__Original Research Article__

Evaluation of Hydrological Response of an Agricultural Watershed to Conservation Measures and Land Use Changes – A Case Study

ABSTRACT

An agricultural watershed falling in the catchment of Godavri bason was selected for the study. Paddy, Maize, Cotton, Red gram and Vegetables are the major crops grown in the watershed. Severe soil erosion consequent degradation of land and lack of water resources for supplementary irrigation and high dependence of rainfed farming leading to poor crop yields were the major problems in the watershed. With a view to address the issues in rainfed farming compounded by increasing adverse effects of climate change, soil and water conservation measures including area and drainage line treatments from ridge to valley were implemented in the watershed from the year 2009 to 2015 with the active participation of local people with facilitation support by a local civil society organization. With the implementation of the conservation measures, visible impact in terms of increased water availability, change in the land use and increased area under cultivation were reported in the watershed. The present study aimed at assessing the hydrological response of the watershed to the conservation measures and land use changes. The study revealed that the runoff as percentage of rainfall from the watershed decreased from 15% in the year 2009 to 10% in the year 2015, signifying the highly positive impact of watershed development programme to act as the best climate change adaptation programme. Further, the additional storage capacity of 336 cubic m per hectare as estimated from the present hydrological response study was found to be in very close agreement with actual storage capacity of 322 cubic m per hectare, created with different conservation works taken up in the watershed.

Key words: Runoff, Watershed, Hydrological Response

INTRODUCTION

Watershed development programmes aim at addressing the inherent issues (including those resulting from adverse effects of climate change) in rainfed areas, which constitute about 50% of cultivated area, contributing to 40-45% of food production in the country. With conservation and regeneration of degraded natural resources through wide range of soil and water conservation (covering both engineering and vegetative measures), productivity enhancement, livelihood support, climate proofing interventions coupled with capacity building initiatives under watershed development programmes, the best possible balance (between natural resources and living beings) in the ecosystem is expected to be restored leading to enhanced resilience to climate change. This is possible with local people active participation in planning, implementation and monitoring of the watershed development projects. The conservation measures in watershed development projects are expected to enhance surface water storage capacity by reducing runoff leading to improved soil moisture and groundwater recharge, which in turn facilitate changes in land use and land cover over a period of time.

While there are several studies on estimation of runoff from watersheds using different hydrological models, the studies on impact evaluation of conservation measures and land use changes in terms of hydrological response in watershed projects are very limited. Soil Conservation Service –Curve Number (SCS-CN) model is the most widely used model these days for estimating runoff from agricultural watersheds because of its simplicity and manoeuvrability to account for variation in the watershed parameters [1, 2 &3]. It requires data on rainfall, land use type, Hydrologic Soil Group (HSG) and Antecedent Moisture Content (AMC) of watershed as input. Accurate determination of Curve Number (CN) is vital for reliable estimation of runoff from the watersheds [4].

The present study was aimed at comparison and evaluation of hydrological response of a watershed before and after execution of conservation measures that influenced runoff and availability of water in terms of surface storage and consequent changes in the land use. In the present study, SCS-CN model has been used for simulating and comparing the hydrological response of watershed to conservation measures and land use changes.

MATERIALS AND METHODS

The selected watershed falls in Siddipet district of Telangana state. The watershed development programme was implemented in the study watershed from the year 2009 to 2014 with local people active participation. The total geographical area of the watershed is 1342 ha and comprised of three habitations. Total population in the watershed was 656 (Male: 346, Female: 310). As per 2011 census. The climate is semi-arid average annual rainfall of 770 mm, of which more than 85% is received during South-West monsoon. The mean maximum and minimum temperatures are about 47^0C and 9^0C respectively. The land use and land cover data for the years 2009 and 2015 obtained through analysis of satellite images (IRS LISS IV) pertaining to May 2009 and February 2015 was used in the study. The texture of the soil is sandy loam and falls under Hydrological Soil Group B.

Based on the daily rainfall for the year 2009 (pre-project) and 2015 (post project) the Antecedent Moisture Condition (AMC) prior to each rain event was evaluated depending on 5-day antecedent rainfall and categorized as AMC I, AMC II and AMC III representing dry, average and wet condition of watershed considering growing season of crop. First the curve numbers were generated for AMC-II. Thereafter, the area weighted CN value for the entire watershed was evaluated for AMC-II, using the information of polygon area and corresponding CN from the attribute table of integrated land use and land cover and HSG combination. Further, this weighted CN value for AMC-II was converted to AMC I and III using the standard relationships.

In order to estimate runoff using SCS-CN model, the daily rainfall for the monsoon season of the years 2009 and 2015 was used as primary input. Depending upon the AMC of the rainfall event under consideration, the weighted CN for the watershed under study was varied. These weighted CN values were used in SCS-CN model and daily runoff was estimated. The seasonal estimated runoff for the years 2009 and 2015 were then computed as the sum of daily runoff and compared. With a view to validate the results of model, the additional storage capacity created with different soil and water conservation measures was collected and compared with results of hydrological response study.

RESULTS AND DISCUSSION

The land use and land cover details i.e. the spatial extent of different land use and cover classes with respect to study watershed for the years 2009 (i.e. pre-treatment) and 2015 (post treatment) are given in Table 1 and 2, respectively. Also, the area under land use and land cover classes as a percentage of total geographical area of the watershed for the years 2009 and 2015 are presented in Fig. 2 and 3, respectively for better comparison.

Before taking up conservation works, among the land use classes scrub land was dominant comprising of 43.20% followed by crop land with 32.70% of total geographical area of watershed. Barren rocky and current fallow areas comprised of 9.25 and 9.10 %, respectively of total geographical area (Table 1 and Fig. 1). Post watershed development, the scrub land came down to 40.24%, while the crop land increased to 37.91% of total geographical area of the watershed (Table 2 and Fig. 2). Improvement in area under water body, plantation, mining and built-up area could be noted in during the post-watershed phase (Table 1 & 2 and Fig. 1 &2).

Table 1 Land Use and Land Cover Details of watershed (pre-treatment, year 2009)

S.No.	Land Use Land Cover	Area (ha)	Area(%)
1	Crop land	438.5	32.70
2	Current fallow	122.4	9.10
3	Scrub land	580.4	43.20
4	Built up land	6.3	0.50
5	Water body	19	1.40
6	Barren rocky	124.1	9.25
7	Mining	2.2	0.16
8	Plantation	49.1	3.66
	Total	**1342**	

Table 2 Land Use and Land Cover Details of watershed (post-treatment, year 2015)

S.No.	Land use Land Cover	Area (ha)	Area(%)
1	Crop land	508.7	37.91
2	Current fallow	2.2	0.16
3	Scrub land	540	40.24
4	Built up land	6.8	0.51
5	Waterbody	33.2	2.47
6	Barren rocky	124.6	9.28
7	Mining	75.7	5.64
8	Plantation	50.8	3.79
	Total	**1342.00**	

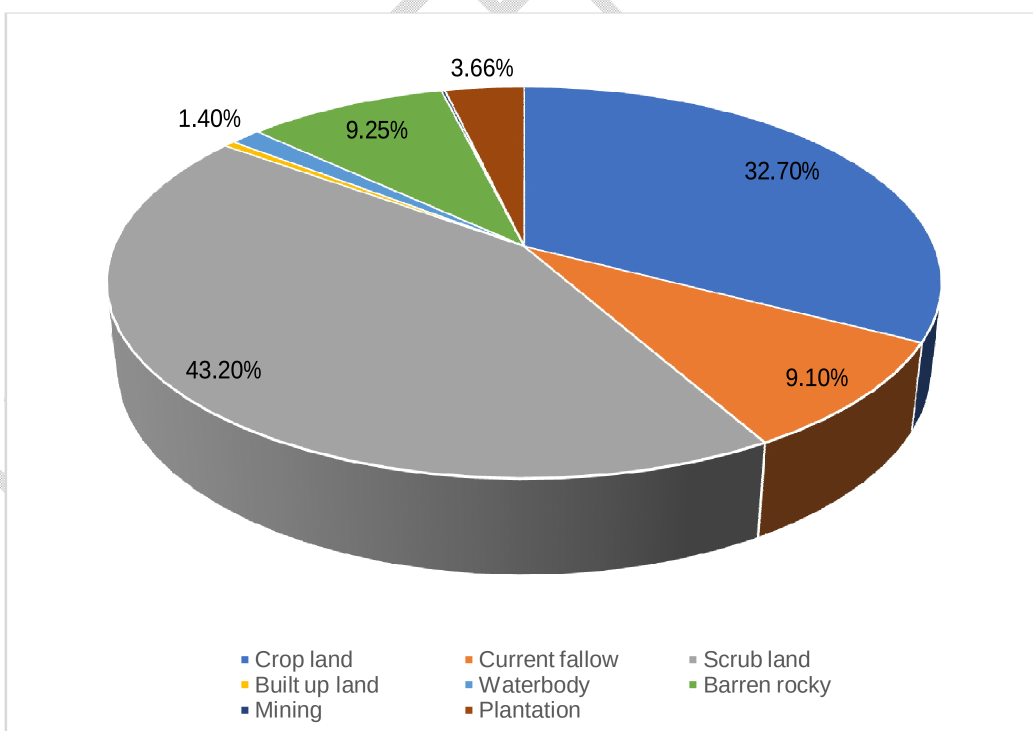

Fig. 1 Land use and Land Cover as % of total geographical area (2009)

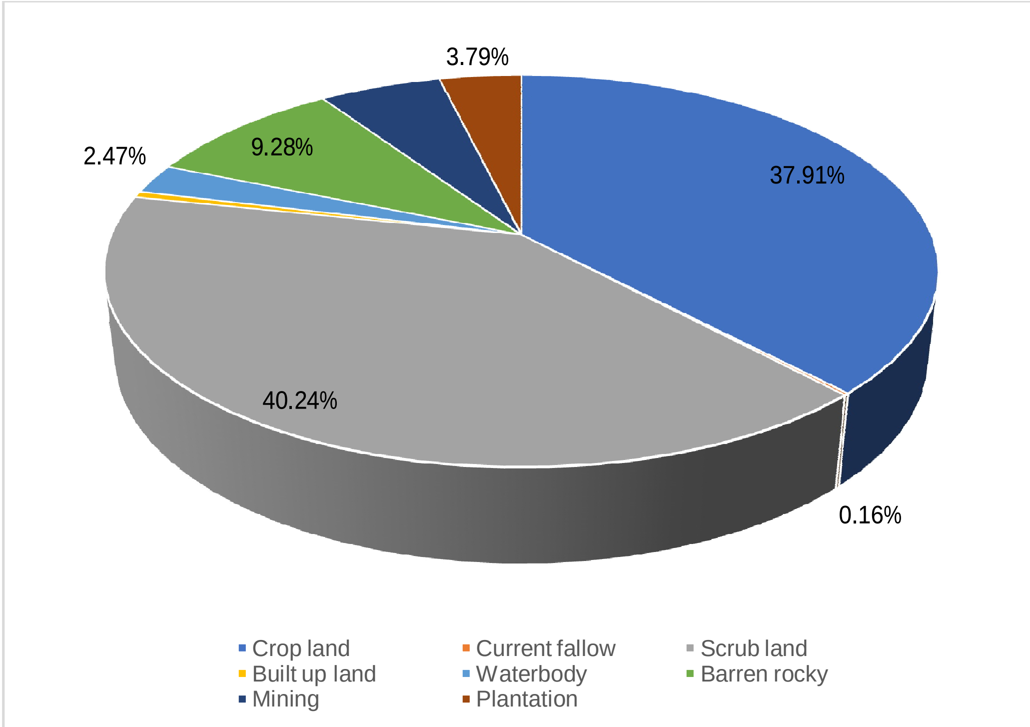

Fig. 2 Land use and Land Cover as % of total geographical area (2015)

Using the land use and land cover details and Hydrologic Soil Group B, the spatially distributed Curve Number (CN) was generated and the area weighted average value of CN was found to be 86 for AMC II condition for the year 2009. However, due to changes in the land use and land cover as influenced by conservation measures, the CN value of the watershed was found to be 68 in the year 2015. This CN value for AMC-II was converted to AMC I and III using the standard relationships.

With a view to compare hydrological response of watershed, runoff was estimated on daily basis using the daily rainfall for the monsoon season of the years 2009 and 2015 with the help of SCS-CN model. Depending upon the AMC of the rainfall event under consideration, the weighted CN for the watershed and the consequent runoff changed. The daily rainfall and estimated runoff for the years 2009 and 2015 are presented in Fig.3 and Fig.4, respectively. Several researchers [5, 6, 7, 8, 9, 10, 11,12, 13 & 14] also used SCS-CN model in combination with geospatial techniques and reported reliable estimation of runoff. Hence, the SCS-CN model has been used in the present study for simulation and evaluation of hydrological response of watershed.

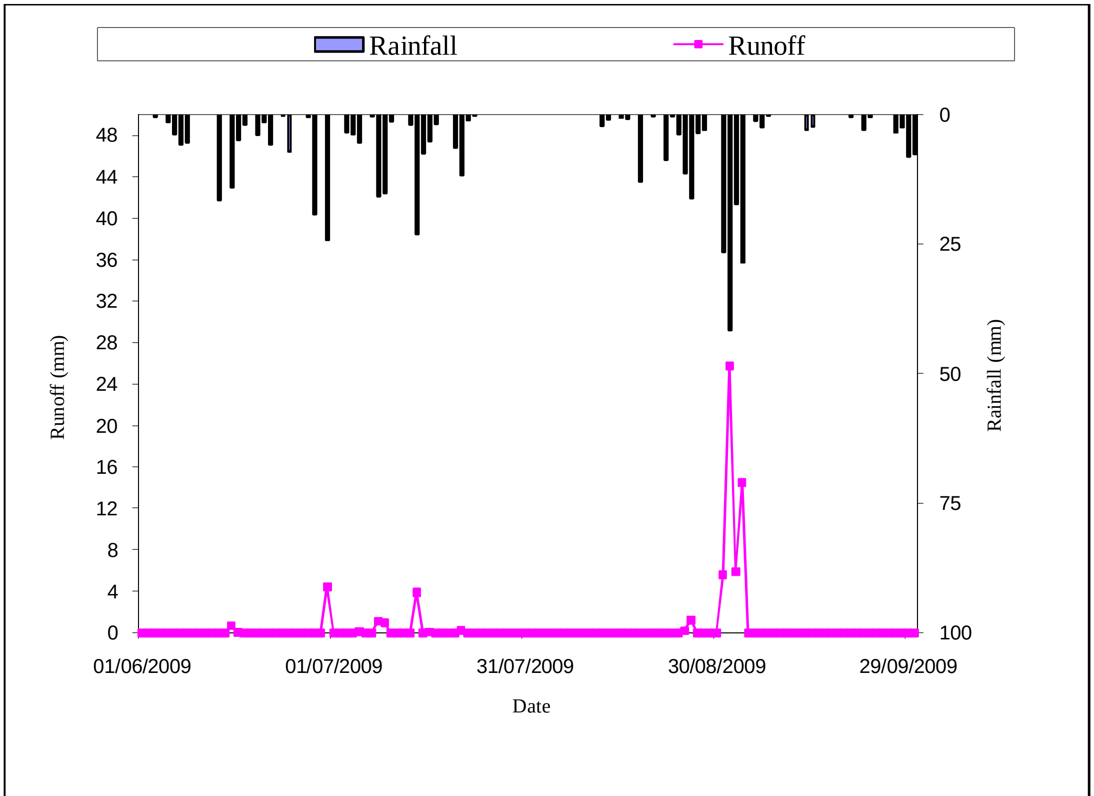

Fig. 3 Hydrological response of watershed (Year 2009)

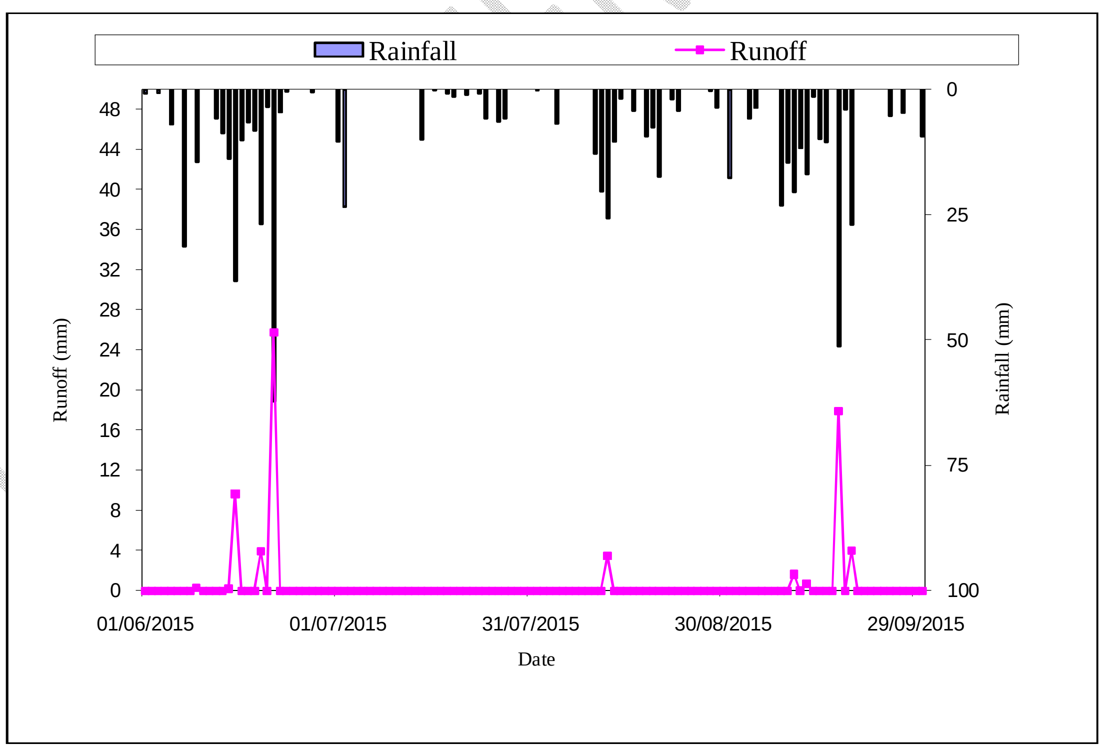

Fig. 4 Hydrological response of the watershed (Year 2015)

The daily rainfall in the year 2009 varied from 41.52 mm to 0.11 mm. In total there were 58 rainy days. However, there are only 15 runoff events. Despite the low seasonal rainfall received during the year 2009, the runoff percentage worked out to be 15% of rainfall. The daily rainfall in the year 2015 varied from 62.12 mm to 0.11 mm. In total there were 61 rainy days and only 11 runoff events. The runoff percentage worked out to be 10% of rainfall despite receiving high rainfall of 672.4 mm in the monsoon season of the year 2015.

The year wise percentage of runoff from the watershed during pre and post watershed development stages is presented in Fig. 5.

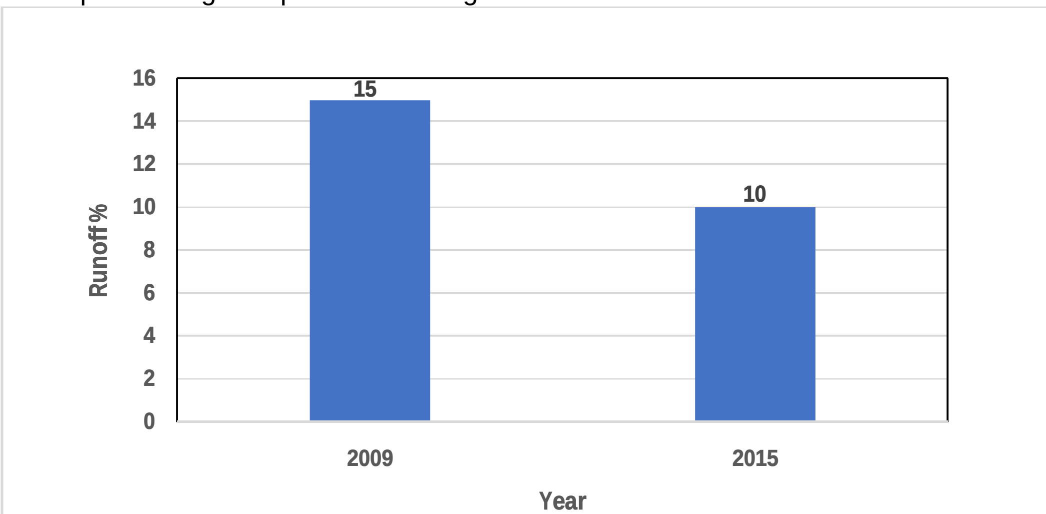

Fig. 5 Year wise percentage of runoff from the watershed

It can be observed that the watershed works helped in controlling runoff by 33% (compared to that of the year 2009) and aided in storing excess runoff in the watershed itself contributing to improved soil moisture, groundwater recharge and improved availability of water. The availability of soil moisture and water resources led to increase in crop land and decrease in scrub land in the watershed. This is in line with the finding of [15], who reported 40-50% runoff harvesting and 10-20% reduction in soil erosion and enhancement of survival of vegetation because of conservation measures in different watersheds in the adjoining Karnataka state.

In absolute terms, there is 5% reduction in runoff resulting from rainfall due to conservation measures. The 5% reduction in runoff converted to volume of water retained(i.e. additional storage) in the watershed works out to 451180.4 cubic m with seasonal rainfall of 672.4 mm and 1342 ha geographical area of watershed (i.e. additional storage = (5/100)*(672.4/1000)*1342*10000). Thus the estimated additional storage capacity was found to be 336.2 cubic m per hectare.

With a view to validate the estimated storage value of 336.2 cubic m per hectare as obtained from the above hydrological response study, the actual volume of storage capacity, created out of different soil and water conservation measures has been collected and presented in Table 3.

Table 3 Surface water storage capacity created in the watershed

S.No.	Treatment	Storage capacity (cubic m)
1	Field Bunding	18918.57
2	Water Absorption Trench	2754
3	Continuous/Staggered Contour Trenches	1237.73
4	Stone Bunding	175.5
5	Pebble Bunding	374
6	Vegetative Barriers	1215

7	Well recharge	6000
8	Dug out Ponds	12000
9	Dug out Earthen Gully Plugs	2000
10	Loose Boulder structures	2850
11	Stone Gully Plugs	4720
12	Sunken Pits	476
13	Rock Fill Dams	1000
14	Brush Wood Dams	228
	Total	**53948.8 Rounded to 53950**

The total surface water storage potential created in the watershed is 53950 cubic m. It can also be observed from Table 3 that the highest storage capacity created is on account of field bunding followed by dug out ponds, while the lowest one is under stone bunding.

As all the soil and water conservation measures executed were of small capacity, with eight fillings in a year the total storage capacity created in the watershed worked out to 431600 cubic m i.e. 322 cubic m per ha in the watershed of 1342 ha area. This is very close to the estimated water storage capacity of 336.2 cubic m per hectare as obtained with hydrological response study, thus clearly validating the finding of the study.

CONCLUSION

In the present study, an effort has been made to evaluate the impact of conservation measures taken up as a part of watershed development programme and consequent changes in the land use by comparing the hydrological response of watershed during pre and post development stages. The study revealed that the runoff from the watershed as percentage of rainfall from 15% in the year 2009 to 10% in the year 2015. The study also established that the estimated additional storage capacity (of 336.2 cubic m per hectare) as assessed as a part of hydrologic response study was in close proximity with actual storage capacity created (of 322 cubic m per ha in the watershed). Similar approach could be used in the ungauged watersheds for quantifying the impact of conservation measures in watershed development projects with similar agro-climatic conditions.

REFERENCES

1 Rao, K.V.R., Bhattacharya, A.K. and Mishra, K. Runoff estimation by Curve Number method-Case studies. Journal of Soil and Water Conservation. 1996; 40:1-7.

2 Mishra, P. and Ravi Babu, R. Hydrological modelling of Gayapaharinala watershed in Chotanagpur plateau. Journal of Water Management. 2008; 16(1): 47-54.

3 Satheeshkumar, S., Venkateswaran, S. and Kannan, R. Rainfall–runoff estimation using SCS–CN and GIS approach in the Pappiredipatti watershed of the Vaniyar sub basin, South India. Earth Syst. Environ. 2017; DOI 10.1007/s40808-017-0301-4

4 Mishra, P. and Babu, R.R. Remote Sensing and Geographic Information System (GIS) Based Runoff Estimation from an Agricultural Watershed. Journal of Soil and Water Conservation. 2022; 21(2): 167-175.

5 Tiwari, K.N., Kumar, M., Sibastian and Paul, K. (1991). Hydrological modelling for runoff determination: Remote Sensing Technique, J. Water Resources Planning and Management, 7(3): 178-184.

6 Sharma, T., Satya Kiran, P.V., Singh, T.P., Trivedi, A.V. and Navalgund, R.R. Hydrologic response of a watershed to land use changes: A Remote Sensing and GIS Approach. Int. J. of Remote Sensing. 2001; 22(11): 2095-2108.

7 Pandey, A. and Dabral, P.P. Estimation of runoff for hilly catchment using satellite data. Journal of the Indian Society of Remote Sensing. 2004; 32(2): 236-240.

8 Verma, S.K., Singh, J., Tiwari, S.C. and Ranade, D.H. Runoff estimation by using Remote Sensing and GIS from watershed. Journal of Soil and Water Conservation. 2006; 5(3): 49-53.

9 Sinha, J. and Pal, D.K. Remote Sensing and GIS towards Runoff assessment Studies in Dulung watershed situated in West Bengal and Jharkhand states. Proceedings of Conference on Current Trends in Remote Sensing and GIS Applications, held at IIT, Kharagpur from 15-17 February. 2007; Pp: 67.

10 Deshmukh, D.S. Chaube, U.C. Hailu, A.E. Gudeta, D.A. Kassa, M.T. Estimation and comparison of curve numbers based on dynamic land use land cover change, observed rainfall-runoff data and land slope. J. Hydrol. 2013; 492:89–101.

11 Mishra, S.K, Chaudhary, A. Shrestha, R.K., Pandey, A and Lal, M. Experimental verification of the effect of slope and land use on SCS runoff curve number. Water Resour. Manag. 2014; 28: 3407–3416.

12 Matej Vojtek and Jana Vojtekova. GIS-based approach to estimate surface runoff in small catchments: A case study. Quaestiones Geographicae. 2016; 35(3): 97-116.

13 Hussein Al-Ghobari, Ahmed Dewidar and Abed Alataway. Estimation of Surface Water Runoff for a Semi-Arid Area Using RS and GIS-Based SCS-CN Method. Water. 2020; 12:1-16.

14 Nandgude, S.B., Salunkhe, S.S., Shinde, V.T., Singh, M and Sahu, R.K. 2021. Comparision of erosion prediction models – a case study of coastal region. Journal of Soil and Water Conservation. 2021; 20(4): 386-394.

15 Rajasekharappa, K. S., Ravi Kumar, B. C. and Murukannappa. Low cost water harvesting – cum-conservational structures for non-arable land in watershed areas of Southern Karnataka. Conference on Livelihood and Environmental Security through Resource Conservation in Eastern Region of India. Abstracts of Conference on Livelihood and Environmental Security through Resource Conservation in Eastern Region of India (LERSC- 2012). April 5-7, 2012, Indian Association of Soil and Water Conservationists, Dehradun, Uttarakhand. In: Praveen Jakhar, M Madhu, HC Hombe Gowda and Md. K. Khan. 2012; Pp: Pp:107