Estimation of Groundwater Recharge using Soil Moisture Balance Model - A Case Study of Kinaye Watershed, Belagavi, Karnataka, India

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Abstract- The purpose of the study is to estimate the Groundwater recharge under different land use / land cover patterns. The area selected for present study is Kinaye sub watershed, i.e. part of Malaprabha Representative Basin which is a right bank tributary of river Krishna. In the last few years, many changes have been occurring in land use patterns due to anthropogenic activities and improper management practices. The soil hydrological parameters such as infiltration, hydraulic conductivity and soil moisture variations have a huge impact on Soil water system due to changes in Land use and Land cover. These parameters were determined by using various field and laboratory methods. Present study involves the groundwater recharge computation using soil moisture balance model for kinaye sub watershed. Initially, the parameters such as Infiltration, Runoff and Evapotranspiration were estimated. Finally the recharge was estimated from soil moisture balance model. The Groundwater recharge estimated showed that the recharge is maximum in forested and plantation areas is about 42%, followed by barren land-35-36%, agriculture land irrespective of the crops showed a recharge of 32%. The least is observed in degraded forests, i.e. in scrubs (15%).

Key Words: Groundwater, Recharge, hydraulic conductivity, infiltration, Soil moisture

I. INTRODUCTION

Groundwater is an important water resource to sustain human life as well as to maintain ecosystem. The application degree of groundwater has relatively increased and the demand for groundwater resources development is also growing with each passing day. To manage groundwater extraction, accurate control of the groundwater recharge is a very important basis. This study is to estimate the infiltration, runoff, evapotranspiration, and recharge in unsaturated zone using soil moisture balance approach (fig.1) for the Kinaye watershed situated in Belagavi. The sustainability of a groundwater system relies on the amount of recharge by rainfall. It is generally agreed that once rain falls on the land surface, the unsaturated zone controls the separation of rainfall into surface runoff and infiltration. The infiltrated water may leave the unsaturated zone through the process of evapotranspiration, and/or may also recharge groundwater reservoirs. To estimate the amount of infiltration recharge, both soil water properties of the unsaturated zone and climatic conditions must be fully considered.

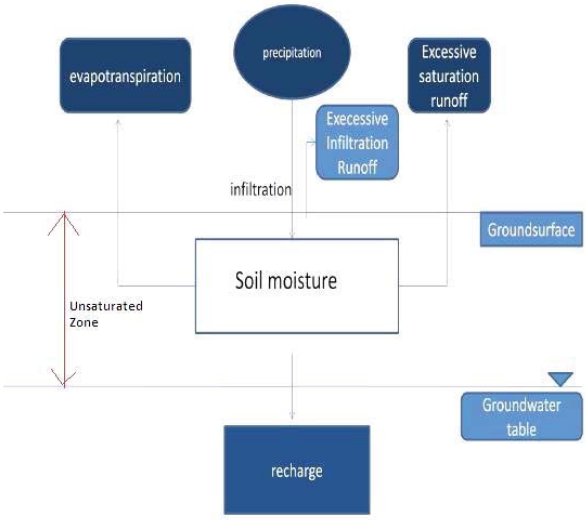


Figure 1 Soil moisture budget

II. STUDY AREA

2.1 General

The Malaprabha River is one of the major tributary of river Krishna in the hard rock region of India. The catchment area up to the first river gauging site is 540 sq. km. The catchment predominantly covered by the red loamy and black soils. These are being underlined by the tertiary basaltic formations of Pre-Cambrian age. The elevation of the catchment ranges from 668 m to 868 m above MSL, but the topography and vegetation show fairly complex pattern i.e., the flat area is being open for agricultural purpose and the steep zone is covered by the deciduous to semi-ever green forest. Most part of the basin is covered by the forest with broad leaved trees, the main species are the teak and rose wood. The forest is thick in western and southern part of the basin with little patches of agricultural fields.

The Kinaye sub watershed is a part of Malaprabha basin. The catchment area of Kinaye sub-watershed is 4521 hectares (45km^2). The watershed is further divided into 8 micro-watersheds. The study area is bounded by a range of hillocks on eastern side and a low ridge in the southwest. The dividing line passing through all these peak points on the hill range and the south west ridge will be the watershed boundary.

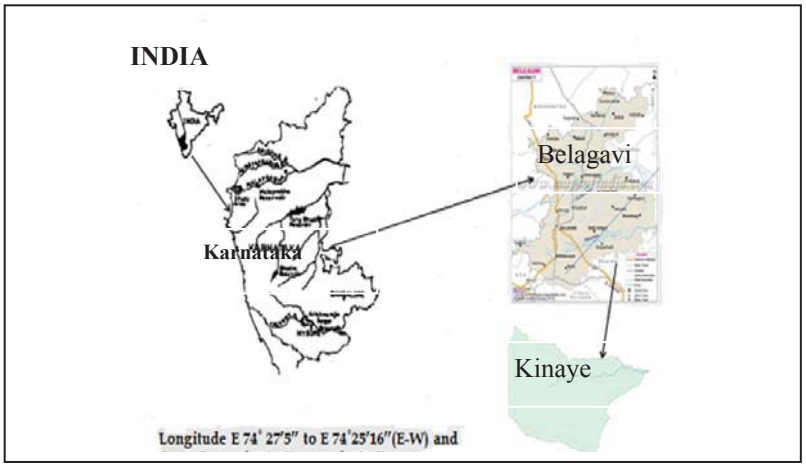


Figure 2 Location of study area

2.3 Physiography

The project area consists of undulating tracts with S-N running hillocks that occupy about 5-6% watershed area. The general slope in the sub watershed is from west to East West, the land slopes in three directions i.e. W-E and N-E. The slope varies from 2% to 6%. The level difference between ridge and valley is 2to 15m. The soil on well lands, Slope ranges from 2% to 6.0%. Major Nalas have their origin in western hillocks. The nalas are dry for most of the period and carry only seasonal flow.

2.4 Climate:

The watershed area comes under South Western hilly zone. Bright sunshine during summer, cloudiness during kharif and extreme cold during Rabi are of common occurrence. The climate shows extreme variations. Fast blowing winds prevail for about 3-4 months. The annual average maximum temperature is 32°C and minimum is 18°C.Annual average rainfall is 1392 mm and is received during SW (more than 90%) & NE monsoon .The rainfall is fairly well distributed enabling to take up cropping in both kharif and rabi season. Runoff producing rains of 670.00 mm received in 48days in a year are not much beneficial as they result in overland flow. Time of concentration being as low as 0.69 hours, infiltration is also less, as such crops wither after 5-8 days of stoppage of rain. Soaking rains are found beneficial to crops but high wind velocity coupled with high sunshine result in higher evapotranspiration losses also.

III. METHODOLOGY

The estimation of Groundwater recharge is based on soil moisture balance approach. Initially, the estimation of soil hydrological parameters such as infiltration, hydraulic conductivity, soil moisture storage, Runoff, evapotranspiration etc., were carried. And finally the Groundwater recharge is estimated by soil moisture balance equation (fig.3).

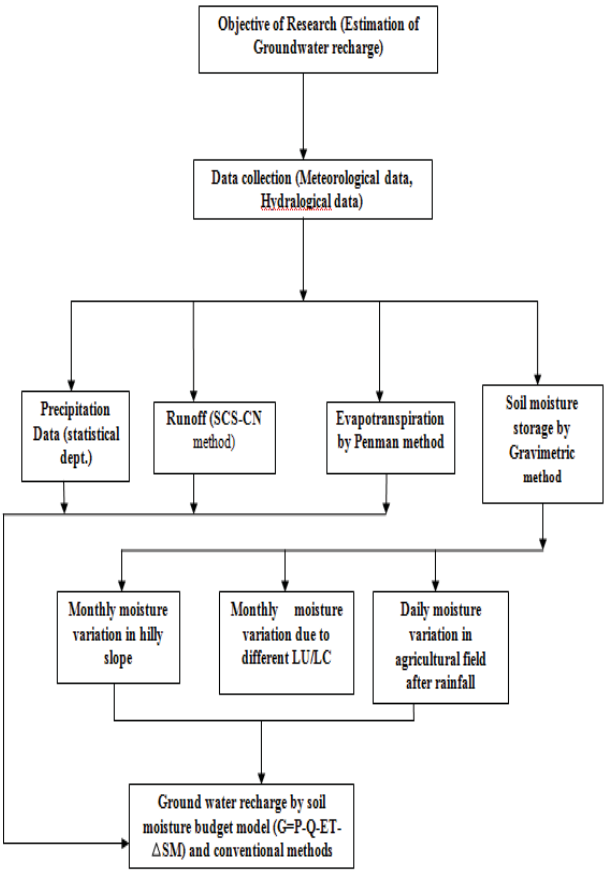


Figure 3. Flow of work

IV. RESULTS AND DISCUSSIONS

4.1 Soil Water Balance

Change in soil water storage occurs throughout the year. Increases due to precipitation, return flow from irrigation, and subsurface inflows. And depletion is a cause of Percolation, gravitational drainage, and evapotranspiration. A soil moisture balance equation describing these changes for any period of time is expressed as:

$$\Delta SM = P + IR - Q - G - ET \qquad \text{(Eq 1)}$$

Where, ΔSM is the change in soil water storage in the soil profile, P is precipitation. IR is return flow from irrigation, G is recharge, ET is evapotranspiration and Q is surface runoff. All quantities are expressed as a depth (inches or mm) of water over a study area for a specific period of time.

4.2 Rainfall Analysis

The average annual rainfall of 15 years (1998-2012) is considered for study. It is noticed that the maximum rainfall occurred in the year 2007(1827.6. mm) and the minimum rainfall was observed during the year 2001 (802.2 mm). Out 15 years, 2001, 2002 and 2012 showed the rainfall much lower than the yearly average rainfall. Figure 4 shows the rainfall variation from 1998 to 2012.

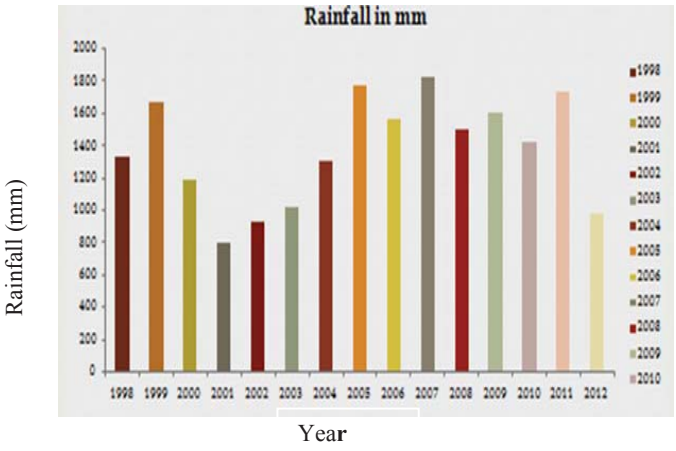


Figure 4.Rainfall Pattern from 1998-2012

4.3 Infiltration and Hydraulic Conductivity

Infiltration tests were carried out by using Disc permeameter under different land use/ land covers and the results are presented in Table 1.

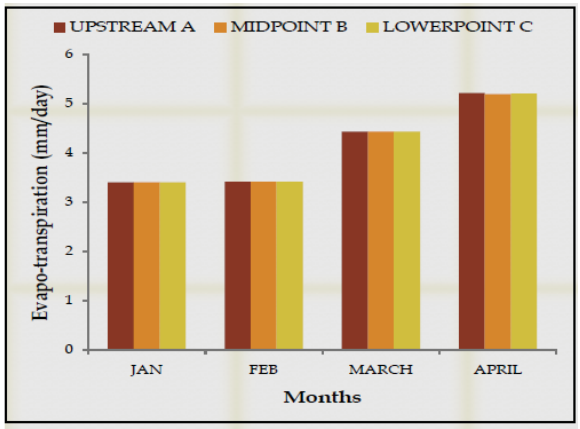
Table 1 Hydraulic Properties of soil samples in Kinaye Watershed.

Sl. No	Land use pattern	Type of soil	Soil texture	Range of Hyd. Cond mm/hr	Range of infiltration mm/hr
1	Forest	Mixed and Red	Light loam to medium loam	30- 35	40-45
2	Agriculture	Mixed & Red	Light to heavy loam	15- 25	20- 30
3	Barren	- do-	Light loam to medium loam	20-30	30- 35

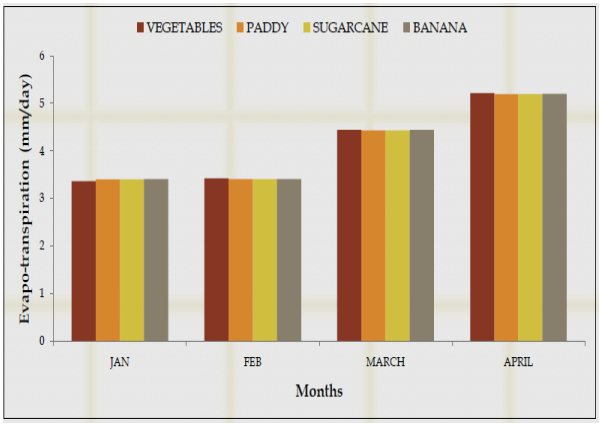
(Source: N.I.H. Belagavi.)

4.4 Estimation of Evapotranspiration using Penman Method

In the present study, estimates of ET are required for the computation of water balance components of the Kinaye watershed. Penman method is used for estimation of ET. Variation of ET under different land covers is shown in figure 5(a), (b) and (c).



(a)



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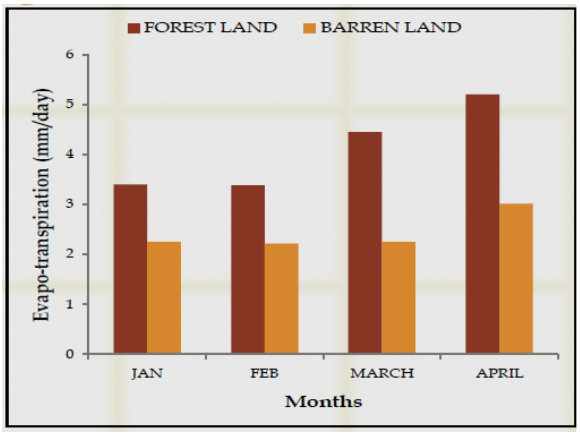
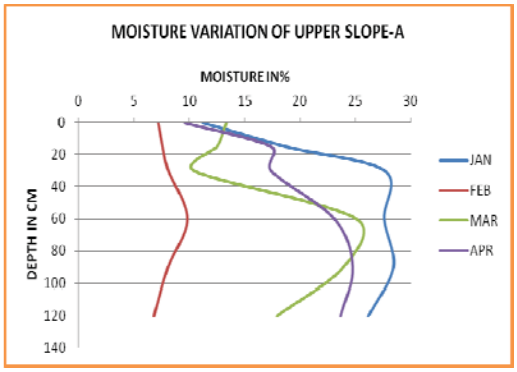


(b)

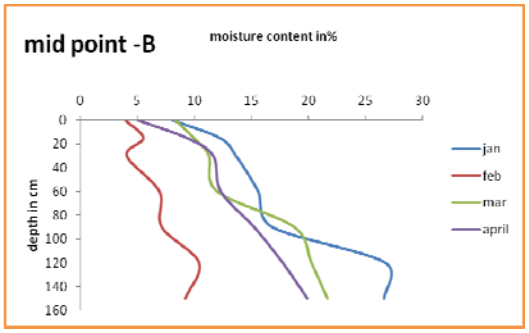
Fig 5(a), (b) and (c) Evapotranspiration of different LU/LC.

4.5 Soil Moisture Analysis:

In the present study, Soil moisture percentage in different land covers is estimated by gravimetric method. Soil moisture is monitored every month by collecting samples up to a depth of 5 to 6 ft. The results indicate that soil moisture variation is quite varied and depend upon various factors such as land use, soil type, type of plantation and rainfall intensity and duration. The present results indicate that there is no marked variation in soil moisture distribution if the region falls under the same agro-climatic conditions. However, it is noted that the moisture content remains for longer duration under forest and plantation covers when compared to degraded lands. Figure 6 (a), (b), (c), (d), (e), (f), (g), and (h) shows Monthly Moisture Variation for non agricultural and agricultural lands.



(a)



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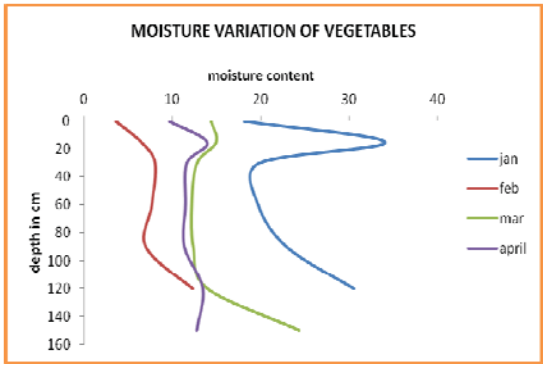

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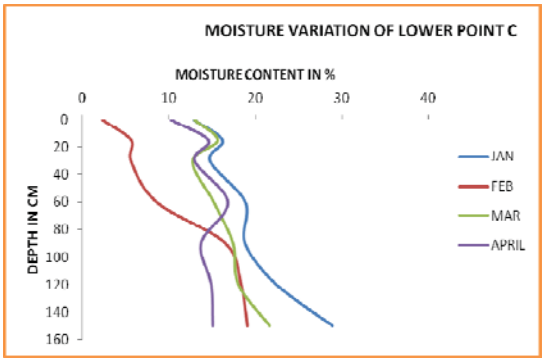

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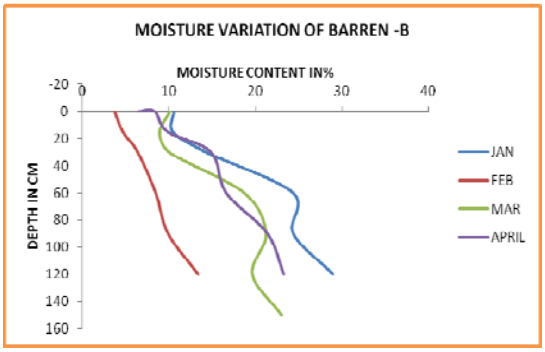

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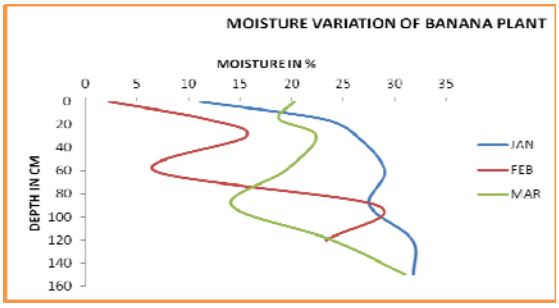

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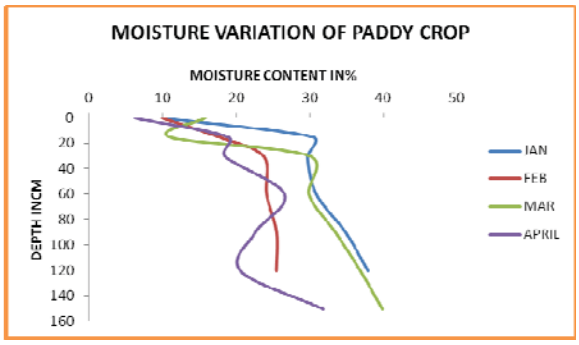

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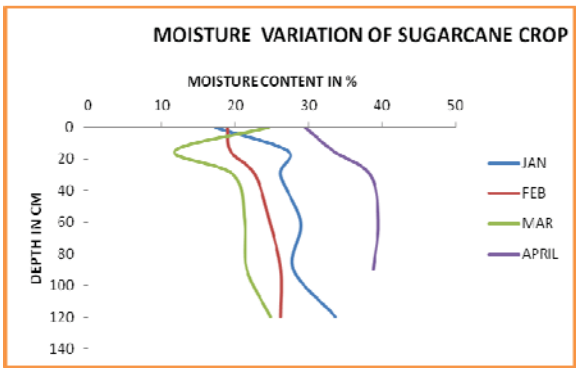

(h)

Figure 6 (a), (b), (c), (d), (e), (f), (g), and (h): Monthly Moisture Variation for non agricultural and agricultural lands

4.6 Runoff estimation using SCS CN method

The runoff was estimated using curve number method. Data pertaining to soil type, texture, organic matter, infiltration rates and hydraulic conductivity were collected from NIH, Belagavi. Curve numbers were fixed accordingly. Rainfall data was collected from the Statistical Department, Govt. of Karnataka. Rainfall events have been identified for analysis based on continuous rainy days in a month in two sets (1998 to 2005 and 2006 to 2012).The estimated runoff versus rainfall is plotted as shown in Figure 7 below. From a plot a correlation coefficient of 0.9635 is obtained.

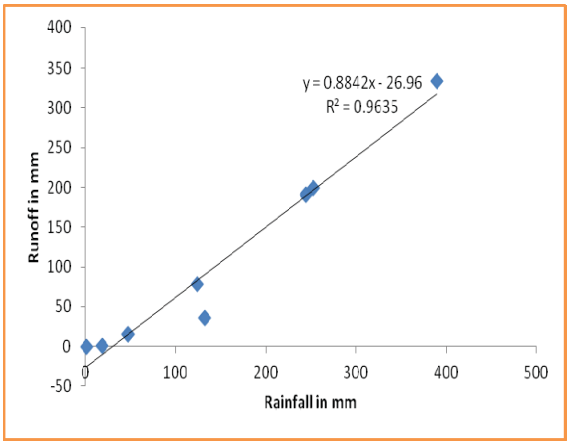

Figure.7. Relationship of Rainfall-Runoff using SCS- Curve Number

4.7 Estimation of Groundwater Recharge.

The groundwater recharge was estimated using soil moisture balance approach. It is observed from table 2, that the ground water recharge was found to be maximum as 29.38% for the year 2003, and minimum was found to be 27.59% for the year 2006. The average ground water recharge for the kinya watershed is computed to be 28.25 % for the 15 year rainfall event.

Table.2.Estimation of Ground water recharge using soil moisture balance approach.

Sl no	year	Average Rainfall in mm	Recharge in mm	Recharge in %
1	1998	1332.2	381	28.59
2	1999	1669.5	475	28.45
3	2000	1193.1	333.84	27.98
4	2001	802.2	232.20	28.94
5	2002	938.4	268.66	28.62
6	2003	1029.9	302.65	29.38
7	2004	1316	366.44	27.84
8	2005	1782.7	499.8	28.03
9	2006	1576.3	435.03	27.59
10	2007	1827.6	509.27	27.86
11	2008	1509.4	419.55	27.79
12	2009	1612.3	450.27	27.92
13	2010	1431.10	402.36	28.11
14	2011	1741.10	486.26	27.92
15	2012	985.10	283.22	28.75

For comparing the values obtained from soil moisture balance approach, the ground water recharge is also estimated using K. L. Rao Method (Arshad et.al 2005). It is observed from table 3 and figure 8 that the rainfall is maximum of 1827.6mm during the year 2007 with a maximum recharge of 19.52% and rainfall is minimum of 802.2mm during the year 2001with a minimum recharge of 12.53%.

Table .3. Recharge values by K. L. Rao method

sl,no	date	Rainfallinmm	Rechargeinmm	recharge
1	1998	1332.2	233	17.49
2	1999	1669.5	317.37	19.01
3	2000	1193.1	198.27	16.61
4	2001	802.2	100.55	12.53
5	2002	938.4	134.6	13.06
6	2003	1029.9	157.47	15.29
7	2004	1316	229	17.4
8	2005	1782.7	345.67	19.39
9	2006	1576.3	294.07	18.65
10	2007	1827.6	356.9	19.52
11	2008	1509.4	277.35	18.37
12	2009	1612.3	303.07	18.79
13	2010	1431.1	257.77	18.011
14	2011	1741.1	335.27	19.35
15	2012	985.1	146.27	14.84

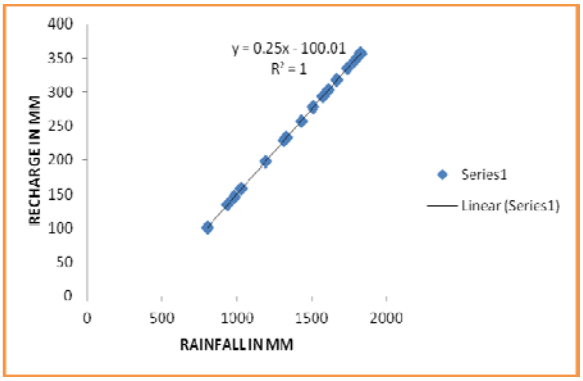

Fig 8 Relationship between Rainfall-Recharge using K.L. Rao methods

V. CONCLUSION

5.1 General

In the present study, detailed analysis of hydrological soil parameters such as infiltration, soil hydraulic conductivity and soil moisture characteristics were carried out. Some of the important observations made through the study are listed below:

- Average annual rainfall of Kinaye sub watershed is 1393mm obtained from period 1998-2012 out of which max. is 1827.6 and min. is 802.2mm.Standard deviation is 331.35, coefficient of variation is 0.24 and Median is 1431.00.
- Hydraulic conductivity and infiltration rate observed for different land use and land cover is Ks of forest is 30-40mm/hr, Agriculture is 10-20mm, Barren land 20-30mm/hr, Shrubs 10-20mm.
- Infiltration rate for forest land 30-50mm/hr, for agriculture 10-30mm/hr barren land 10-30mm/hr, Shrubs 20-30mm/hr.
- Studies of pre monsoon revealed monthly soil Moisture variations of about 8-10% and of post monsoon 10-12%.
- Daily soil Moisture distribution after rainfall event is found to be 15%.
- Runoff estimated from SCS-CN Method is 35.89%, from Inglis method is 32%, Khosla's Method is 86.86%, lacey method is 35.77 and from Arc SWAT model is 34.5%.
- Evapotranspiration by Penman method is 61%, ET by Turc method is 31.60%. The estimated ET showed a close comparison with that estimated by Nikhil (2015) through SWAT model (32%). Penman method gave a very high ET which may be due to the limited data available.
- Annual ground water recharge by soil moisture method is 28.25% and by K.L Rao method is 17.81% of rainfall.

Based on the above observations following conclusions are drawn:

- There are wide variations in rate infiltration and hydraulic conductivity with respect to land use/land cover change and also with respect to soil texture and structure. Further, down slope movement of water in the saturated and unsaturated phases, particularly during periods of above average rainfall, provides areas of high water content and so low infiltration at breaks - in-slope and near the stream.
- Overland flow generated from areas of low soil moisture storage and / or high moisture content can run over areas with higher infiltration capacity. Catchments with uniform slopes have higher infiltration rates as compared to the regions with higher slopes. However, in the present study area variation in slope is very limited, therefore, higher recharge is observed. The Infiltration excess overland flow is negligible in most part of the watershed.
- Soil moisture variations observed in different land use/land covers indicated that the moisture content depends not only on redistribution of moisture after infiltration but also on the type of crops, soil type and also on the mode of irrigation supplied. This is quite evident from the present study.

- The Ground water recharge estimated showed that the recharge is maximum in forested and plantation areas (42%) followed by barren land (35-36%), agriculture land irrespective of the crops showed a recharge of 32%. The least is observed in degraded forests, i.e. in scrubs (15%).

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