpur, Kelawade sub basin receive more than 800 mm rainfall. The amount of rainfall gradually decreases towards east (Degaon, Shindewadi) i. e. less than 600 mm. However, in this part, the drainage area is very less. The area of lowest rainfall (<500 mm) is situated along the eastern divide margin of Karha-Saswad plateau The seasonal pattern is almost similar to the annual distribution of rainfall, since more than 90% of the annual rainfall is concentrated during the monsoon season.

- *Rainfall Frequency & Recurrence Interval*

Frequency of rainfall event of a specified period is expressed in terms of recurrence interval. Estimation of recurrence interval of extreme maximum or extreme minimum rainfall event is useful for watershed planning and development. The probability of these extreme rainfall events is most significant while designing hydraulic structures, implementing soil conservation practices etc. 24 hours peak rainfall values from three raingauge stations were used to estimate the recurrence interval, that is the time span after which an event of similar or greater magnitude of the observed event is likely to occur –

$T = 1/p$ …………. (Eq. 1 – IV)

Where, T is the recurrence interval in years, p is the plotting position of the event, which can be obtained by using following formula -

$p(\%) = m/n+1*100$ …………. (Eq. 2 – IV)

Where, **m** is the rank number of event after arranging rainfall data in descending order by their magnitude and **'n'** is the total number of years of record. This method is referred as Weibull's method (Singh, 1994). It is used to calculate the return periods of expected maximum rainfall for a specified recurrence interval. **Fig. 3** illustrates the plots of three sites namely Bhor, Saswad and Velhe and table 4 gives the recurrence intervals for different rainfall maxima of respective raingauge stations.

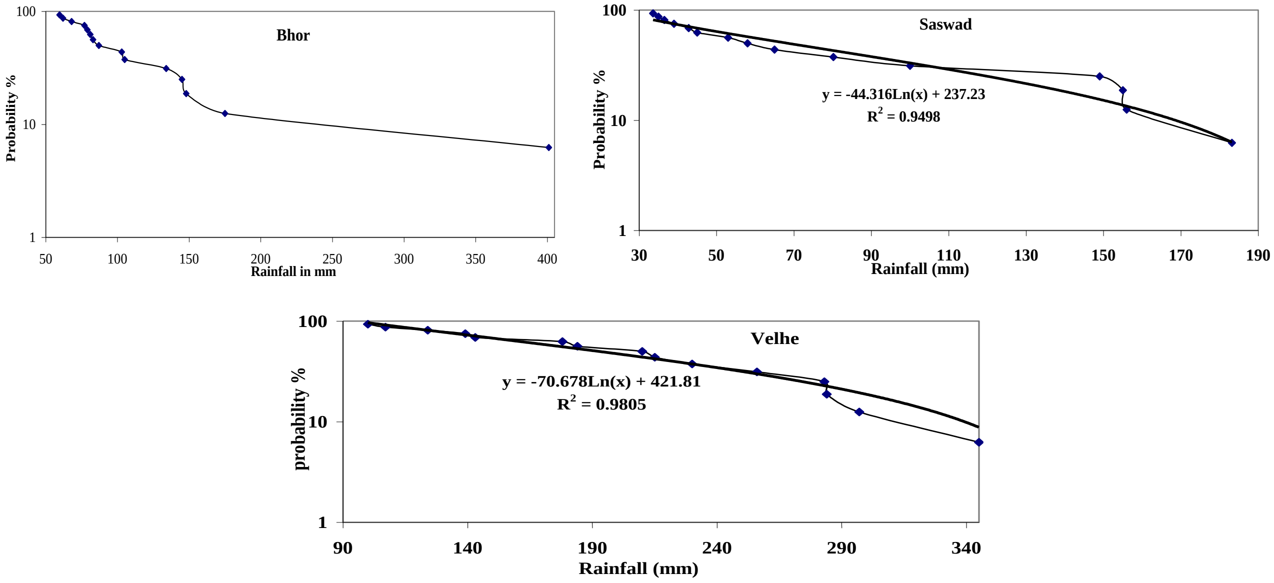

Fig 3:- Rainfall Frequency Curve for 24 Hours Peak Rainfall (Based on Rainfall Data Analysis)

Raingauge Station	Rainfall (mm)	Probability (%)	Recurrence Interval (T) Years
Bhor	400	06	16
	200	10	9
	150	25	2
	100	45	1
	50	94	1
Velhe	400	5	16
	150-250	50	2-3
	100-150	95	1
Saswad	180	5	16
	100	30	3
	30-40	90	1

Table 4:- Recurrence Interval for Different rainfall maxima at Three Stations (Source: Computed by Author)

III. RESULTS AND DISCUSSION

The result demonstrate that although the maximum 24-hr rainfall values are associated with storm events over the area surrounding to the Shivganga Basin, the upper reaches (Kalyan, Kondhanpur), the middle reaches (Shivapur, Khed), and lower reaches (Kelawade, Salwade, Nasrapur) has significant impact in the form of rainfall to have large flashy floods from the source to the confluence. At Bhor and Velhe stations, 5 to 6 percent probability of 400 mm rainfall in 24 hours has a recurrence interval of 16 years while the probability of 100mm or less rainfall occurs every year whether the rainfall is above or below normal. At Saswad station rainfall more than 100mm occurs once in three years. This clearly indicates that, Shindewadi and Degaon (eastern sub basins) has very low probability of 100mm rain as compare to Kondhanpur and Kelawade sub basins, which are having greater probability of 100 mm rainfall i.e. every year. This indicates that highest daily precipitation totals do not necessarily indicate the occurrence of highest runoff. Therefore, it is evident from the above discussion that though the magnitude of the 24-hr rainfall is more at particular station, it may not be always associated with producing large runoff. Hence, the analysis of the daily rainfall data reemphasizes the fact that high daily rainfall totals do not necessarily indicate the occurrence of flashy discharge or runoff in the Shivganga River, if the storm event is localized and is of a short-duration. Wet spells that are widespread, of a longer duration (2-3 day) are generally responsible for the high runoff.

Hydrologic Abstractions: Amount of precipitation, which does not appear as overland flow or runoff, is considered as hydrologic abstractions. Evaporation and infiltration are the most important abstractions in the hydrologic-budget equation. These abstractions are very small as compare to runoff event hence can be neglected. The bulk of evaporation takes place before runoff events is usually long. Whereas infiltration occurs or commences as soon as overland flow initiates. These losses have significant influence in the available volume of water in the basin. Therefore abstractions i. e. evaporation and infiltration losses must be considered in order to understand the total surface runoff generated from the rainfall.

Evaporation Loss: Evaporation is an important hydrologic loss that affects the hydrological output or runoff of a river basin. Evaporation over the entire drainage basin varies with season and is inversely related to rainfall. In order to know about evaporation losses of the Shivganga Basin, mean monthly pan evaporation data from Velhe station has been used, as the Shivganga Basin is situated in the vicinity to about of 12 km areal distance in the north having similar climatic conditions. Mean monthly average pan evaporation values for the year 2005 have been considered to obtain average annual evaporation for the entire area. Table 5 shows monthly pan evaporation values for the year 2005.

Month (Evaporation Year 2005)	Mean Monthly Evaporation (mm)
January	3.1
February	4.0
March	5.3
April	8.2
May	9.7
June	5.3
July	4.2
August	4.0
September	4.3
October	4.6
November	3.5
December	3.0

Table 5:- Mean Monthly Evaporation at Velhe
(Data Source: Tehsil Office, Velhe)

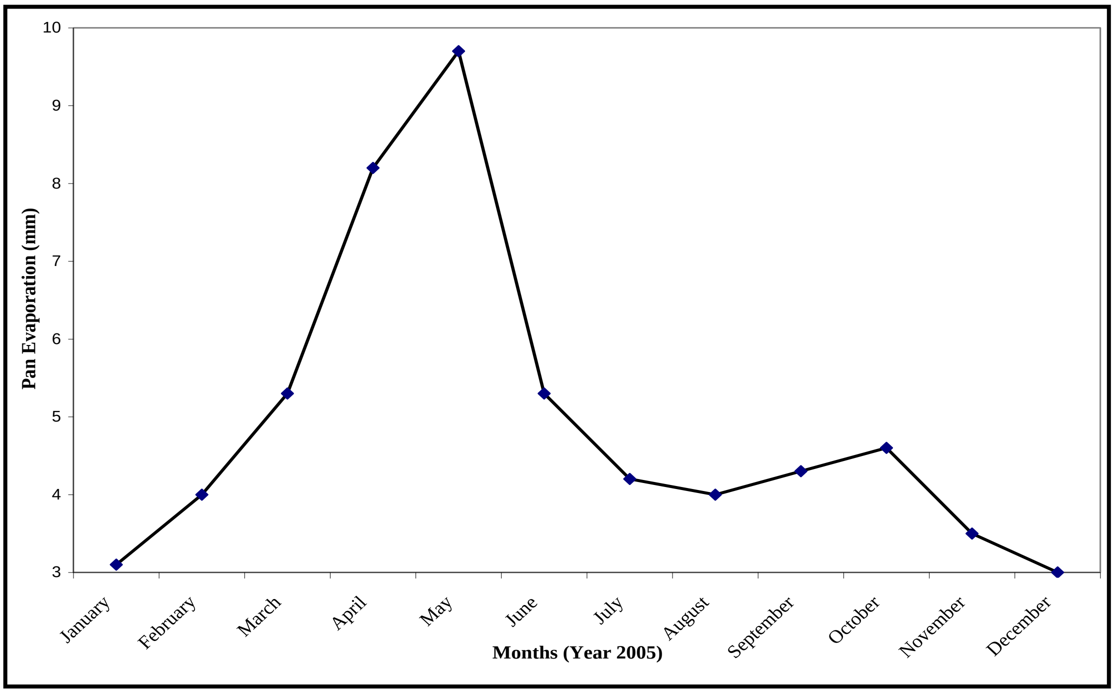

Fig 4:- Mean Monthly Evaporation (mm) in Shivganga Basin
(Source: IMD, Pune)

On the basis of above values, average daily pan evaporation of the Shivganga Basin comes fluctuates around **5.0mm per day**, and average annual evaporation is around 1800mm per year. **Fig 4** reveals that summer months experience higher evaporation losses because of high temperatures, and negligible rainfall. The graph also shows drastic reduction of evaporation during monsoon season (June to September) whereas in winter also declines after October maxima and gradual rise after January. As per the statistics with Groundwater Survey and Development Agency, Pune (Sarbukan, 2001) and, Pune Z. P. Village-Shivar Water Content Computation Chart (2003), nearly 40% of the total rainfall loss is due to evaporation and 15% infiltration loss enhances the groundwater storage. Considering these 55% losses, net 45% rainfall is available only for runoff.

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