International Journal of Plant & Soil Science

Volume 34, Issue 24, Page 1154-1163, 2022; Article no.IJPSS.97955
ISSN: 2320-7035

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

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Authors' contributions

This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.

Article Information

DOI: 10.9734/IJPSS/2022/v34i242864

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://www.sdiarticle5.com/review-history/97955

Original Research Article

Received: 20/10/2022
Accepted: 29/12/2022
Published: 31/12/2022

ABSTRACT

An agricultural watershed falling in the catchment of Godavri basin 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 on 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

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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. As the study watershed is an ungauged one, the hydrological response of watershed was simulated with commonly used SCS-CN model duly validated with additional surface storage capacity created in the watershed. The study revealed highly positive impact of conservation measures and land use changes on hydrological behaviour of watershed. The main observed change in hydrological response of watershed was the decrease in the monsoon seasonal runoff by 33% (from 15 % before taking up catchment management measures to 10 % of seasonal rainfall after the project). The conservation measures were found to facilitate storing excess runoff in the watershed itself contributing to improved soil moisture, groundwater recharge and availability of water. 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.

Keywords: Hydrological response; agricultural watershed; conservation measures and SCS-CN model.

1. 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.

Hydrological models give the relationship between rainfall and runoff, which is known to be non-linear and complex. These models are approximations of complex hydrologic cycle and help in better understanding of the hydrologic processes within a given watershed ecosystem. In India most of the watersheds are ungauged. Hence, the hydrological models are useful to generate synthetic flows to understand and evaluate the hydrological behaviour of the watersheds. There is no dearth of hydrologic models, which are useful for runoff estimation. However, most of these models were developed for other agro-climatic conditions and require huge volume of input data. Simple models, which require commonly available data (like daily rainfall, land use and soil type, etc.) as input would be helpful to simulate the runoff from the ungauged watersheds.

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 [1-3]. The SCS-CN model computes direct runoff using the empirical relationships, developed by United States Department of Agriculture (USDA). 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.

2. MATERIALS AND METHODS

The selected watershed falls in Siddipet district of Telangana state. The location map of the watershed is given in Fig. 1. 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 with 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^{0}C and 9^{0}C respectively. The land use and land cover data for the years 2009 and 2015 was collected and used in the study. The texture of the soil is sandy loam and falls under HSG 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 different land class and HSG combination for AMC-II condition. Thereafter, the area weighted CN value for the entire watershed was evaluated for AMC-II. 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 was then computed as the sum of daily runoff and compared. The percentage of runoff to rainfall was also evaluated and compared for the years 2009 and 2015. With a view to validate the results of model, the additional storage capacity created with different soil and water conservation measures was collected. As the study watershed is an ungauged one, the hydrological response of watershed simulated with SCS-CN model was duly validated with additional storage capacity resulting from the conservation measures implemented in the watershed.

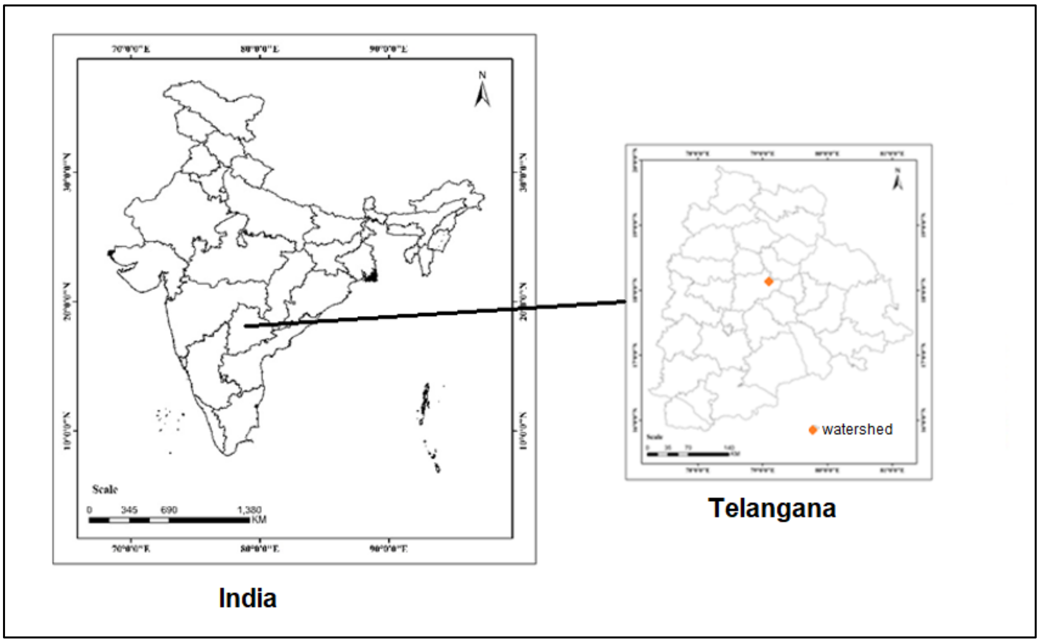

Fig. 1. Location map of study watershed

3. 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 Tables 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 given in Table 1 and 2 as also presented in Figs. 2 and 3, respectively for better comparison.

Before taking up conservation works, among the land use classes, scrub land was dominant comprising of 43.25% followed by crop land with 32.67% of total geographical area of watershed. Barren rocky and current fallow areas comprised of 9.25 and 9.12%, respectively of total geographical area (Tables 1 and Fig. 2). 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. 3). Further, the current fallow land decreased from 9.12% (Table 1 and Fig. 2) to 0.16% (Table 2 and Fig. 3) of total geographical area of the watershed during the post-project (2015) stage. Also, improvement in area under water body, plantation, mining and built-up area could be noted in during the post-watershed phase (Tables 1 & 2 and Figs. 2 & 3). However, increase in area under mining (from 0.16% to 5.64% of total geographical area) is a serious concern for the watershed as it has possible negative environmental impacts. The same could not be investigated further as it is beyond the scope of the present study. The marginal increase in area under plantation and considerable increase under water body (Tables 1 & 2 and Figs. 2 & 3) are expected to have positive impact on the watershed ecosystem.

Using the land use and land cover details and Hydrologic Soil Group(HSG) B, the Curve Number (CN) was generated for each land use and HSG combination and the area weighted average value of CN was found to be 86 for AMC II condition for the year 2009. Similarly, the weighted average CN duly taking into account of changed land use and cover for the year 2015 was evaluated. However, the CN value of the watershed was found to be 68 in the year 2015 due to changes in the land use and land cover as influenced by conservation measures. These CN values (i.e. 86 and 68) for the years 2009 and 2015 meant for AMC-II were converted to AMC I and III using the standard relationships.

Table 1. Land use and land cover details of watershed (pre-treatment, year 2009)

S. no.	Land use land cover	Area (ha)	Area(%)
1	Scrub land	580.4	43.25
2	Crop land	438.5	32.67
3	Barren rocky	124.1	9.25
4	Current fallow	122.4	9.12
5	Plantation	49.1	3.66
6	Water body	19	1.42
7	Built up land	6.3	0.47
8	Mining	2.2	0.16
	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	Scrub land	540	40.24
2	Crop land	508.7	37.91
3	Barren rocky	124.6	9.28
4	Mining	75.7	5.64
5	Plantation	50.8	3.79
6	Waterbody	33.2	2.47
7	Built up land	6.8	0.51
8	Current fallow	2.2	0.16
	Total	**1342**	

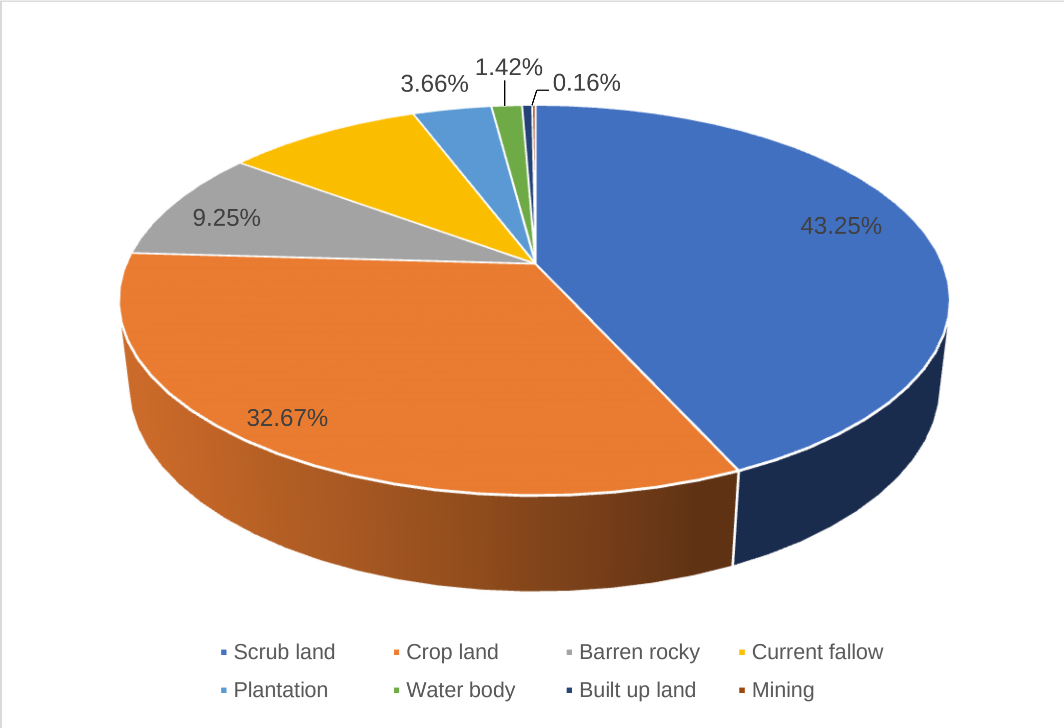

Fig. 2. Land use and Land Cover as % of total geographical area (2009)

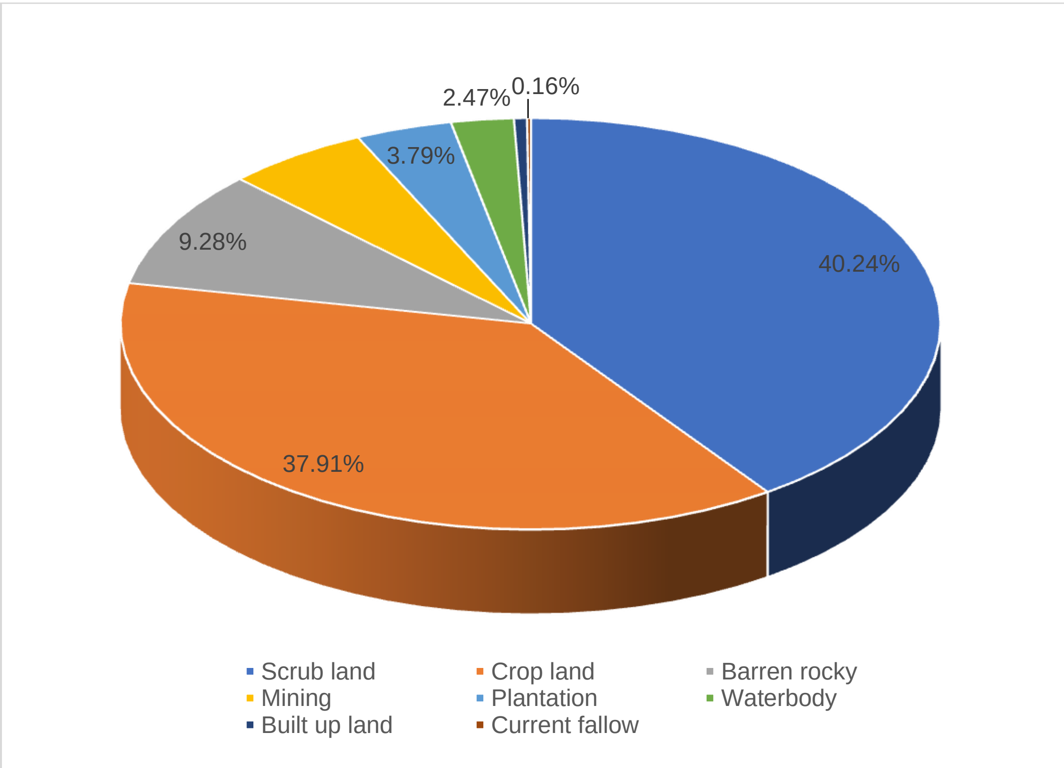

Fig. 3. Land use and land cover as % of total geographical area (2015)

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 on the AMC of the rainfall event under consideration, the weighted CN for the watershed and the consequent runoff changed. The daily rainfall and runoff estimated using SCS-CN model for the years 2009 and 2015 are presented in Fig. 4 and Fig. 5, respectively. Several researchers [5-15] also used SCS-CN model in combination with geospatial techniques and reported reliable estimation of runoff.

The daily rainfall in the year 2009 varied from 41.52 mm to 0.11 mm (Fig. 4). In total there were 58 rainy days. However, there are only 15 runoff events. The seasonal rainfall and runoff worked out to 431.4 and 65 mm, respectively for the year 2009. Despite the low seasonal rainfall (of 431.4 mm), received during the year 2009 compared to normal seasonal average rainfall of 655 mm, the runoff percentage was worked out to 15% of rainfall.

Nirmala et al. [15] calibrated and validated SCS-CN model in combination with geospatial techniques for Halia river basin falling in Nalgonda district of Telangana state and reported that the runoff ranged from 10.5 % to 17.5% of average annual rainfall during 1951 to 2020. The present study finding that runoff of 15% before treatment in the study watershed is very near to the range of 10.5 to 17.5% of rainfall indicated by [15].

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 seasonal rainfall and runoff were worked out to 672.4 and 67.7 mm, respectively for the year 2015. The seasonal runoff percentage was worked out to be 10% of rainfall despite receiving relatively 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. 6.

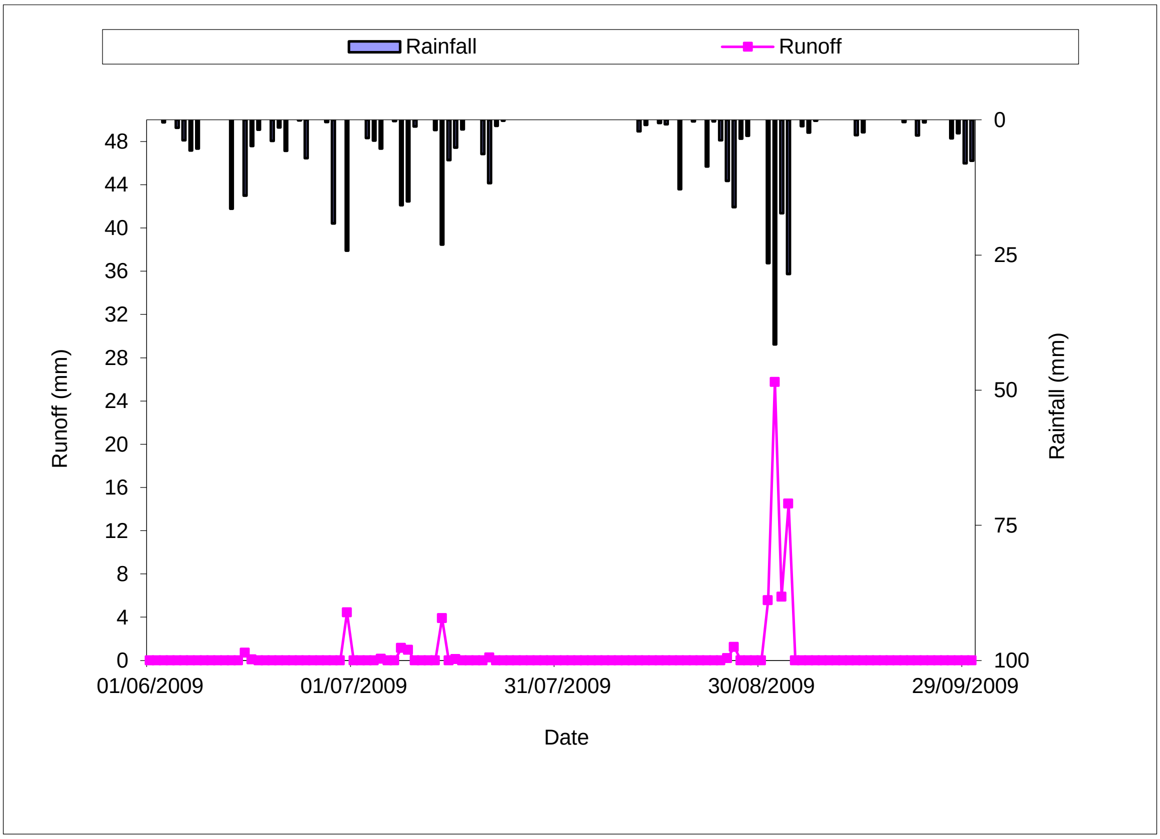

Fig. 4. Hydrological response of watershed (Year 2009)

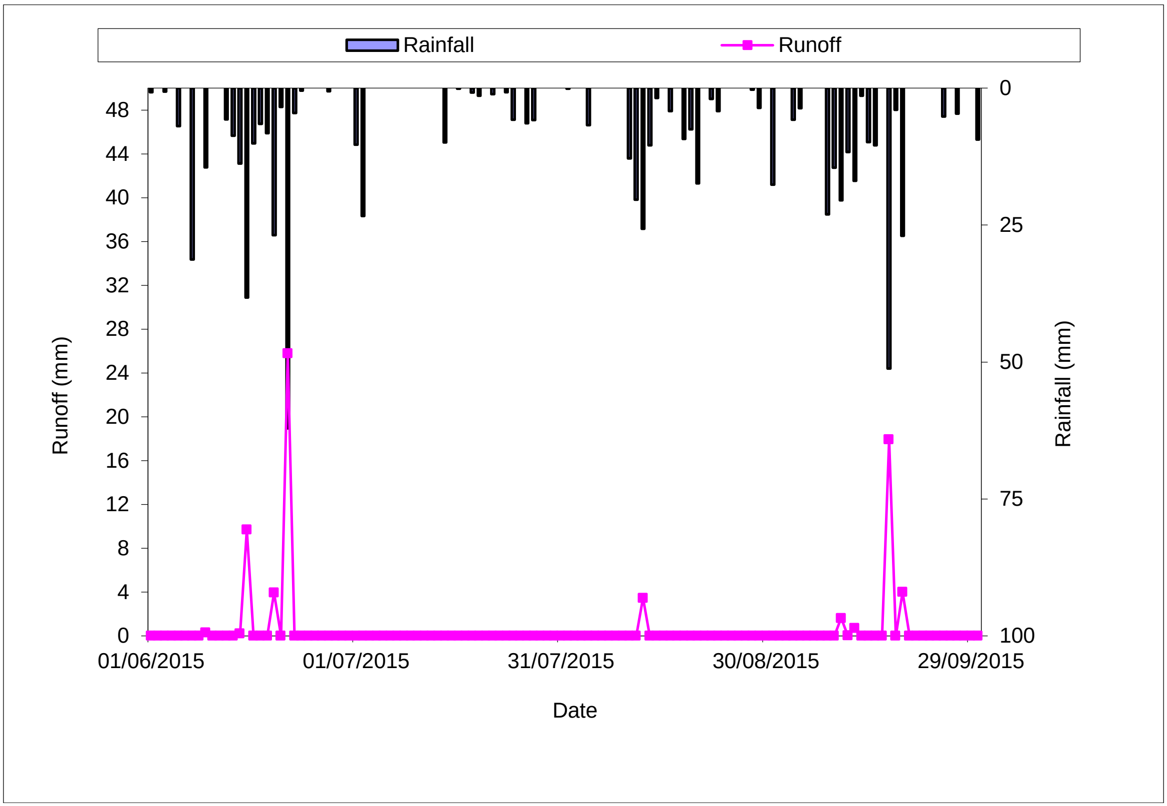

Fig. 5. Hydrological response of the watershed (Year 2015)

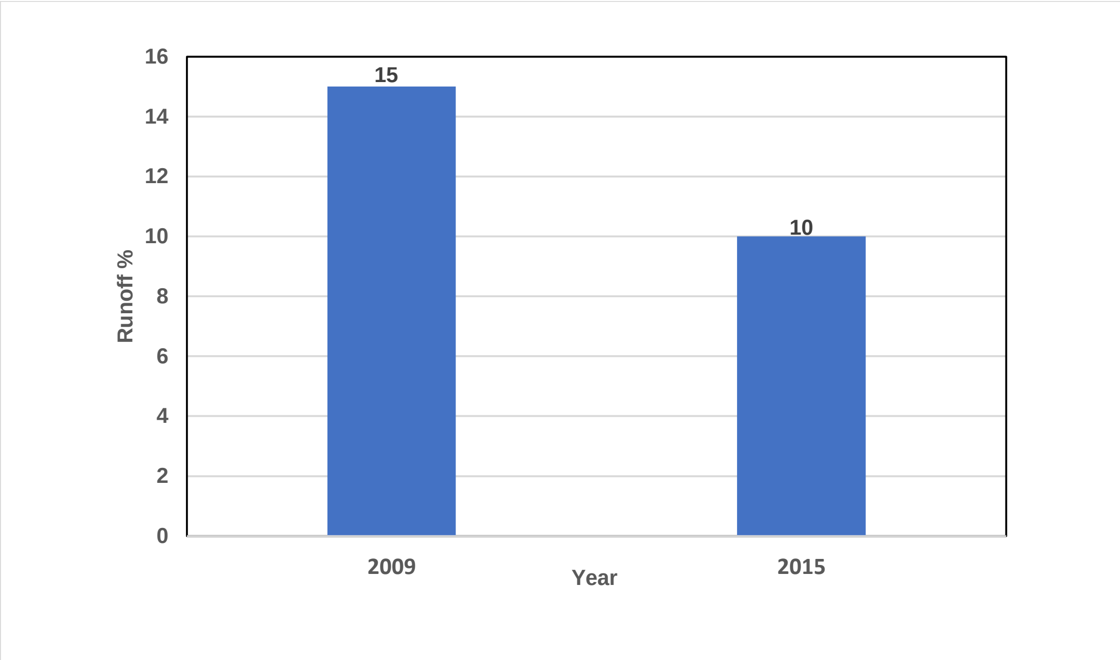

Fig. 6. Year wise percentage of runoff from the watershed

It can be observed from Fig. 6 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 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 [16], 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 (as percentage of rainfall), resulting from rainfall due to conservation measures in the post-watershed project stage. Further, the additional storage volume is obtained by multiplying runoff reduction percentage with rainfall received and geographical area of watershed in consistent units. The 5% reduction in runoff converted to volume of water retained (i.e. additional storage) in the watershed worked out to 4,51,180.4 cubic m with seasonal rainfall of 672.4 mm (for the year 2015 i.e. post-project phase) and 1342 ha geographical area of watershed. Thus, the estimated additional storage capacity was found to be 336.2 cubic m per hectare (additional storage volume in cubic m divided by geographical area (in hectare) of watershed).

Overall, the impacts of conservation measures on the hydrological behaviour of watershed are found to be positive in the study watershed. The main observed change in hydrological behaviour was the decrease in monsoon seasonal runoff by 33% (from 15 % before taking up catchment management measures to 10 % of seasonal rainfall after the project).

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.

The total surface water storage potential created in the watershed is 53950 cubic m (Table 3). 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 about 60 rainy days) in a year the total storage capacity created in the watershed worked out to 4,31,600 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.

The surface storage of water due to conservation measures to the tune of 322 cubic m per hectare resulted in changes in the land use, thus reducing the runoff from the watershed. This is expected to have influenced the groundwater recharge and water balance in the watershed.

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**

4. 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 decreased by 33% from 15% in the year 2009 to 10% (of seasonal rainfall) 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 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.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Rao KVR, Bhattacharya AK, Mishra K. Runoff estimation by Curve Number method-Case studies. Journal of Soil and Water Conservation. 1996;40: 1-7.
2. Mishra P, 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, 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, Babu RR. 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 KN, Kumar M, Sibastian, Paul K. Hydrological modelling for runoff determination: Remote sensing technique. J. Water Resources Planning and Management. 1991;7(3):178-184.
6. Sharma T, Satya Kiran PV, Singh TP, Trivedi AV, Navalgund RR. 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, Dabral PP. Estimation of runoff for hilly catchment using satellite data. Journal of the Indian Society of Remote Sensing. 2004;32(2):236-240.
8. Verma SK, Singh J, Tiwari SC, Ranade DH. Runoff estimation by using Remote Sensing and GIS from watershed. Journal of Soil and Water Conservation. 2006;5(3):49-53.
9. Sinha J, Pal DK. 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;67.
10. Deshmukh DS. Chaube UC, Hailu AE, Gudeta DA, Kassa MT. 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 SK, Chaudhary A, Shrestha RK, Pandey A, 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, 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, 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 SB, Salunkhe SS, Shinde VT, Singh M, Sahu RK. Comparison of erosion prediction models – a case study of coastal region. Journal of Soil and Water Conservation. 2021;20(4): 386-394.
15. Nirmala B, Rejani R, Kumar SK, Kumar SR. Estimation of runoff using SCS-CN method and geographic information system under changing climatic scenarios in Halia catchment. Indian Journal of Soil Conservation. 2022;50(2):113-119.
16. Rajasekharappa KS, Ravi Kumar BC, 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;107.

Peer-review history:
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