Assessing Water Balance Influenced by Conservation Measures for Sustainable High-Value Vegetable Cultivation: A Case Study of Battuvagu Watershed in Telangana

ABSTRACT

In the recent years, the adverse effects of climate change have been found to be exacerbating the complex problems in rainfed areas that constitute about 50% of cultivated area, contributing to 40% of food production of India. While climate change affects many aspects of the environment, its impact on water resources is often swift and apparent, with far-reaching consequences for ecosystems, human well-being, and sustainable development In this context, water budgeting at watershed level and its management are crucial towards promotion of climate resilient agriculture in the rainfed ecosystems. Comprehensive assessment of water balance was attempted estimating the demand from agriculture, domestic and livestock needs and availability of water in terms of groundwater recharge from different sources and effective surface water stored in an agricultural watershed falling in Siddipet district of Telangana state of India. The study revealed that the total water balance of the study watershed was negative (- 1.18 ha-m) before implementation of watershed development project, while it turned out to be positive (+ 67.91 ha-m) during the post-project phase. This study revealed the effectiveness of soil and water conservation measures taken up as a part of watershed development project in enhancing groundwater recharge and effective surface water storage capacity leading to positive water balance. The study further critically evaluated the use of groundwater for meeting the water demand in terms of stage of development in the pre and post project scenarios.The study concluded that there is a need for controlling the over extraction of groundwater through crop diversification especially towards high value vegetable cultivation based on water availability with active people participation along with awareness building, propagation of efficient water application (micro-irrigation) methods, group mode of irrigation, and conjunctive use of surface and groundwater, etc. for long-term water security in the watershed.

Comment [LI1]: This sentence does not explain enough about the study methodology.

Key words: water balance, watershed, conservation, groundwater, Siddipet and Telangana

INTRODUCTION

Water is a vital resource for sustaining life, agriculture, and economic development. In India, where about 60% of the population depends on agriculture, water management becomes crucial, especially in rainfed areas that contribute around 40% to the country's food production [13]. Rainfed regions, which make up nearly 50% of the cultivated area in India, face persistent water scarcity due to the erratic nature of rainfall, exacerbated by climate change. This has increased the need for sustainable water management practices, particularly water budgeting at the watershed level, to ensure water security and agricultural resilience.

Watershed-based water budgeting offers a holistic approach to managing water resources by integrating surface water and groundwater availability with the demands of agriculture, domestic use, and livestock [12]. A watershed is a land area that channels rainfall to streams, rivers, or lakes, and serves as a natural unit for water resource planning. Water budgeting in this context involves calculating the total water inflow (rainfall, surface water storage, and groundwater recharge) and comparing it to the total water demand within the watershed. The aim is to identify water deficits or surpluses and guide resource allocation and conservation efforts accordingly [11].

The need for water budgeting becomes even more pressing when viewed in the context of climate change. Shifts in rainfall patterns, increased frequency of droughts, and more intense flooding are expected to worsen water scarcity in rainfed areas [3]. Rainfed agriculture is particularly vulnerable because it depends entirely on rainfall for crop irrigation. Watershed-level water budgeting offers a solution by assessing water availability and guiding water-efficient agricultural practices, such as crop diversification and micro-irrigation [2, 4, 6, 7, 9, 10]

Watershed development projects typically include interventions like contour bunding, percolation tanks, check dams, and afforestation, which improve groundwater recharge and surface water retention. These measures have been proven to reduce runoff and reduce water stress in agricultural communities by ensuring better water management and availability during critical periods [5, 6, 14]

[9] carried out water budget analysis of a Babhulgaon watershed in Maharashtra state of India under deficit rainfall years and concluded that the deficiency of water resources in the watershed can be overcome by harvesting the available potential of runoff and efficient utilization by increasing micro irrigation techniques like drip, sprinkler irrigation and also decreasing area of high water required crops and modifying in cropping pattern according to water budget. These practices help reduce water demand while improving crop yields, making agriculture more resilient to climate change.

Water budgeting and water management enhances agricultural productivity and improves water use efficiency through crop diversification and micro-irrigation techniques. This approach has shown to be particularly beneficial in promoting climate-resilient agriculture in drought-prone areas [2]. The water budgeting must also account for the need to regulate groundwater extraction and promote water-saving technologies like drip and sprinkler irrigation. Crop diversification, where high-water-consuming crops are replaced with less-demanding varieties, is another key strategy for achieving sustainable water use in these areas [1,8]. Appraisal of water resources at tempo-spatial scales enables proper planning for water resource utilization and efficient management for sustainable development [11].

The water budgeting at the watershed level is an essential tool for managing water resources sustainably in India’s rainfed areas. By balancing water availability with demand and promoting efficient water use, water budgeting contributes to the long-

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term resilience of agriculture and water security. As the impacts of climate change continue to intensify, adopting watershed-based water management practices will be critical to ensuring the sustainability of water resources and food security in India.

In this background, the present study aims at studying the water balance of an agricultural watershed as influenced by conservation measures taken up from ridge to valley in an agricultural watershed in Telangana state of India. The study also critically evaluated the usage of groundwater in the watershed in terms of stage of development.

Comment [LI2]: There is a need for additional literature studies related to groundwater conservation and exploitation measures for agricultural development.

METHODOLOGY

The study was conducted in a watershed located in the hard rock zone of Siddipet district, Telangana, India. The location map of the watershed is given in Fig. 1. With a total geographical area of 1,342 hectares, the watershed falls within a semi-arid climate, with an average annual rainfall of 770 mm, of which over 85% occurs during the South-West monsoon. The watershed development program was implemented from 2009 to 2014, with strong local community involvement. The region experiences extreme temperatures, with mean highs of 47°C and lows of 9°C [7].

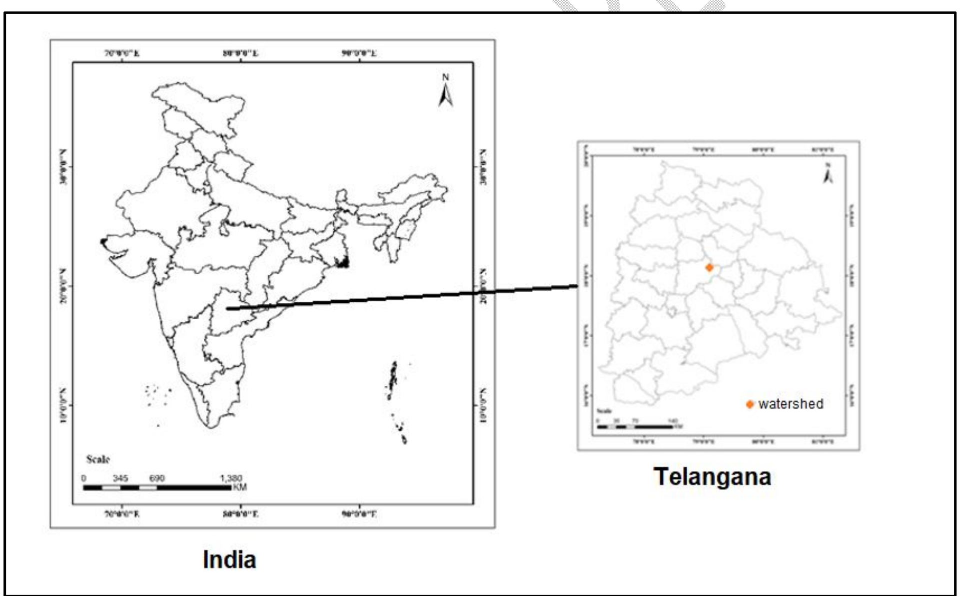

Fig. 1 Location map of study watershed [7]

The first step involved collecting data on the human and livestock population within the watershed to assess water demand for domestic, livestock, and industrial purposes before and after the project. Additionally, land use details were analyzed, focusing on irrigation areas and water needs for crops in the Kharif and Rabi seasons. The irrigation requirements for perennial crops were also determined. These assessments were combined to estimate the total water demand for the region.

Following this, an inventory of surface storage structures, such as tanks, nala bunds, and various soil and water conservation interventions, was compiled. The surface water storage capacity was calculated, considering average number of times these structures could be filled, duly accounting for seepage and evaporation loss of water. The hydrological year is taken as June to May of the two consecutive years for the present water balance study. Using the details of watershed's geographical area and rainfall data for both pre- and post-project periods were gathered, the total water inflow into the watershed was estimated.

Runoff was estimated using Strange's Theory, which simplifies the calculation by considering land cover, soil type, and catchment characteristics. The groundwater recharge was calculated based on rainfall, return flows, water stored in surface structures, and runoff. Total water availability was then determined by combining surface water storage and groundwater recharge. Groundwater recharge was calculated by considering factors such as recharge percentage, watershed area, with adjustments based on the characteristics of the local aquifer. The total water available in the watershed is computed as the sum of effective storage in various conservation structures and total groundwater recharge.

The water balance was them calculated by subtracting total water demand from total water availability. Soil moisture, which plays a key role in supporting rainfed crops, was accounted towards meeting the needs of rainfed crops, evaporation and other losses. It was ensured that the final water budget provided a more accurate reflection of available water resources in the watershed.

To automate the water balancing exercise, MS- Excel is used. Lastly, the study also examined the usage of surface and groundwater in the watershed, with particular attention to evaluation of stage of groundwater development during the pre- and post-project phases.

Comment [LI3]: The steps in this methodology should be written in a brief abstract, and also be an addition to the literature review.

RESULTS AND DISCUSSION

While the watershed development project was implemented from 2009 to 2014, the pre-project (year 2008) and post-project year 2015) water balance of the watershed was worked out. The rainfall during 2008 and 2015 was 855.6 mm and 792 mm, respectively. Thus, there is shortfall of rainfall by 8% in the year 2015.

The results of water balance study in terms of water demand, water availability and net deficit/excess in the pre- and post- project stages of Battuvagu watershed development project in Telangana state of India are given Table 1 and Table 2 and discussed as below:

Table 1: Details of human and livestock population and water demand (pre and post project stages)

S. No.	Category	Population (No.)		Water requirement (ha-m)	
		2008	2015	2008	2015

1	Human	656	701	2.394	2.559
2	Cattle	191	280	1.046	1.533
3	Small ruminants	116	125	0.042	0.046
4	Poultry	257	227	0.0023	0.0020
	Total			**3.4843**	**4.140**

Table 2: Water Balance of Battuvagu watershed (pre and post project phases)

S.No.	**Parameter**	**Quantity (ha-mm)**	
		Pre-Project (2008)	**Post-Project (2015)**
Water demand			
1	Water demand for humans and livestock	3.48	4.14
2	Water demand for irrigation of crops	168.79	186.19
3	Total water demand in the watershed ((1)+(2))	172.27	190.33
Water availability			
4	Rainfall contributing to ground water recharge	114.82	159.43
5	Ground Water Recharge from other sources	17.66	35.69
6	Runoff	172.23	106.29
7	Soil moisture build up (used by rainfed crops), evaporation and other losses	861.16	797.15
8	Surface water stored/retained in the watershed	38.97	86.13
9	Evaporation loss of surface water stored/retained	11.69	25.84
10	Effective surface water stored/retained in the watershed	27.28	60.29
11	Balance surface water going out of watershed	133.26	20.16
12	Groundwater recharge due to outflowing surface runoff water	11.33	2.82
13	Total groundwater recharge/available (4+5+12)	143.81	197.94
14	Total water availability in the watershed ((10)+(13))	171.09	258.23
Net water balance			
15	Deficit/Excess ((14)-(3))	-1.18	67.91
Stage of groundwater development			
16	Stage ((3)/(12)*100) in %	120	96

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Estimation of Water Demand:

The details of human and livestock population and their estimated water requirement based on standard average use are given in Table 1. The water demand assessment was made for drinking water and other needs of human beings and livestock and irrigation needs of crops. There is no industry present in the study watershed and hence the same was not considered for the estimation of water demand. The water demand during the post project phase of watershed development project increased by 19% with the increase in human and livestock population (Table 1).

While most of the cultivation of crops is mainly dependent on rainfall i.e. rainfed and consequent availability of soil moisture, limited area was under irrigation using open wells and bore wells, while there is no practice of use of surface stored water. The main crops cultivated with irrigation facility using open and bore wells included Maize, Paddy, and Vegetables. Based on the crop wise area under cultivation and water requirement od crops, the total water use for irrigation purpose during pre-project phase was estimated as 168.79 ha-m (Table 2) during the pre-project phase (year 2008), while the same is estimated at 186.19. ha-m (Table 2) during post project phase (year 2015), signifying the increase of irrigation water demand by 10.4% during the post-project phase with increased area under cultivation with irrigation.

The total water demand in the watershed in the year 2008 was 172.27 ha-m (Table 2). This demand encompasses 3.48 ha-m for domestic & livestock use (Table 1 and Table 2) and a significant portion of 168.79 ha-m for irrigation of crops, as given in Table 2. In the post project period, the demand for domestic & livestock use increased to 4.14 ha-m (Table 1 and Table 2). Further, the demand for crops rose to 186.19 ha-m, resulting in total water demand of 190.33 ha-m during the post-project phase (Table 2).

Comment [LI4]: This analysis of the results should be written before the table, and it needs a little revision in the way it is written so that it is easy to understand.

Estimation of Water Availability:

The total water demand in the watershed in the year 2008 was 172.27 ha-m. This demand encompasses 3.48 ha-m for domestic & livestock use and a significant portion of 168.79 ha-m for agricultural activities. The main crops cultivated in the watershed include Maize, Paddy, Vegetables. In the post project period, the demand for domestic & livestock use was increased to 4.14 ha-m. Similarly, the demand for irrigation of crops rose to 186.19 ha-m.

Water inflow:

The total water inflow into the watershed is mainly on account of rainfall. With geographical area of 1342 ha and rainfall of 855.6 mm (during 2008) and 792 mm (during 2015), respectively, the total water inflow into the watershed is estimated at 1148.22 ha-m and 1062.86 ha-m during the years 2008 and 2015, respectively.

Water Storage:

In the pre-project stage (year 2008), there was limited rainwater storage capacity of 38.97 ha-m. There were mainly three traditional storage tanks with a storage capacity of 37.92 ha-m and four number mini-percolation tanks with a storage capacity of 1.05 ha-m, thus totalling to 38.97 ha-m.

In the post-project phase (year 2015), with the execution of soil and water conservation measures additional storage capacity of 47.16 ha-m has been created, resulting in enhanced storage capacity of 86.13 ha-m (Table 2) i.e. 121% increase in the water storage capacity in the watershed. However, the effective surface water stored//retained in the watershed in the year 2008 and 2015 duly accounting of evaporation loss of 11.69 ha-m during pre-project phase and 25.84 ha-m during post project phase, stood at 27.28 and 60.29 ha-m, respectively (Table 2).

Groundwater recharge:

Groundwater recharge was estimated from rainfall, return flows, stored surface water, and runoff in the pre and post project stages. It stood at 143.81 and 197.94 ha-m, respectively (Table 2) i.e. about 38 % increase in the groundwater recharge in the watershed due to execution of conservation measures in the post-project phase.

Runoff:

The estimated runoff for the years 2008 and 2015 stood at 172.23 and 106.29 ha-m, respectively (Table 2), indicating substantial decrease in runoff due to conservation measures taken up and land use and land cover changes in the watershed.

Soil moisture and evaporation:

The soil moisture build up that meets the requirement of rainfed crops, evaporation and other losses was estimated at 861.16 and 797.15 ha-m, respectively. The reduction in rainfall during 2015 resulted in reduced soil moisture build up.

The total water availability:

The final total water availability was found to be 171.09 ha-m (Table 2) in the pre-project phase, while it worked out to 258.23 ha-m (Table 2)during post project phase, despite receiving deficit rainfall by 8% compared to that of the year 2008 i.e. pre-project year under consideration of the study. Thus the total water availability in the watershed was enhanced by about 51% of that of pre-project phase, signifying the effective role of soil and water conservation measures.

Net water balance (Deficit/Excess):

As the final step of water balance study, the net water balance in terms of deficit/excess was worked out. The above results are summarized in the Figure 2, which graphically presents the comparative position of water demand, availability and deficit/excess during pre and post phases of implementation of watershed development projects. As seen from Figure 2, despite increasing in water demand, with the improvement in water availability, the final net water balance worked out to be positive during the post project phase. The study revealed that the water balance

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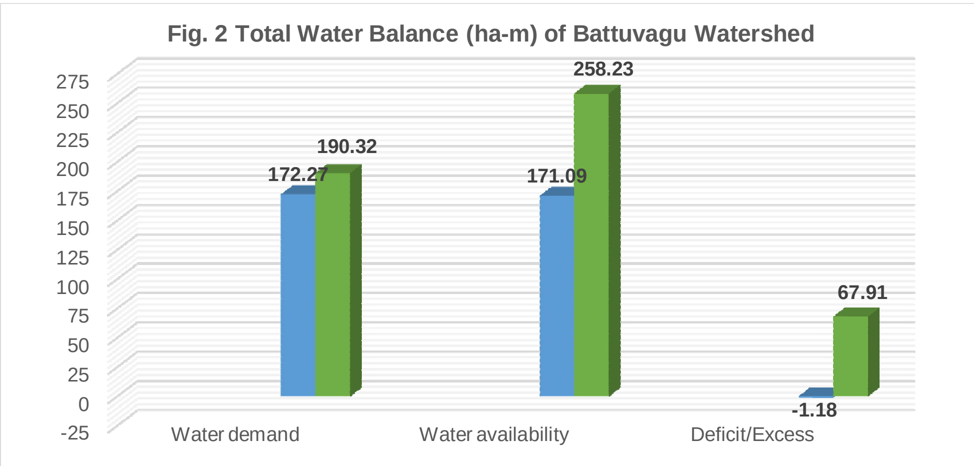
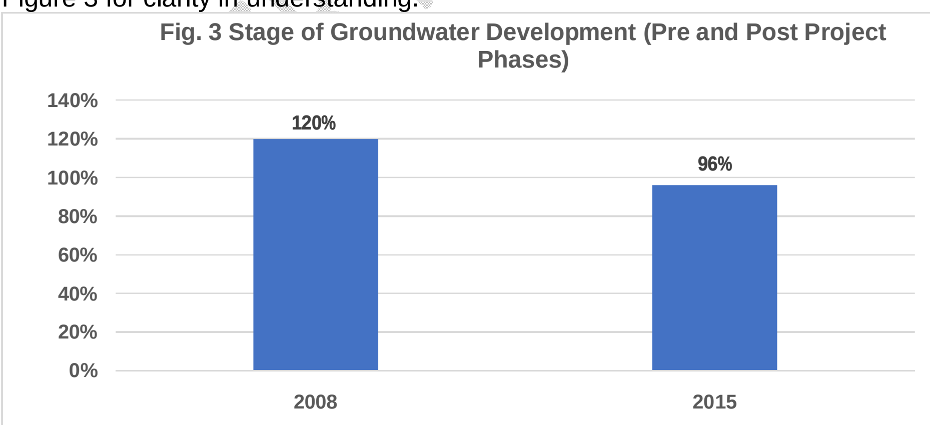
of the study watershed was negative (- 1.18 ha-m) before implementation of watershed development project, while it turned out to be positive (+ 67.91 ha-m) during the post-project phase (Table 2 and Figure 2).



Further, the study of usage of surface and groundwater by the community revealed that presently the surface water is not used for irrigation and other purposes, while the groundwater is extensively used for both irrigation of crops and other needs including drinking and domestic needs humans and livestock in the watershed. The stage of ground water development is evaluated in percentage by dividing the total water demand with total groundwater (Table 2). A comparative chart outlining the stage of groundwater development during pre and post project stages is presented in Figure 3 for clarity in understanding.



The stage of groundwater development was found to be 120% during pre-project phase i.e. over exploited category, while it has come down to 96% with increased recharge and groundwater availability (Table 2 and Figure 3). Though there is substantial increase in effective surface storage of water in the Battuvagu watershed that led to positive total water budget, however use of surface water is not found during the study. Even the present stage of development of 97% makes the watershed to be in critical category, signifying the need crop diversification towards less water consuming high value vegetable cultivation.

In view of the above, for long-term sustainability of interventions and positive impact on water balance in the Battuvagu watershed, there is a need to promote crop diversification towards high-value vegetables based on water availability. Active community participation, along with raising awareness, is crucial for implementing efficient water application methods like micro-irrigation and ensuring the conjunctive use of surface and groundwater. Also, group irrigation models connecting bore wells with pipe network and use of micro-irrigation need to be promoted for the benefit of smallholders duly inculcating the sense of cooperation as also treating groundwater as a common resource. These measures will lead to sustainable water management and secure long-term water resources for agricultural productivity. Decisive action in this direction is essential to prevent future water scarcity in the watershed.

CONCLUSION

India now being the one of the water stressed country with high population and increased evidence of water resource vulnerability to adverse effects of climate change, necessitates a shift towards viewing water as a shared common resource by the communities. This needs community led participatory water management through conservation measures coupled with water balancing study-based crop diversification. The present study provided vital evidence of highly positive impact of community led participatory watershed development towards achieving positive total water balance. However, the study also pointed out the serious concern of high level of extraction of groundwater use both for irrigation and domestic purposes. Hence, Crop diversification towards low-water, high-value vegetables should be promoted through community engagement. This would involve massive community awareness creation, promotion of conjunctive of use of surface and groundwater, adoption of group irrigation and efficient water application methods, etc., based on water availability in addition to effective maintenance of conservation measures taken up as a part of watershed development programme.

Comment [LI5]: The conclusion should be brief and clear enough

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