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Sustainable Cashew Cultivation through Water Footprint Assessment and Conservation in Rayagada and Gajapati Districts, Odisha (India)

Arun Bhagat[1], Aparna Yadav[2], Faraz Rupani[3], Gyana Ranjan Baral[4], Marcella D'Souza[5] and Nikhil Nikam[6]

ABSTRACT

Cashew cultivation, initially introduced for soil erosion control, has developed into an important contributor to global trade and a major livelihood source for small and marginal farmers, who represent over 70% of growers in India. In Odisha, with nearly 2.23 lakh hectares under cashew, large-scale plantations were initiated during 1954–55 under the Soil Conservation Department. This study focuses on Gajapati and Rayagada districts, where tribal communities rely on cashew cultivation but face constraints such as soil erosion due to hilly terrain, post-monsoon water scarcity, and climate variability.

Targeted soil and water conservation (SWC) interventions were implemented in selected villages of Gunupur and Gumma blocks to address these challenges. The study estimates the water footprint of cashew, assesses the impact of SWC measures on soil erosion, and identifies strategies to improve productivity. Results indicate that the average water footprint is about 15 m^3/kg for raw nuts and 50 m^3/kg for shelled nuts, with water deficits of 223 mm (948 m^3/ha) in Gajapati and 224 mm (971 m^3/ha) in Rayagada.

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The implementation of SWC measures – such as contour trenches, bench terraces, water absorption trenches, coconut husk burial, mulching, and modified bunds – can reduce soil erosion, alleviate water deficits, and improve soil health, thereby supporting sustainable yields across plantation stages. In the absence of irrigation infrastructure, improved SWC practices are essential for enhancing cashew productivity, addressing climate change impacts, and sustaining livelihoods in these regions.

Keywords: Cashew Cultivation, Water Footprint, Soil and Water Conservation, Water Deficit, Soil Erosion

Introduction

Cashew (Anacardium occidentale L.), native to Brazil (Mangalassery et al., 2024; Nair, 2020; Malik and Bhadauria, 2020; Jusna Mariya, 2009), was introduced to India by Portuguese explorers in the 16th century (Achaya, 2017) and has since become well adapted to diverse agro-climatic conditions (Mog et al., 2026; Poduval, 2022; Warren, 2015). In India, it is predominantly grown along coastal regions of Maharashtra, Goa, Karnataka, Kerala, Tamil Nadu, Andhra Pradesh, Odisha, and West Bengal (Hegde, 2022), often on sloping, degraded, and marginal lands as a rainfed crop (Mangalassery et al., 2024; Adjei and Alormu, 2020; Rupa et al., 2013), mainly for soil conservation and wasteland development (Prabhakaran and Nedumaran, 2022). At present, cashew plays a significant role in global trade and foreign exchange earnings (Tola and Mazengia, 2019), with India producing nearly 9.98 lakh metric tons from about 10.30 lakh hectares (Nayak and Paled, 2018). This labour-intensive sector sustains the livelihoods of small and marginal farmers (Hegde, 2022), though productivity levels remain lower compared to other producing countries (Kamble, 2023).

Odisha accounts for about 2,23,450 hectares under cashew, with an annual production potential of 1,21,280 metric tons (DCCD, 2023). Large-scale plantation activities were initiated during 1954–55 under the Soil Conservation Department to control soil erosion. Cashew cultivation provides employment and income to numerous rural and tribal households, many of whom depend heavily on it. However, farmers in Gajapati and Rayagada districts face multiple constraints, including post-monsoon water scarcity due to insufficient water-holding structures, soil erosion on undulating terrain, and adverse impacts of climate change that reduce productivity.

Water resources in these regions are increasingly under pressure due to declining per capita availability, competing sectoral demands, pollution, low water-use efficiency in agriculture, and shifting monsoon patterns that influence runoff

and groundwater recharge (Kaur and Gauttam, 2022). Although irrigation has the potential to improve yields (Gondim et al., 2024; Saroj and Rupa, 2014), access to reliable water sources remains limited for small and marginal farmers (Saha et al., 2023). Water scarcity intensifies soil moisture stress, increases dependence on groundwater, and ultimately reduces crop yields (Nigatu et al., 2022). Climate change further compounds these issues through rising temperatures, increased evapotranspiration, altered rainfall regimes, and prolonged dry spells, affecting both water availability and quality (Nair et al., 2024).

Irregular rainfall during January to May aggravates moisture stress, negatively affecting flowering and fruit set (Mog et al., 2022). This is particularly evident in Gajapati and Rayagada districts, where it leads to premature nut drop and reduced yields (Dayal et al., 2022). In this context, in-situ soil and water conservation (SWC) measures play a crucial role in capturing rainwater and ensuring its availability during critical crop growth stages (Borah et al., 2024), thereby improving yields (Mahajan et al., 2021), reducing soil erosion, and conserving both pre- and post-monsoon runoff.

To address these challenges, the Watershed Organisation Trust (WOTR), with support from ANDHERI HILFE (AH) and the German Federal Ministry for Economic Cooperation and Development (BMZ), implemented SWC interventions in selected villages of Gunupur and Gumma blocks in Rayagada and Gajapati districts. These interventions aim to enhance productivity, reduce the gap between actual and potential yields (Gawankar et al., 2020), improve farmers' incomes, and strengthen India's competitiveness in the global cashew sector (Ramteke et al., 2024). The present study highlights the economic significance of cashew in Odisha and aims to assess its water footprint, evaluate the effectiveness of SWC interventions in controlling soil erosion, and propose practical strategies to improve sustainability and productivity.

Study Area

The study was conducted in Gajapati and Rayagada districts of Odisha, situated in the Eastern Ghats and characterized by hilly, forested terrain. These regions are prone to severe soil erosion and experience acute water scarcity during the non-monsoon period (Srivastava, A., & Chinnasamy, 2024; Manivannan et al., 2017; Swamy, 2018). For this study, four villages—Tada, Gade, Guleijung, and Kudinguda-Sanamunisingi—were randomly selected from 39 villages across Gunupur and Gumma blocks where soil and water conservation (SWC) interventions had been implemented by the Watershed Organisation Trust (WOTR) with financial support from ANDHERI HILFE (AH) and the German Federal Ministry for Economic Cooperation and Development (BMZ).

Information on water availability, changes in cashew yield, and plantation health was collected from five representative farmers in each village, resulting in a total sample of 20 farmers. The geographic details of the selected villages are presented in Table 1.

Table 1: Location details of selected study villages

District	Block	Study Village	Longitude (°E)	Latitude (°N)	Area (ha)
Rayagada	Gunupur	Tada	83.950	19.009	498.7
Rayagada	Gunupur	Gade	83.921	19.033	295.2
Gajapati	Gumma	Guleijung	83.989	18.984	110.1
Gajapati	Gumma	Kudingu-da-Sanamu-nisingi	83.924	19.010	156.9

Data Collection

Field data were collected using focus group discussions (FGDs), field observations, and structured questionnaires. In addition, long-term gridded weather data—comprising rainfall and maximum and minimum temperatures for 44 years (1980–2023)—were obtained from the Indian Meteorological Department (IMD) (Soni and Tripathi, 2024; Kumar et al., 2024; Pai et al., 2014; Srivastava et al., 2009).

Methodology

This section describes the methods applied to estimate the water footprint and assess the hydrological effects of soil and water conservation (SWC) interventions, particularly in relation to soil erosion.

Water Footprint (WF)

The water footprint quantifies the volume of freshwater used, both directly and indirectly, in the production of goods, particularly crops, relative to output. It comprises green, blue, and grey water components and is commonly expressed in m^3/ton or liters/kg. This indicator evaluates production efficiency by accounting for water consumption as well as the volume required for pollutant assimilation, thereby providing insights into sustainable water use.

In this study, blue and grey water footprints of cashew cultivation were assessed through village-level focused group discussions (FGDs) with cashew growers, along with detailed information on irrigation practices and nutrient

application across plantations of different ages. Field visits to two cashew processing units—Shri Krishna Cashew Industry in Padmapur, Gajapati, and Shri Narayana Cashew Industry in S. P. Guda, Gunupur, Rayagada—were also conducted to understand water use during primary processing of shelled cashews. The assessment followed standard procedures outlined in the Water Footprint Assessment (WFA) Manual (Aldaya et al., 2012) to ensure a systematic and comprehensive evaluation of water use across all components.

Green Water Footprint (WFgreen)

The green water footprint is defined as the ratio of green water use—i.e., soil moisture or rainfall stored in the root zone (excluding runoff) and lost through evapotranspiration during the crop growth period—to the economic yield (t/ha). Green crop water use (CWUgreen) was estimated as the lesser of crop evapotranspiration (ETc) and effective rainfall (ER) over the crop period. Effective rainfall was assumed as 70% of average seasonal rainfall, following Dastane (1974).

Daily ETc was calculated using reference evapotranspiration derived from the Hargreaves–Samani (HS) method (Allen et al., 1998) along with stage-specific crop coefficients (Kc) obtained from the Regional Fruit Research Station, Vengurla, Maharashtra. As the cashew varieties Bhubaneshwar-1, Balabhadra (BH-85), and Jagannatha (BH-6), commonly cultivated in Odisha, are related to Vengurla types (with Bhubaneshwar-1 being a progeny of Vengurla 36/3; Eradasappa et al., 2022), their stage-wise Kc values were converted into daily coefficients to estimate ETc for plantations of different ages.

Blue Water Footprint (WFblue)

The blue water footprint is expressed as the ratio of blue water consumption (m^3/ha) over the crop growth period to the economic yield (t/ha). Blue crop water use (CWUblue) refers to the volume of irrigation water applied in addition to effective rainfall (ER), and total CWUblue was estimated as the cumulative irrigation supplied during the crop cycle.

Grey Water Footprint (WFgrey)

The grey water footprint represents the volume of freshwater required to dilute pollutants to acceptable water quality standards and serves as an indicator of environmental impact. Under organic farming systems, this component can be negligible or even approach zero, emphasizing its role in reducing pollution. In the present study, focus group discussions (FGDs) with farmers in Gunupur and Gumma blocks indicated that cashew cultivation is entirely under cultivation without chemical fertilizers all across plantations of different ages.

Farmers depend solely on rainfall and organic inputs, resulting in negligible contributions from both blue and grey water footprints at the field level.

However, at the processing stage, water use becomes relevant, as approximately 3 liters of water are required to process one kilogram of shelled cashew from raw nuts. The analysis in this study is confined to on-farm water footprints and excludes additional components such as transport, marketing, input production, and supply chain processes. Since only about 20–30% of raw cashew weight is recovered as shelled kernels, the water footprint of shelled cashews is estimated to be 3–4 times higher than that of raw cashews.

Soil Erosion Estimation

The Unit Stream Power Erosion and Deposition (USPED) model (Oliveira et al., 2022; Warren et al., 2005), an extension of USLE and RUSLE, was used to evaluate soil erosion before and after soil and water conservation (SWC) interventions. Soil loss was estimated within the USLE framework incorporating USPED modifications, with all parameters processed in a GIS environment. Rainfall erosivity (R) for India was derived following Tiwari et al. (2016) using CHIRPS daily rainfall data (2020–2023) at 5 km resolution (Funk et al., 2015). Soil erodibility (K) was computed using standard equations, while slope length (L) and slope steepness (S) factors were generated from 30 m SRTM DEM data.

The cover management factor (C) was estimated annually using NDVI, and the support practice factor (P) was assigned based on land use/land cover classes. A QGIS-based modelling framework was developed to integrate all parameters with watershed boundaries, enabling estimation of soil erosion and deposition at the watershed scale and subsequent downscaling to the village level. Field verification further supported the effectiveness of SWC interventions in reducing soil loss and improving water conservation in cashew plantations.

Results and Discussion:

This section examines the water footprint of cashew cultivation in Rayagada and Gajapati districts of Odisha, along with the role of soil and water conservation (SWC) measures in controlling soil erosion. Table 2 summarizes the average yields of raw and shelled cashew nuts across plantations of different age groups. Nut yield increases with tree maturity, leading to a reduction in water footprint per unit, but tends to decline beyond 15–20 years. The results indicate that Rayagada exhibits a marginally higher water footprint than Gajapati, primarily due to a greater dependence on green water derived from effective rainfall. Figure 1 presents the water footprint (m^3/kg) of raw and shelled cashews across plantations of varying ages in both districts.

Table 2: Average cashew production across plantation age groups (25 plantations covered)

Districts	Age of Plantation (years)	Raw Cashew Yield (kg/ha)	Shelled Cashew Yield (kg/ha)
Gajapati and Rayagada	1–4	375	112.50
	5–10	875	262.50
	>10	1125	337.50

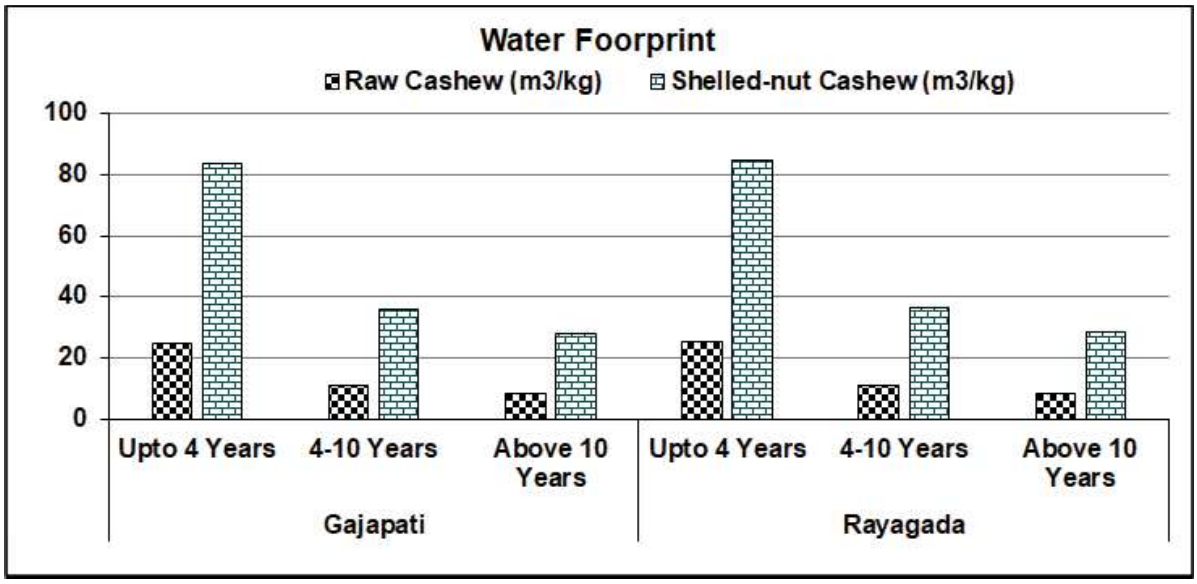

Figure 1: Water footprints of raw and shelled nut cashews of different-aged plantations in Gajapati and Rayagada

Water Deficit in Cashew Plantation

A water deficit arises when crop evapotranspiration (ETc) exceeds precipitation, causing physiological stress that negatively impacts plant growth, yield, and quality (Wang and Frei, 2011; Thitisaksakul et al., 2012). In cashew plantations, the magnitude of water deficit varies with tree age and location, as ETc changes while effective rainfall remains relatively stable. Estimating per-hectare water deficits across different age groups is essential for planning suitable in-situ soil and water conservation (SWC) measures. Recommended interventions include Continuous Contour Trenches (CCT), Graded Trenches (GT), Staggered Contour Trenches (SCT), Semi-Elliptical Trenches (SET), Crescent-Shaped Trenches (CST), Water Absorption Trenches (WAT), Continuous Bench Terraces (CBT), Reverse Terraces (RT), Modified Crescent Bunds (MCB), Tree Base Terraces (TBT), Coconut Husk Burial (CHB), larger pits, and mulching (Borah et al., 2024;

Mangalassery et al., 2024; Mahajan et al., 2021; Mangalassery et al., 2019; Rejani and Yadukumar, 2010). These measures help ensure adequate water availability during different crop growth stages. Figure 2 presents ETc, water deficit (mm), and water deficit (m^3/ha) for cashew plantations of varying ages in Gajapati and Rayagada districts, emphasizing the need for location- and age-specific SWC strategies (Rejani and Yadukumar, 2010; Saroj and Rupa, 2014).

The findings indicate that water deficit increases with plantation age due to rising evapotranspiration relative to effective rainfall. In Gajapati, deficits increase from 143 mm in 1–4-year-old plantations to 293 mm in plantations older than 10 years, while in Rayagada they rise from 153 mm to 306 mm across the same age classes. These patterns highlight the intensifying water stress in mature plantations and underscore the importance of targeted SWC interventions—such as trenching, mulching, and terracing—to reduce water deficit, enhance resilience, and maintain productivity under variable climatic conditions.

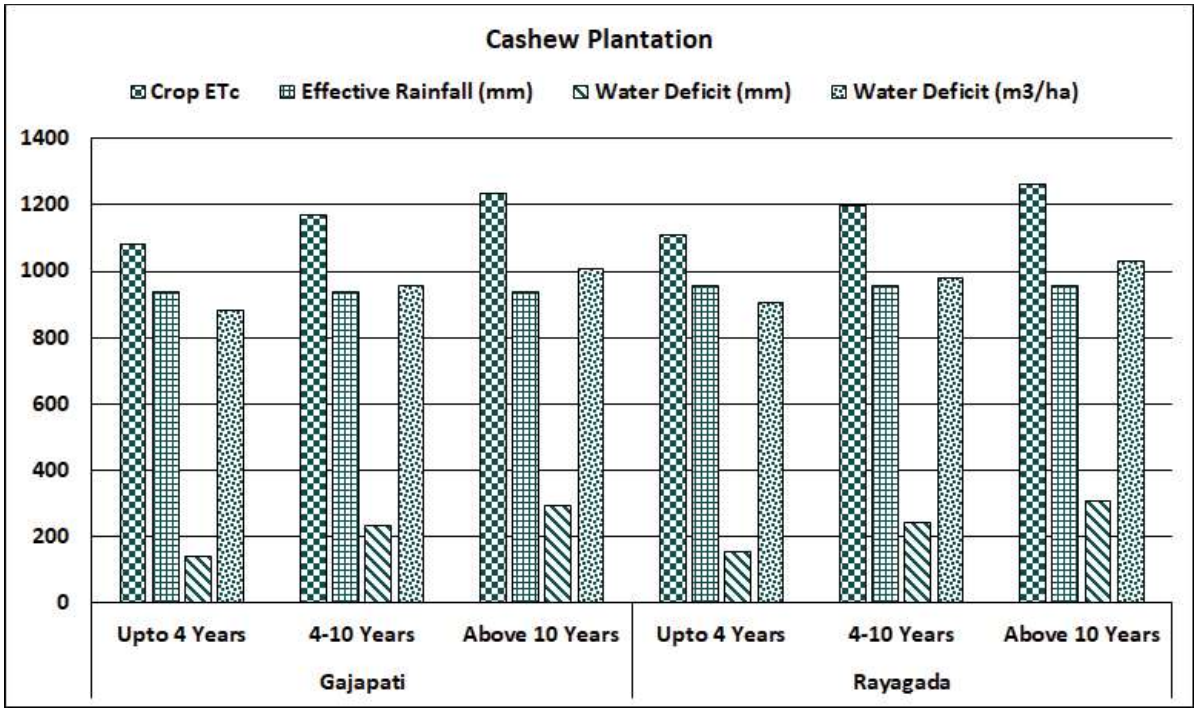

Figure 2: Average annual crop evapotranspiration, water deficit (mm), and water deficit (m3/ha) in different-aged cashew plantations of Gajapati and Rayagada districts

Impact of Soil and Water Conservation Interventions on Soil Erosion

Figure 3 shows the effect of soil and water conservation (SWC) interventions on soil erosion in cashew plantations across the study villages. Analysis of erosion rates in the four villages indicates a substantial decline in annual soil loss following the implementation of geotagged SWC measures. The watershed-

level assessment compared erosion conditions before and after the interventions. Gade village recorded a reduction of approximately 21 tons/ha/year between 2020 and 2023, while Guleijung showed a decrease of about 11 tons/ha/year, where measures such as Continuous Contour Trenches (CCT), farm bunds, stone bunds, and Water Absorption Trenches (WAT) were implemented. Sanamunisingi exhibited a moderate reduction of around 9 tons/ha/year, whereas Tada village achieved a notable decline of about 15 tons/ha/year during the same period. These reductions, summarized in Figure 3, contribute to improved soil moisture retention and are likely to enhance productivity in cashew plantations (Mensah et al., 2025; Mangalassery et al., 2024; Prabhakaran and Nedumaran, 2022; Mahajan et al., 2021; Nair and Nair, 2021; Jena and Panda, 2020; Rupa et al., 2013; Saroj and Rupa, 2014).

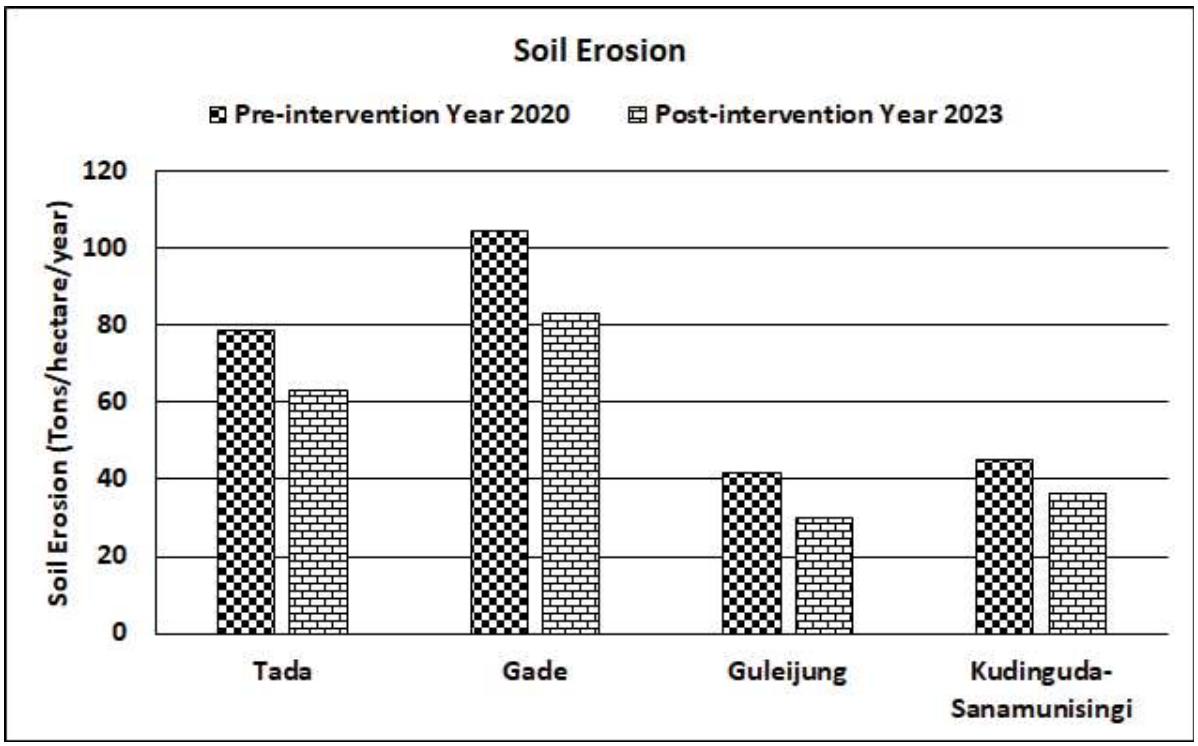

Figure 3: Village-wise soil erosion rate (tons/ha/yr) for the years 2020 and 2023

Study Findings

The study highlights the multiple benefits of cashew cultivation in the Gumma and Gunupur blocks, particularly its role in water management and soil conservation through soil and water conservation (SWC) practices. In Gajapati and Rayagada districts, the average water footprint of cashew is estimated at 15 m^3/kg for raw nuts and 50 m^3/kg for shelled nuts, while plantations face water deficits of 223 mm (948 m^3/ha) and 224 mm (971 m^3/ha), respectively, indicating the need for improved SWC interventions. The adoption of these

measures has led to a significant reduction in soil erosion across the project villages, enhancing soil quality and strengthening hydrological processes such as runoff regulation, soil moisture retention, and groundwater recharge.

Upscaling Field-Tested Water Conservation Measures for Enhanced Cashew Productivity

The effective implementation of soil and water conservation (SWC) interventions in cashew plantations of Rayagada and Gajapati districts indicates strong potential for scaling up across similar rainfed and hilly regions of Odisha and eastern India. The findings demonstrate that simple and cost-effective measures—such as Continuous Contour Trenches (CCTs), Water Absorption Trenches (WATs), farm bunds, mulching, and small water harvesting structures—can substantially reduce soil erosion, improve soil moisture retention, and alleviate water deficits in rainfed cashew systems. These interventions contribute to improved yield stability, better plantation health, and enhanced resilience to climate variability, while also supporting natural resource conservation.

For wider adoption, convergence with government schemes such as MGNREGA, RKVY, and IWMP, along with integration into existing horticulture and watershed programs, is critical. Capacity building of extension personnel and farmer field schools on these practices can promote dissemination through demonstrations and farmer-to-farmer learning. In addition, strengthening linkages with local cashew processing units can enhance economic incentives for farmers. Overall, scaling up these SWC interventions provides a practical and evidence-based approach for climate-resilient cashew production, improved water-use efficiency, and sustainable livelihoods in fragile rain-fed regions.

Conclusions

The study provides key insights into cashew cultivation and its role in supporting local economies. Water footprint analysis indicates that cashew plantations require considerable water, highlighting the importance of modern soil and water conservation (SWC) practices for reducing water deficits, minimizing soil erosion, and improving soil quality. In the absence of irrigation facilities, the adoption of such measures becomes critical for addressing climate variability, sustaining yields, and enhancing plantation resilience.

In addition, policy support through the promotion of improved cashew varieties, farmer training on advanced cultivation practices, and financial assistance for plantation development and processing infrastructure can further enhance productivity and farmer incomes. Such efforts will strengthen market competitiveness while promoting sustainable agriculture and regional economic growth.

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Disclaimer

The views expressed in this study are solely those of the authors and do not necessarily reflect the official positions of their affiliated organizations.

Financial Interests

The authors declare no financial conflicts of interest.

Credit Author Statement

Arun Bhagat: Conceptualization, methodology, investigation, data curation, formal analysis, original draft writing, review, and editing.

Aparna Yadav: Methodology and formal analysis for soil erosion.

Faraz Rupani: Review and editing.

Gyana Ranjan Baral: Data collection and field support.

Marcella D'Souza: Conceptualization and supervision.

Nikhil Nikam: Formatting and data analysis support

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