Rainfall analysis and design of water harvesting structure in water scarce Himalayan hilly regions

Sangita Mishra S.
Assistant Professor, Saraswati College of Engineering, Mumbai University,
Sector-5, Kharghar-410210, Navi Mumbai, Maharashtra, India
dr.sushreemishra80@gmail.com
doi: 10.6088/ijcser.2014050003

ABSTRACT

Irregular rainfall pattern and high surface runoff are the main reasons of water scarcity and subsequent drought conditions in Himalayan hilly regions. Hence in this study, an attempt was made to assess the water scarcity in these regions through rainfall and runoff analysis. The Henval watershed, covering an area of 6608 ha (66.08 km$^2$) and lies between 78°15’ to 78°25’ E longitude and 30°20’ to 30°30’ N latitude at an elevation that varies from 1200 to 2760 m above (MSL) was taken up for this study. The rainfall in the study area starts during May and lasts upto November. It was noticed that the uniformity of rainfall was pronounced from 23$^{rd}$ to 37$^{th}$ week (4$^{th}$ June to 10$^{th}$ September), whereas during the other weeks rainfall distribution was poor and erratic. Analysis of surface runoff by SCS CN model indicated that a considerable portion of precipitation flows off the watershed as runoff resulting in water scarcity and the main reason of agricultural drought in the watershed. Hence, there is a great need of storage of the water from runoff for future needs to avoid drought. Farm ponds can be used for storing water during rainy season as in hilly watersheds, they are found to be economical. As the study area is rainfed, a number of farm ponds can be constructed in higher order drainage networks of the area for water storage.

Keywords: Himalayan hills, rainfall analysis, SCS model, water harvesting structure, Henval watershed.

1. Introduction

In hilly areas, the climate is kaleidoscopic, composed of myriad individual segments continually changing through space and time. Great environmental contrasts occur within short distances as a result of the diverse topography and highly variable nature of the energy and moisture fluxes within the system. As a result, higher elevations experience higher temperatures. Higher temperatures would increase evaporation from streams and reservoirs, soil dryness and the needs of crops and other plants for supplemental water. Due to the unavailability of adequate supplemental water, drought is a prominent feature of hilly agrarians.

In the Himalayan mountains, “naula” (1-2 m deep, approximately lined wells to get water from seepage) and "dhara" (springs) are the main sources of water for drinking and household consumption. Deforestation, grazing and trampling by livestock, erosion of top fertile soil, forest fires and development activities (e.g. roadwidening, mining, building construction, etc.) reduces the infiltration rate and sponge action of the land, which results in unchecked flow of water during the monsoon to cause sudden swelling of streams and rivers, so that there are floods in the foothills and even in the plains, and droughts in the villages located on the slope of the mountains. The difficulty to reach the nature of hilly areas possesses serious
limitation on ground observation. Field experimentation and information collection to develop planning activities for proper planning and management of water resources is therefore necessary.

Several studies had been carried out regarding the nature of monsoon, the behavior of rainfall and the water harvesting practices of the hilly regions. Mittal and Sharma (1998) proposed watershed management plans in Shivalik foothills to avoid drought situations. The technology of rainwater harvesting and utilization of rain water for supplemental irrigation proved most promising for the region. Singh et al. (2004) carried out a research in Doon Valley, situated in the sub-mountainous lower hill regions of Himalayas. The study revealed that in high rainfall areas, on an average runoff of 16% of monsoon rainfall can be expected from agricultural treated watersheds. A farm pond of capacity 2 ha-m was suggested for a catchment of 10-12 ha. These studies give a picture of the climatic variations, rainfall, runoff and the methods for harvesting water from runoff in watersheds in Himalayan low hills. More work can be done on the drought analysis at Himalayan mid hills and high hills based on the cropping sequences or cropping pattern and on conservation of water by different methods. Keeping this in view, the present study was conducted to study the topography, soil conditions, land use pattern, soil characteristics, and rainfall behavior for analysis of drought in a hilly watershed. The main objectives of this research work were to analyze of rainfall pattern, rainfall behavior and surface runoff in the watershed and to design a suitable water harvesting structure in suitable areas of watershed.

2. Study area

Watershed that drains into Henval river, tributary of Bhagirathi river, covering an area of 6608 ha (66.08 km²) and lies between 78⁰ 15’ to 78⁰ 25’ E longitude and 30⁰ 20’ to 30⁰ 30’ N latitude at an elevation that varies from 1200 to 2760 m above (MSL) has been taken up for this study. It is located near Chamba - Ranichauri, on Rishikesh - Uttarkashi route, in Tehri Garhwal district of Uttarakhand (Figure 1).

The climate of this region is generally humid temperate but observed variations are attributed to physiographic aspects such as altitude, aspect, slope, drainage condition, vegetation etc. The valleys are hot in summer and cold in winter. The average temperature in this area varied from 3°C to 30°C. The average yearly rainfall varies from 1200 to 1400 mm. About 70 to 80% is received during June and September. The relative humidity measured daily at 8.30 hrs varied from 60 to 70 per cent in the northern hills and 30 to 40 percent in the south-western dry areas.

Dense and mixed forests are predominant in the study area followed by agricultural land. Dense forest was observed mainly in northern aspects (north, north-east, north-west) and higher altitude (above 1500m). Main composition of dense forest, located in north side of study area, was pine, deodar, and oak whereas, eastern side was surhi dominated, which was planted by forest department.

The drainage network of the study area is well developed and dendritic to semi-dendritic in nature. But streams of the area are seasonal in nature and remain dry in non-rainy seasons. Small amount of water is only available in the downstream portion of the main stream. The soils of this region are derived from metamorphic rocks such as biotite- schist and phyllite. They are brown to greyish brown and dark grey in color, besides being non-calcareous and neutral to slightly acidic in reaction. The texture of soil is sandy loam (water holding capacity...
is approximately 2.5 to 3.8 cm) to loamy sand (water holding capacity is approximately 1.27 to 2.54 cm).

According to survey conducted at Henval watershed, it was found that there were more than 8 different types of crops grown, out of which maximum area was under wheat. In mid hills (1200m-1700m), crops like ragi, rainfed rice, wheat, citrus, peach, plum, potato etc. were cultivated in south aspect and in north aspect, ragi, tomato, peach, plum, apricot, apple etc. were being cultivated. In high hills (1700m-2500m) amaranth, ragi, French bean, peas, cabbage, potato, apple, apricot, pea, walnut etc. were being cultivated. In very high hills (>2500m), buckwheat, peas, cabbage, potato, apple and apricot were practiced, where soil erosion is a major problem.

3. Methodology

3.1 Rainfall analysis

Rainfall is an important factor that decides the severity of drought in a particular region. The schedule of irrigation of a crop in a rainfed farming region is also decided by the pattern of rainfall in a season. Water conservation techniques such as rain water harvesting, rainfall cistern system etc. are all rainfall dependent. Hence, the rainfall data were collected for a period of 22 years (1985 to 2006) from Agrometeorological Observatory, College of Forestry, Hill Campus, Ranichauri, which was nearest to the study area (Henval watershed). The data were analyzed for their yearly, monthly and weekly behavior. Accordingly, the daily rainfall data were arranged in years, months and standard meteorological weeks and the averages of the same were worked out for weekly rainfall.
3.2 Runoff analysis

The rainfall runoff relationship is important for implying techniques like water harvesting. Runoff is that part of precipitation which traverses over surface/subsurface after compensation for various losses. Runoff potential and peak rate of runoff for Henval watershed was carried out using SCS CN method in this study. The curve number method required individual storm rainfall, land use type, hydrologic soil group and antecedent moisture condition of watershed as input. In this method, the potential maximum retention storage of watershed was related to a discrete number called curve number which was a function of land use, different land treatments, and antecedent moisture condition and soil type of watershed. Curve number is dimensionless and its value varies from 0 to 100.

3.3 SCS curve number method

This method was applied to the Henval watershed. As the rainfall data were available for daily rainfall occurring in a calendar year, SCS curve number method was used to estimate runoff for individual storms in a 24 hr period.

Dhruva Narayan (1993) presented following formulae to calculate runoff for different regions of India.

\[ Q = \frac{(P - 0.35S)^2}{(P + 0.7S)} \text{ for all regions} \] ........................ (1)

and

\[ Q = \frac{(P - 0.15S)^2}{(P + 0.9S)} \text{ for black soil region} \] ........................ (2)

The retention parameter \( S \) is determined based on antecedent moisture condition (AMC) and given by the following relationship (USDA, SCS, 1972).

\[ S = \left( \frac{25400}{CN} \right) - 254 \] ................................. (3)

3.3 Estimation of water demand

The reference evapo-transpiration \( (ET_o) \) was estimated by using the FAO Penman-Monteith (1998) method from the available data of temperature, relative humidity, wind speed and sunshine hours. It was a method with likelihood of correctly predicting \( ET_o \) in a wide range of location and climates and had provision for application in situations where limited data were available. A particular form of Penman-Monteith equation known as FAO Penman-Monteith equation had been used to estimate daily \( ET_o \). The final form of the FAO Penman-Monteith equation was as given below,

\[ ET_o = \frac{0.408 \Delta (R_n - G) + \gamma \frac{900}{T + 273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34 u_2)} \] ..........................(4)

where \( ET_o = \text{reference evapo-transpiration} \text{ (mm day}^{-1}\text{)} \)
Rainfall analysis and design of water harvesting structure in water scarce Himalayan hilly regions

Sangita Mishra S.

\[ \Delta = \text{slope of saturation vapour pressure curve (kPa}^0\text{C}^{-1}) \]
\[ R_n = \text{net radiation (MJ m}^2\text{ day}^{-1}) \]
\[ G = \text{soil heat flux density (MJ m}^2\text{ day}^{-1}) \]
\[ \gamma = \text{psychometric constant (kPa}^0\text{C}^{-1}) \]
\[ T = \text{mean daily air temperature (}^0\text{C}) \]
\[ e_s = \text{saturation vapour pressure (kPa)} \]
\[ e_a = \text{actual vapour pressure (kPa), and} \]
\[ u_2 = \text{average daily wind speed at 2 m height (m sec}^{-1}) \]

Calculation of ET\(_o\) using equation 4 on daily basis required meteorological data consisting of maximum and minimum daily air temperatures (\(T_{max}\) and \(T_{min}\)), mean daily actual vapor pressure (\(e_a\)) derived from dew point temperature or relative humidity (\(R_h1\) and \(R_h2\)) data, daily average of 24 hours of wind speed measured at 2m height (\(u_2\)), net radiation (\(R_n\)) measured or computed from solar and long wave radiation or the actual duration of sunshine hours (\(n\)). The extra terrestrial radiation (\(R_n\)) and day light hours (\(n\)) for a specific day of the month was also computed. As the magnitude of soil heat flux (\(G\)) beneath the reference grass surface was relatively small, it was ignored for daily time stake.

3.4 Estimation of crop Evapo-transpiration

The crop evapo-transpiration was worked out by multiplying the reference evapo-transpiration (ET\(_o\)) values by the crop coefficients.

\[ ET_{\text{crop}} = K_e \times ET_o \]

Where
\[ ET_{\text{crop}} = \text{crop evapo-transpiration} \]
\[ K_e = \text{crop coefficients} \]
\[ ET_o = \text{reference evapo-transpiration} \]

The crop coefficients were considered weekly. For each week, for different crops the weighted value of the crop coefficients was used. It was weighted with the respective area under the particular crop. Length of crop growth stages and crop coefficient values were taken from (FAO, 1977)

3.5 Estimation of effective rainfall

The total incident rainfall was not used for analysis. To account for losses due to surface runoff and deep percolation, the effective rainfall was used. The effective rainfall (also called as dependable rainfall) was taken as 70% of the actual rainfall.

3.6 Estimation of water demand

The total water demand was then calculated by using the values of crop evapo-transpiration and effective rainfall. Thus the final demand estimated as:

\[ \text{Net water demand} = \text{Crop evapo-transpiration} – \text{Effective rainfall} \]
3.7 Design of water harvesting structure depending on water demand

Different water harvesting structures viz. tied ridging or basin listing (formation of small basin) had been used at many places and found to be very effective in conserving rainwater in soil profiles and in increasing crop yields (Ahn, 1977 and Haney, 1978) in Himalayan hills. The objective of basin listing was to hold rainfall in a place where it falls until it infiltrates into the soil. This method facilitated the conservation of moisture when rainfall was low. When precipitation was very heavy, the excess water could be drained away by breaking the cross-ties when found necessary. Tied ridging had been found beneficial for moisture conservation and in increasing yield of cotton (Rao and Ramachandran, 1974). But, these rainwater conservation practices are in less use because of slowness of operations, difficulties in weed control tillage and above all, its high cost.

To overcome this problem, the dugout pond (farm pond) was considered as the water harvesting structure in this study because it is economical. The design of dugout pond for supplemental irrigation envisaged the determination of specification for the following: storage capacity, shape, dimensions (depth, side slope, bottom width and top width) and outlet.

3.8 Storage capacity

The storage capacity depending on the water demand worked out as above was considered for the design of the harvesting structure. Provisions have to be made to account for the loss in storage capacity due to silting, evaporation and percolation losses. Pond capacity has been increased by 5 per cent to account for different losses.

\[ V = B \times L \times D \]  

Where 
\[ V = \text{design storage capacity of the pond,} \]
\[ B = \text{width of the pond,} \]
\[ L = \text{length of the pond, and} \]
\[ D = \text{average depth of pond} \]

3.9 Shape

Shape of pond depends upon topography, available space, geology, digging equipment and economy. Excavated ponds are of three types according to their shape: square, rectangular or circular. Rectangular ponds have the geometrical advantage, in that they have the highest storage capacity and least circumferential length for a given surface area and side slope. Curve shape for circular pond offer difficulties in their construction. Hence either square or rectangular ponds were suggested. Rectangular ponds were considered with 1:2 ratios of width and length.

3.10 Dimensions of water harvesting structure

Depth (D): For the same volume of water stored, deeper the pond, lesser is the area occupied by the tank and also lesser are evaporation losses. However, with increased depth, the seepage loss also increased. When construction is done with human labour, any increase in
depth beyond 2.5 to 3 m becomes uneconomical since the cost increases out of proportion to the volume of excavation. It also becomes uneconomical and difficult for lifting devices operated with human and animal power. For rectangular cross-section structure, the width (B) of the pond was given as:

\[ B = \frac{V}{L \times D} \]  

Where, \( V \) = design storage capacity of the pond, \( B \) = width of the pond, \( L \) = length of the pond, and \( D \) = average depth of pond

3.11 Outlet

Outlet was constructed as rectangular or square channel. Outlet position proposed little lower (15-20 cm) than the elevation of the inlet to avoid backing up of the water. The discharge capacity of the outlet was assumed to be half as that of the inlet capacity as peak rate of runoff.

4. Results and Discussion

The rainfall behavior of the study area was studied and the rainfall data for 22 years (1985 to 2006) were analyzed at weekly, monthly and annual time scales.

4.1 Rainfall Analysis

4.1.2 Weekly rainfall

The rainfall in the study area starts during May and lasts upto November. To know the exact duration and amount of rainfall, the critical analysis of rainfall was done on weekly basis. It reveals that the rainfall at Henval watershed starts in 23\textsuperscript{rd} week and it continues till 33\textsuperscript{rd} week with maximum amount during 33\textsuperscript{rd} week (74.9 mm). During this period, this region experiences four peaks in 28\textsuperscript{th}, 29\textsuperscript{th}, 31\textsuperscript{st}, and 33\textsuperscript{rd} week with an increasing trend. The steady trend of rainfall was observed for 29\textsuperscript{th}, 31\textsuperscript{st}, and 33\textsuperscript{rd} week and was found to be 67.5, 74.9 and 63.6 mm, respectively. From 33\textsuperscript{rd} week to 40\textsuperscript{th} week there was decrease in rainfall (figure 2). From the analyzed data, it was found that the rainfall more than 20.0 mm occurred during 23\textsuperscript{rd} week followed by subsequent weeks, which continued upto 39\textsuperscript{th} week. The uniform rain was observed from 23\textsuperscript{rd} to 35\textsuperscript{th} week with the least during 24\textsuperscript{th} week (23.72 mm). During 24\textsuperscript{th} to 26\textsuperscript{th}, 32\textsuperscript{nd}, 34\textsuperscript{th}, 35\textsuperscript{th}, and 37\textsuperscript{th} week, the rainfall was with poor distribution. From 43\textsuperscript{rd} week to 22\textsuperscript{nd} week, which fall in non-monsoon seasons, the rainfall showed erratic behavior. Thus it was noticed that the uniformity of rainfall was pronounced from 23\textsuperscript{rd} to 37\textsuperscript{th} week (4\textsuperscript{th} June to 10\textsuperscript{th} September), whereas during the other weeks its distributions was poor and erratic.

4.1.3 Monthly rainfall

The data for mean monthly rainfall for a period of analysis (1985 to 2006) are depicted in Figure 3. It was observed that the rainfall started from May with its increasing trend as the days progressed up to August. It was maximum (251.83 mm) during August, after which rainfall started to decline till November. The maximum rain occurs during June-October
months (about 62 %), while during the remaining months its distribution was very poor i.e. little rainfall, particularly in November (10.04 mm). The data were also analyzed for its statistical parameters such as standard deviation (σ) and coefficient of variation (C_v). The coefficient of variation (C_v) was found very less in August as 50.770 and maximum in October as 268.734. This variation in C_v indicates that rainfall variation during August month was less but, in October months there was large variation in the rainfall. Therefore, accurate prediction of rainfall in October is difficult.

4.1.4 Annual rainfall

It was observed that the total annual rainfall for this period was of erratic nature with the minimum value of 719.10 mm in 2001 and maximum value of 1840.20 mm in 1998. The average annual rainfall at Henval watershed during 22 years of analysis was found to be 1217.98 mm. The peak values of annual rainfall were observed during year 1998 followed by 1990, 1986, 1988, 1993, and 1995, whereas troughs were observed during year 2001 followed by 1992, 1987, 1999, 1991, 2006 for which annual rainfall were less than mean annual rainfall (1217.98 mm), as shown in Figure 4. It was be noticed that the percentage of seasonal rainfall with respect to annual rainfall was maximum with 83.5 per cent during the year 1999 and minimum with 50.5 per cent during the year 1987.

4.2 Runoff estimation using SCS curve number method

Surface runoff estimation is of immense importance as it directly affects hydrological and watershed management planning. The curve number method (SCS, 1972), also known as the hydrologic soil cover complex method, was used to estimate runoff of the study area. In the present study, the study area was classified into different classes namely agriculture, dense forest and barren land using LISS III satellite imagery.

The daily rainfall data for 22 years period was analyzed. The values of maximum potential retention (S) obtained from weighted CN for the watershed area was used for the estimation of runoff from SCS model. The curve numbers for the watershed were generated using land use/land cover map. For that hydrologic soil groups were decided using runoff potential of the land and basic infiltration rate. The weighted curve numbers for AMC- I, II and III conditions were found to be 42.96, 64.20 and 80.48 respectively, for entire watershed.

The catchment area of watershed was 6608 ha, which was considered for the estimation of the runoff. The boundary of the catchment was delineated using the G.I.S. software Geomatica V 9.1. The daily surface runoff was estimated by using the SCS Curve Number method. On the basis of estimated daily runoff values the annual runoff and seasonal runoff values were computed for each year. The annual runoff, more than 200, mm was observed in 3 years (1993,1998, 2003), and less than 200 mm in rest 19 years. The average annual and seasonal runoff was found to be 129.45 mm and 89.02 mm, respectively.

The average seasonal runoff was found to be almost 79 per cent (i.e.78.99 %) of annual runoff. The maximum annual runoff was found to be 289.7 mm in the year 1998 and 67.5 mm in the year 1999 was minimum among all 22 years’ runoff data. The total of average weekly runoff was found to be 397.75 mm and maximum in the 26th week with the runoff of 36.57 mm. The average value of the average weekly runoff for 22 years was found as 7.5 mm/week. The average weekly runoff distribution for 22 years’ period is shown in Figure 5.
Rainfall analysis and design of water harvesting structure in water scarce Himalayan hilly regions

Sangita Mishra S.

Figure 2: Mean weekly rainfall distribution at Henval watershed.

Figure 3: Mean monthly rainfall distribution (1985-2006) in Henval watershed.

Figure 4: Average annual rainfall distribution at Henval watershed

From runoff analysis, it was observed that a considerable portion of precipitation flows off the watershed as runoff resulting in water scarcity and the main reason of agricultural drought in the watershed. Hence, there is a great need of storage of the water from runoff for future needs to avoid drought. Farm ponds are small tanks and reservoirs constructed for the purpose of storing water from surface runoff. These are useful for irrigation water supply for the cattle, fish production etc. They play a significant role in areas of rainfed agriculture.
They are used for storing water during rainy season and using the same for irrigation subsequently.

As the study area is rainfed, a number of farm ponds can be constructed in higher order drainage networks of the area for water storage. A small area of the Henval watershed was chosen for the construction of a farm pond as in hilly watersheds they are found to be economical.

![Annual and seasonal runoff distribution for period 1985-2006.](image)

Figure 5: Annual and seasonal runoff distribution for period 1985-2006.

The water demand for the Kanatal area of Henval watershed was estimated on the basis of weekly analysis of the crop evapo-transpiration, effective rainfall, surface runoff and the water received from the canal. Water harvesting structures were suggested on the basis of water demand.

4.3 Water demand estimation

4.3.1 Estimation of reference Evapo-transpiration

The reference evapo-transpiration was estimated using the standard FAO Penman-Monteith method. The maximum value of the reference evapo-transpiration was found to be 33.62 mm in 23rd standard meteorological week while it was found minimum for 2nd week with the value of 9.22 mm. The average value was found to be 18.59 mm/week. The average value of total reference evapo-transpiration for the year was estimated as 968.80 mm.

4.3.2 Estimation of crop Evapo-transpiration

The crop evapo-transpiration was calculated by multiplying the reference evapo-transpiration by the respective crop coefficient. As Kanatal is located at the elevation of more than 1500 m, elevation, the crop water requirement was found maximum in the 33rd week as 17.66 mm, whereas it was found minimum as 0.00 mm for 13th to 26th week as there was no crop in these weeks. The average value of weekly crop evapo-transpiration was found to be as 6.41 mm/week. The annual crop evapo-transpiration was found to be 333.18 mm.
4.3.3 Estimation of effective rainfall

The effective rainfall was estimated according to USDA Soil Conservation Service Method. For study area, it was found maximum in the 31st week as 65.92 mm. The annual effective rainfall value was found to be 1150.27 mm.

4.3.4 Estimation of irrigation water requirement

The irrigation water requirement was worked out by subtracting the value of the effective rainfall from the crop evapo-transpiration. The overall flood (surface) irrigation efficiency of 40 per cent was assured for Kharif and Rabi season and that for sprinkler or drip irrigation 90 per cent was used. It was observed that the maximum weekly irrigation requirement was during the 50th week (7.52 mm).

4.3.5 Estimation of water demand

The maximum water demand was observed in the 46th week. The average weekly rainfall in this week was very less (1.527 mm). So a water harvesting structure was designed to conserve the runoff and also to meet the water demand of crops.

4.3.6 Design storage capacity of the harvesting pond

Weekly runoff recycling was considered for estimating the required design storage capacity. The design storage capacity of the pond was determined as the maximum difference between the water demand calculated for drip irrigation method and the runoff estimated by Curve Number method. It was worked out to be 9.77 m³ for Kanatal.

4.3.7 Dimensions of the water harvesting structure

The dugout pond was considered as the water harvesting structure. Based on the storage capacity, design of water harvesting pond was done for Kanatal area. The pond was considered Reinforced Cement Concrete (R.C.C.) structure to take care of the problems arising from the seepage and percolation losses. The details of shape and dimensions of the pond are given below.

Storage capacity: To take care of evaporation losses the storage capacity of the pond was increased by 5 per cent. A free board of 15 cm was also provided to avoid overtopping of water.

Shape: Based on the topographical limitations of the area, the pond was considered of the rectangular shape.

Dimensions: Considering the storage capacity, the length, width and depth of the water harvesting pond was worked out to be 3.42, 2, 1.5 m, respectively (Figure 6)

Outlet: Outlet may be constructed as rectangular channel. Outlet position was kept 15 cm lower than the elevation of the inlet to avoid backing up of the water.
Rainfall analysis and design of water harvesting structure in water scarce Himalayan hilly regions
Sangita Mishra S.

The foundation view and the top view of the water harvesting structure are shown in Figure 6. The foundation was constructed of cement concrete (1:2:4) and gravel bed of 10 cm thickness was provided for stability of the structure.

![Foundation View and Top View of Water Harvesting Structure](image)

**Figure 6:** Layout of a proposed farm pond in Henval watershed

5. Conclusion

The present study concerned the assessment of water scarcity in Himalayan mid hills. The weekly, monthly and annual rainfall analysis revealed that the rainfall pattern is quite irregular in this region and distributed only in 4-5 months and the streams are mostly dry in non-monsoon season. From runoff analysis, it was observed that a considerable portion of precipitation flows off the watershed as runoff resulting in water scarcity and the main reason of agricultural drought in the watershed. Hence, there is a great need of storage of the water from runoff for future needs to avoid drought. Farm ponds can be used for storing water during rainy season as in hilly watersheds, they are found to be economical. As the study area is rain fed, a number of farm ponds can be constructed in higher order drainage networks of the area for water storage.

6. References


3. Dhruva Narayana, V.V., (1993), Soil and Water conservation Research in India, ICAR, New Delhi.


