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Studies on Rainfall-Runoff Relationship for Assessment of Rainwater Harvesting Potential under Marathwada Region

Ananya Mishra[1], M. S. Pendke[2], B. W. Bhuibhar[3], K. K. Dakhore[4], U. M. Khodke[5] and D. P. Waskar[6]
Vasantrao Naik Marathwada Agricultural University, Parbhani - 431 402 (India)
Corresponding Author : M. S. Pendke, Email : mspendke1@rediffmail.com

Abstract

The rainfall available in the watershed is key factor for determining the availability of water to fulfill the different demand mainly for agriculture, hydropower water supply, industry, etc. A watershed is that contributes runoff water to a common point Runoff is one of the important hydrologic variables used in most of the water resource applications. Runoff is the total surface flow from a given drainage area. Rainfall duration, intensity and aerial distribution influence the rate and volume of runoff. Watershed characteristics such as slope, shape and size, cover of soil and duration of rainfall have a direct effect on the peak flow and volume of runoff from any area (Chandler and Walker, 1998). Rainfall and runoff are significant constitute the sources of water for recharge of ground water in the watershed. Estimation of runoff in a watershed is very important to manage the water resources efficiently. Most of the part of the Marathwada region is comes under assured rainfall zone. The region receives mean annual rainfall of 880 mm. Rainfall in uncertain and erratic in this region and sometimes suffers from severe droughts. The rainfall data for Aurangabad, Parbhani and Nanded stations were collected from the Agro-meteorological station under VNMKV, Parbhani. Runoff was estimated using SCS curve number method considering the all parameters like soil type, vegetation etc. The rainfall runoff relationship was worked out for further planning of small water harvesting structures like farm ponds. The runoff potential for Aurangabad, Parbhani and Nanded station is found to be 20.07 %, 28.31 % and 31.69 % respectively, indicating a good scope for rainwater harvesting and thereby, many more rainwater harvesting structures can be constructed based on site specific conditions. A relation between rainfall and runoff for Aurangabad, Parbhani and Nanded stations were worked out as Y = 0.301X - 55.711 (R^2 value - 0.75), Y = 0.4043X - 88.882 (R^2 value - 0.8687) and Y = 0.6018X - 209.2 (R^2 value -0.9575) respectively. The linear rainfall-runoff relation obtained can be used for finding out runoff corresponding to any rainfall occurring in the area. The rainfall runoff relationship will be useful for determination of rainwater harvesting potential and its reuse for enhancing production potential of various rainfed crops.

Key words : Micro-catchment, Rainfall, Runoff.

Water resource has the prime concern for any future planning and development of water harvesting structures in watershed. The rainfall available in the watershed is key factor for determining the availability of water to fulfill the different demand mainly for agriculture. Rainfall and runoff are significant constitute for the sources of water. Evaluation of water availability by understanding of rainfall and runoff is essential. Global warming affects the rainfall change which influence the stream flow rate, hydrologic cycle, water demand (especially in agriculture) requires review in planning, design and management of hydraulic structures (Deasy Nalley,2012). Estimation of runoff in a watershed is very important to manage the water resources efficiently. Changes in run-off and its distribution will depend on likely future climate scenarios. Runoff in a watershed affected by geomorphological factors, particularly, land use change affects the runoff volume and the runoff rate significantly. Due to uneven distribution of rainfall and mismatch between demand and water availability requires large storage structures to control the natural

1. M. Tech. student, 2. Agril. Engineer, 3. Head, 4. Agrometeorologist, 5. Associate Dean and Principal, and 6. Director of Research.

flow according to the requirement of the region (S. Kundu, D. Khare *et al.*, 2015). A direct plotting of rainfall against runoff for individual storms produce a satisfactory correlation. The rainfall-runoff relation may be greatly enhanced by taking into account as parameters, some influencing factors such as storm frequency, condition of initial soil moisture, duration of storm and the year. Runoff is one of the important hydrologic variables used in most of the water resource applications. The amount of runoff from a given drainage area depends on many inter related factors. Watershed characteristics such as slope, shape and size, cover of soil and duration of rainfall have a direct effect on the peak flow and volume of runoff from any area (Chandler and Walker, 1998). Intensity of rainfall has dominating effect on the runoff yield.

Marathwada region of Maharashtra state, comprised of eight districts, lies between 17° 35' to 20° 40' N latitude and 74° 40' to 78° 16' E longitude. The altitude ranges between 300 to 900 m above mean sea level. The region experiences wide variability within and in between districts in respect of rainfall situation and also different soil type predominant in various parts of region. Occurrence of frequent droughts, unseasonal rains and hailstorms are the features of climate change in the region. Marathwada region of Maharashtra state is basically a rainfed area with average annual precipitation of 890 mm. Though the majority area falls under assured rainfall zone, it is characterized by 2-3 prolonged dry spells during crop growth period which resulted in variations in crop production and productivity and overall socioeconomic condition of farmers. The average productivity of all *kharif* crops varies depending of monsoon behavior.

Agro-climatically Marathwada region is divided into three zones. The Central Maharashtra plateau zone is the biggest one with assured rainfall pattern with Parts of Aurangabad, Beed, Jalna, Osmanabad, Latur, Nanded, Hingoli and Parbhani. Towards the western end, the parts of Aurangabad, Beed & Osmanabad come under the scarcity, whereas the north eastern part of the region i.e. Hingoli and Nanded has moderately high rainfall. The region receives annual rainfall in the range of 500 to 1100 mm and comes under assured rainfall zone (60%), moderately high rainfall zone (20%) and scarcity zone (20%). The soils in the region are deep black, medium black, coarse and shallow. The information on jurisdiction, rainfall pattern, soil and crops under various agro-climatic zones of Marathwada region is given as under;

Particulars	**Scarcity Zone**	**Assured Rainfall Zone**	**High rainfall zone)**
Jurisdiction	Aurangabad (7T) Beed (3T) Osmanabad (4T)	Aurangabad (3T) Jalna (3T) Beed (4T) Osmanabad (3T) Latur (4T) Parbhani (6T) Nanded (4T) Hingoli (2T)	Hingoli (3T) Nanded (5T)
Latitude longitude	74°.40' to 76°.20' 19°.40' to 20°.40'	76°.20' to 77°.30' 18°.20' to 20°.40'	77°.30' to 78°.16' 18°.20' to 19°.40'
Mean annual rainfall	500-700 mm	700-900 mm	900-1250 mm
Distribution of rainfall and soils	Bi-modal distribution of rain-June-Sept,monsoon & Oct-Dec, post monsoon Deep black (11%) Medium black (65%) Shallow/coarse textured (24%)	Bi-modal distribution of rain-June-Sept,monsoon & Oct-Dec, post monsoon Deep black (23%) Medium black (60%) Shallow/coarse textured (17%)	Bi-modal distribution of rain-June-Sept,monsoon & Oct-Dec, post monsoon Deep black (24%) Medium black (48%) Shallow/coarse textured (28%)
T = Taluka			

In the present case study, surface runoff was estimated for the three stations viz. Parbhani, Aurangabad and Nanded each from assured rainfall zone, rain scarcity zone and moderately high rainfall zone respectively for further planning of small rainwater harvesting structures.

Methodology

The daily rainfall data for the years 2011-2021 have been collected from Meteorological Observatory, All India Coordinated Research Project on Agro-Meteorology, VNMKV, Parbhani. The daily runoff for the each runoff producing rainfall event was estimated using SCS curve number method. The rainfall and runoff data was analyzed and grouped in as fortnightly manner.

The SCS curve number techniques is based on recharge capacity of the watershed. The recharge capacity was determined by antecedent moisture condition and by physical characteristics of the watershed. Antecedent moisture condition (AMC) was used as an index of watershed wetness. (Ponce and Hawkins 1996).

Three levels of AMC are used.

AMC I: Lowest runoff potential

AMC II: Average condition

AMC III: Highest runoff potential

The criteria of AMC as presented in Table 3.5.

Table 3.5 Rainfall limits for estimating antecedent moisture condition

Antecedent moisture condition	5-days total antecedent rainfall, mm		Runoff production condition
	Dormant season	Growing season	
AMC – I	< 12.7	< 35.6	Lowest runoff potential
AMC – II	12.7 to 27.9	35.6 to 53.5	Moderate runoff potential
AMC – III	> 27.9	> 53.3	Highest runoff potential

Hydrological Soil Group (HSG) plays an important role in runoff production from a particular land surface of watershed. Following are the four hydrological soils groups.

HSG-A : Low runoff potential, sandy or gravel soils, high infiltration rate

HSG-B : Moderately low runoff potential, moderately deep soils, well drained Moderately coarse textured soil with moderate infiltration rate.

HSG-C : Moderately high runoff potential soils, moderately clay soil with low infiltration rate

HSG-D : High runoff potential soils, deep clay, high swelling potential, low infiltration rate

The selection of curve numbers is based on various hydrologic soil cover, land use, treatment or cultivation practices, hydrological condition of the area and hydrological soil group.

The equation for Indian condition for black soil region for AMC II is as follow;

$$CN = \frac{25400}{54 + S} \quad \text{... (1)}$$

Where, S = Potential maximum retention, mm

Hence, the runoff depth was calculated using following formulae;

$$Q= \frac{(P- 0.3\ S)^2}{(P - 0.7\ S)} \quad \text{for AMC I} \quad \text{...(2)}$$

$$Q= \frac{(P- 0.1\ S)^2}{(P - 0.9\ S)} \quad \text{for AMC II and III} \quad \text{...(3)}$$

Where; Q = Depth of runoff, cm, P =

Precipitation, cm and S = Potential maximum retention, cm

Considering the available maps of land use/ land cover and hydrological soil group, the area of each class of land was worked out. Assigning the suitable curve numbers for respective land use and HSG to each area, the weighted curve number was determined and used in estimation of runoff potential.

Amutha and Porchelvan (2009), Bansode and Patil (2014), Bhura *et al*. (2015) and Mishra *et al.* (2005) used SCS curve number method for runoff estimation. Similar technique was used in this study for estimation of runoff potential.

Result and Discussion

Estimation of Cure Numbers : CN values were estimated based on hydrologic soil group, average slope of land and land use pattern of the area for the three stations *viz.*, Aurangabad, Parbhani and Nanded. The weighted values of curve numbers for three AMC condition were calculated as per USDA SCS-CN method and presented in Table 1.

The hydrologic soil group of Aurangabad was observed as 'C' with slope rage of 1-3 %. The weighted curve numbers for Aurangabad station was calculated as 71, 85 and 94 for AMC I, II and III respectively. The hydrologic soil group of Parbhani was observed as 'D' with slope rage of 0.5-3.5%. The weighted curve numbers for Parbhani station was calculated as 77, 89 and 95 for AMC I, II and III respectively. The hydrologic soil group of Nanded was observed as 'D' with slope rage of 0.5-4.0%. The weighted curve numbers for Nanded station was calculated as 79, 91 and 97 for AMC I, II and III respectively.

Table 1. Curve Numbers for Parbhani, Nanded and Aurangabad stations

Soil type	Aurangabad	Parbhani	Nanded
	Light to medium	**Medium to deep black**	**Medium to deep black**
Hydrological soil group	C	D	D
Slope range of land	1-3	0.5 to 3.5	0.5 to 4.0
AMC			
I	71	77	79
II	85	89	91
III	94	95	97

Estimation of runoff volume : From the rainfall data of last 11 years (2011-2021), the daily surface runoff was estimated and thereby, the yearly runoff was calculated for all the three stations *viz*, Aurangabad, Parbhani and Nanded. The average runoff of 11 years was calculated and also noticed the maximum runoff year.

The Year-wise rainfall, runoff and % runoff for Aurangabad station is presented in Table 2.

Data revealed that the average rainfall causing runoff for Aurangabad station was found to be 635.55 mm which generated mean runoff of 131 mm i.e. 20.07 per cent. The maximum rainfall which causes runoff was recorded as 1046.6 mm in the year 2020 which generated runoff of 314 mm i.e 30.42 per cent. This runoff potential information will be useful in planning of rainwater harvesting structures in the area.

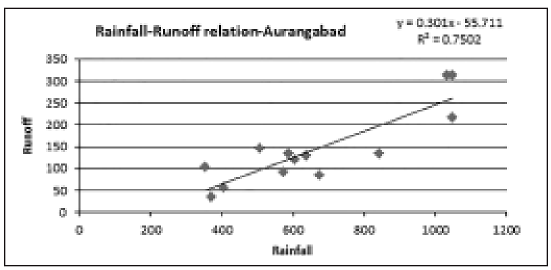

Fig. 1. Rainfall-runoff relationship for Aurangabad Station.

Table 2. Year-wise rainfall, runoff and % runoff for Aurangabad station

Year	Annual rainfall, mm	Total rainfall which contributes runoff, mm	Runoff, mm	% Runoff	Runoff coefficient
2011	589.2	586.2	135	23.02	0.230
2012	375.5	369.4	36	9.74	0.097
2013	736.4	673.9	86	12.76	0.127
2014	527.3	405.9	57	14.04	0.140
2015	595.3	505.1	147	29.10	0.291
2016	612.2	604.6	120	19.84	0.198
2017	576.3	573.7	92	16.03	0.163
2018	358.9	352.3	103	29.23	0.292
2019	881.2	841.3	134	15.92	0.159
2020	1061.2	1046.6	217	20.73	0.207
2021	1109.5	1032	314	30.42	0.304
Average	674.81	635.55	131	20.07	0.200
Maximum	1109.5	1046.6	314	30.42	0.304

Rainfall-runoff depth relation for Aurangabad station : The rainfall-runoff relationship for Aurangabad station is graphically represented in Fig. 1.

The relation obtained can be used for finding out runoff corresponding to any rainfall occurring in the area. For the study area, the relation was found to be linear. The relation obtained was Y = 0.301X – 55.711 and the R^2 value was 0.75.

The Year-wise rainfall, runoff and % runoff for Parbhani station is presented in Table 3.

Data revealed that the average rainfall causing runoff for Parbhani station was found to be 853.43 mm which generated mean runoff of 257 mm i.e. 28.31 per cent. The maximum rainfall which causes runoff was recorded as 1196.4 mm in the year 2020 which generated runoff of 385 mm i.e. 37.98 per cent.

Rainfall-runoff depth relation for Parbhani station : The rainfall-runoff relationship for Parbhani station is graphically represented in Fig. 2.

Table 3. Year-wise rainfall, runoff and % runoff for Parbhani station

Year	Annual rainfall, mm	Rainfall, mm	Runoff, mm	% Runoff	Runoff coeffi-cient
2011	677.5	636	164	25.78	0.339
2012	688.2	678	140	20.64	0.206
2013	1217.1	1134.4	345	30.41	0.304
2014	560.2	422.7	60	14.19	0.141
2015	574.8	414.1	70	16.90	0.169
2016	1159.5	1142.1	385	33.70	0.337
2017	995.7	987.2	375	37.98	0.379
2018	808.1	802.4	304	37.88	0.378
2019	968.6	950.8	299	31.44	0.314
2020	1098.7	1023.6	376	36.73	0.367
2021	1719.3	1196.4	309	25.82	0.258
Average	951.60	853.43	257	28.31	0.283
Maximum	1719.3	1196.4	385	37.98	0.378

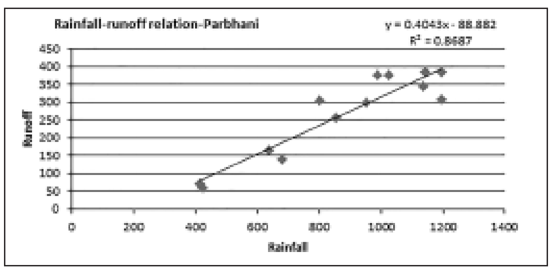

Fig. 2. Rainfall-runoff relationship for Parbhani Station

The relation obtained can be used for finding out runoff corresponding to any rainfall occurring in the area. For the study area, the relation was found to be linear. The relation obtained was Y = 0.4043X – 88.882 and the R^2 value was 0.8687

The Year-wise rainfall, runoff and % runoff for Nanded station is presented in Table 4.

Data revealed that the average rainfall causing runoff for Nanded station was found to be 816.81 mm which generated mean runoff of 280.78 mm i.e. 31.69 per cent. The maximum rainfall which causes runoff was recorded as 1230.3 mm in the year 2021 which generated runoff of 550 mm i.e. 44.7 per cent.

Table 4. Year-wise rainfall, runoff and % runoff for Nanded station

Year	Annual rainfall, mm	Rainfall,	Runoff,	% Runoff	Runoff coeffi-cient
2011	708.1	697.1	205.3	29.45	0.294
2012	662.7	662.7	122.2	18.43	0.184
2013	1111.9	1091.6	414.2	37.94	0.379
2014	436.5	434	99	22.81	0.228
2015	599	465.2	71	15.26	0.152
2016	1124.8	1094	479.7	43.84	0.438
2017	641.8	633.6	161.5	25.48	0.254
2018	799.5	749.8	272.8	36.38	0.363
2019	1027.1	1007.7	344	34.13	0.341
2020	924.7	918.9	368.9	40.14	0.401
2021	1293.4	1230.3	550	44.7	0.447
Average	848.13	816.81	280.78	31.69	0.316
Maximum	1293.4	1230.3	550	44.7	0.44

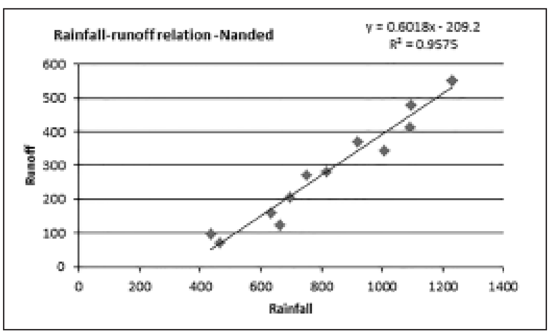

Fig. 3. Rainfall-runoff relationship for Nanded Station

Rainfall-runoff depth relation for Nanded station : The rainfall-runoff relationship for Nanded station is graphically represented in Fig. 3.

The relation obtained can be used for finding out runoff corresponding to any rainfall occurring in the area. For the study area, the relation was found to be linear. The relation obtained was Y = 0.6018X – 209.2 and the R^2 value was 0.9575.

Satheesh kumar *et al*. (2017) conducted study on rainfall–runoff estimation using SCS–CN and GIS approach in the Pappiredipatti watershed of the Vaniyar sub basin, South India and found simialr results. Similarly, Vinithra and Yeshodha (2013) used rainfall-runoff modelling using SCS-CN method as a case study of Krishnagiri district, Tamilnadu and found similar results which confirms with results of the current study.

Conclusion

Rainwater harvesting appears to be one of the most promising alternatives for the escalating demand of fresh water for rainfed agriculture. Hydrological analysis is the basic criteria for design of any rainwater harvesting structure. Rainfall-runoff relationship proved to be the most valuable information for identification of runoff potential at any station. Similarly, SCS curve number method also proved to be the most appropriate method for estimating runoff. Following conclusions were drawn from the current study.

1. The runoff potential for Aurangabad, Parbhani and Nanded station is found to be 20.07%, 28.31% and 31.69% respectively, indicating a good scope for rainwater

harvesting and thereby, many more rainwater harvesting structures can be constructed based on site specific conditions.

2. A relation between rainfall and runoff for Aurangabad, Parbhani and Nanded stations were worked out as Y = 0.301X – 55.711 (R^2 value - 0.75), Y = 0.4043X – 88.882 (R^2 value - 0.8687) and Y = 0.6018X – 209.2 (R^2 value -0.9575) respectively.

3. The linear rainfall-runoff relation obtained can be used for finding out runoff corresponding to any rainfall occurring in the area.

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