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

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Rainfed areas are crucial for India's agriculture, covering 50% of the total farmland and contributing 40% of the country's food production. In recent years, the adverse effects of climate change have been found to be exacerbating the complex problems in vulnerable rainfed areas. 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

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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. It involved collection of data on population, land use, and estimating irrigation water needs for crops, humans and livestock, followed by inventorying surface storage structures. Further, water inflow, runoff, and groundwater recharge were calculated using standard methods. The water balance was then determined by subtracting total demand from total availability. The study revealed that the water balance improved significantly, shifting from a deficit (-1.18 ha-m) of pre-project phase to a surplus (+67.91 ha-m) during post-watershed development. Thus, 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 also evaluated the use of groundwater 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 market driven, less water consuming 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.

Keywords: Water balance; watershed; conservation; groundwater; Siddipet; Telangana.

1. 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 [1]. 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 [2]. 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 [3].

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 [4]. 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 [5-10].

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 [7,11,12]

Water budget analysis of a Babhulgaon watershed in Maharashtra state of India under deficit rainfall years was carried out and it was 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 decreasing area of high water required crops and modifying in cropping pattern according to water budget [10]. 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 [5]. 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 [13,14]. Appraisal of water resources at tempo-spatial scales enables proper planning for water resource utilization and efficient management for sustainable development [3].

Groundwater is the main source of irrigation for more than 60% of irrigated area of the country. The irrigation in rainfed areas is mainly dependent on groundwater which in turn is dependent on rainfall [15]. Since the 1960s, the government's support for the "green revolution" to ensure food security has increased the demand for groundwater for agriculture. Rapid rural electrification combined with the availability of modern pump technologies has led to an increase in the number of borewells to meet that demand. Over the last 50 years, the number of borewells has grown from 1 million to 20 million, making India the world's largest user of groundwater [16]. The Central Groundwater Board (CGWB) in the latest dynamic groundwater resource assessment report 2023 [17] estimated that about 25% of groundwater blocks are overexploited, critical, and semi-critical. The report cautioned that the situation is particularly alarming in three major regions – north-western, western, and southern peninsula. While watershed development projects help in conservation of water and enhanced groundwater availability, there is a need to ensure that the precious groundwater is used judiciously.

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-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 evaluated the usage of groundwater in the watershed in terms of stage of development.

2. 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 [8].

The step wise methodology followed, both for the scenarios of pre and post project phases of watershed project is detailed below:

Step 1: Data Collection on Population(human and livestock) and Estimation of Water Demand

The first step involved collecting data on the human and livestock population within the watershed. This data was used to assess water demand for domestic, livestock, and industrial purposes, both before and after the project.

Step 2: Collection of Land Use and Estimation of Irrigation Requirements

In the second step, land use details were gathered, focusing on irrigation areas and the water needs for crops during the Kharif and Rabi seasons. Additionally, the irrigation requirements for perennial crops were determined. Then the total irrigation water requirement for all the crops is assessed.

Step 3: Estimation of Total Water Demand

As the third step, the assessments from population, livestock, and irrigation needs were combined to estimate the total water demand for the region.

Step 4: Inventory of Surface Storage Structures

The fourth step involved compiling an inventory of surface storage structures, such as tanks, nala bunds, and various soil and water conservation interventions. The surface water storage capacity was calculated by considering how often these structures could be filled, with adjustments for seepage and evaporation losses. The hydrological year for this water balance study spanned from June to May of two consecutive years.

Step 5: Estimation of Total Water Inflow

In the fifth step, the total water inflow into the watershed was estimated using geographical area and rainfall data from both the pre- and post-project periods.

Step 6: Runoff Estimation

The sixth step involved estimating runoff using Strange's Theory, which simplifies the calculation by factoring in land cover, soil type, and catchment characteristics.

Step 7: Groundwater Recharge and Total Water Availability

The seventh step calculated groundwater recharge based on rainfall, return flows, water stored in surface structures, and runoff. The total water availability was determined by combining surface water storage and groundwater recharge. Groundwater recharge was adjusted for factors such as recharge percentage and watershed area, with further adjustments based on the local aquifer's characteristics.

Step 8: Calculation of Water Balance

In the eighth step, the water balance was calculated by subtracting total water demand from total water availability. Soil moisture, which supports rainfed crops, was considered along with evaporation and other losses, ensuring a more accurate reflection of available water resources in the watershed.

Step 9: Estimation of Groundwater Usage

The study also examined the use of surface and groundwater in the watershed, with particular attention to the stage of groundwater development during both the pre- and post-project phases.

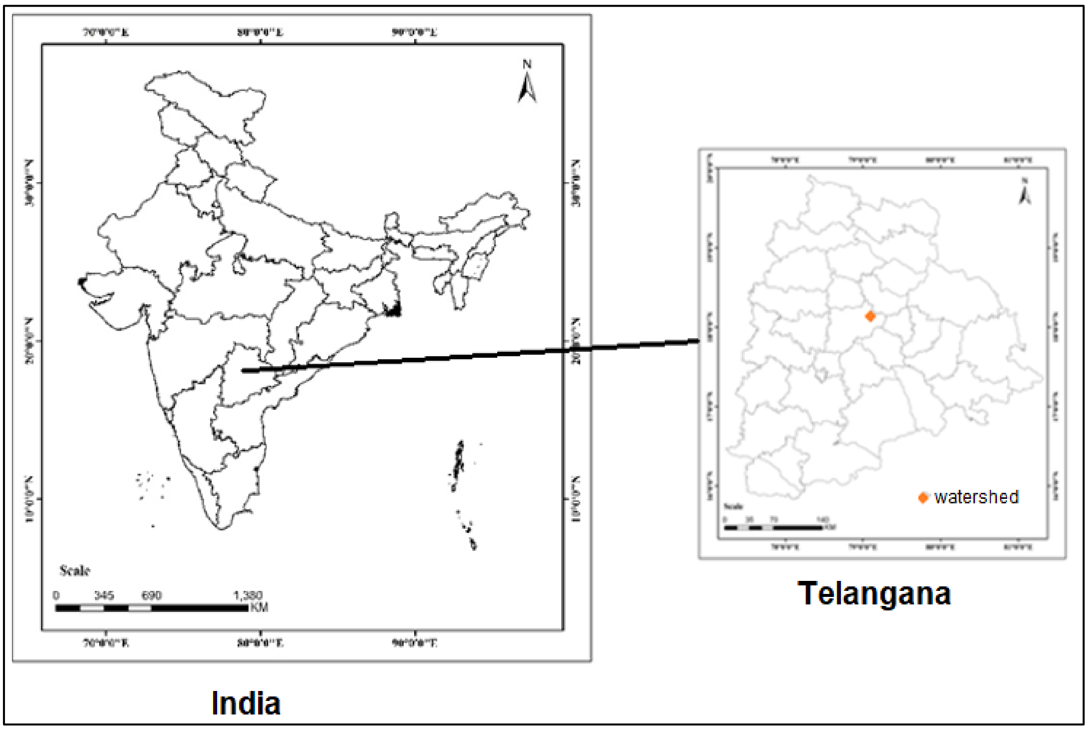

Fig. 1. Location map of study watershed [8]

All the estimates are made in ha-m that refers to the amount of water spread over one hectare to a depth of one meter. The above steps for water balancing and estimation of groundwater extraction were automated using MS Excel and used both for pre and post project phases of Battuvagu watershed.

3. 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:

3.1 Estimation of Water Demand

The details of the human and livestock population, along with their estimated water needs, are shown in Table 1. Water demand was assessed for drinking and other uses for both people and livestock, as well as for irrigation needs of crops. Since there are no industries in the watershed, industrial water demand was not considered. After the watershed development project, water demand increased by 19% due to the rise in human and livestock populations (Table 1).

Most crop cultivation in the area relies on rainfall (rainfed agriculture) and soil moisture, with only a small portion irrigated area using open wells and bore wells. Surface-stored water is not used for irrigation. The main irrigated crops include maize, paddy, and vegetables. During the pre-project phase (2008), the total water used for irrigation was estimated at 168.79 ha-m (Table 2), which increased to 186.19 ha-m in the post-project phase (2015), indicating a 10.4% rise in irrigation water demand due to expanded cultivation area with irrigation.

In 2008, the total water demand in the watershed was 172.27 ha-m, with 3.48 ha-m for domestic and livestock use, and 168.79 ha-m for crop irrigation (Table 1 and Table 2). By 2015, domestic and livestock water demand had risen to 4.14 ha-m, and crop irrigation demand increased to 186.19 ha-m, bringing the total water demand to 190.33 ha-m in the post-project phase (Table 2).

3.2 Estimation of Water Availability

3.2.1 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.

3.2.2 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).

3.2.3 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.

3.2.4 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.

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)/(13)*100) in %	120	96

3.2.5 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.

3.2.6 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.

3.3 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 Fig. 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 Fig. 2, despite increasing water demand, with the improvement in water availability due to conservation measures, the final net water balance worked out to be positive during the post project phase. The study revealed that the 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 (Table 2 and Fig. 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 of 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 recharge (Table 2). A comparative chart outlining the stage of groundwater development during pre and post project stages is presented in Fig. 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 Fig. 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 96% makes the watershed to be in critical category, signifying the need crop diversification towards less water consuming high value vegetable cultivation that improves profitability of agriculture.

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 market driven 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.

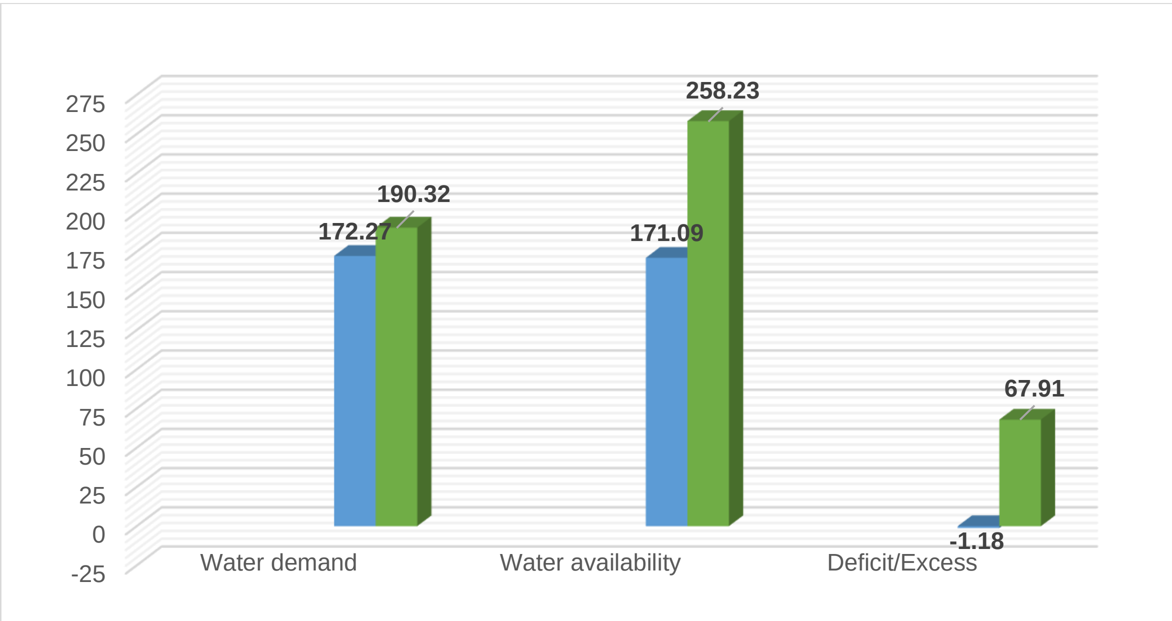

Fig. 2. Total Water balance (ha-m) of Battuvagu watershed

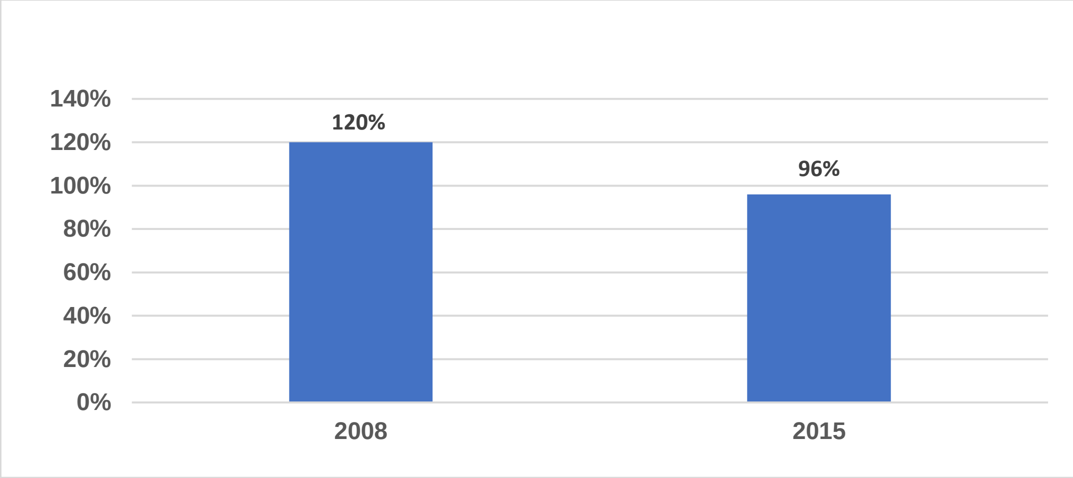

Fig. 3. Stage of groundwater development (Pre and Post Project Phases)

4. CONCLUSION

The watershed conservation measures in Battuvagu transformed the water balance from negative to positive, increasing both groundwater recharge and surface water storage. Despite higher water demand, the interventions successfully improved water availability during post-watershed development stage. However, continued high reliance on groundwater requires immediate action. Promoting crop diversification towards less water consuming high value vegetable crops, efficient irrigation especially micro-irrigation, conjunctive use of surface and groundwater, group irrigation, community-led water management is essential to sustain these gains and ensure long-term water security.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of this manuscript.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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