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Water Management in Cashew Plantation: Case Study in Rayagada and Gajapati Districts, Odisha (India)

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Abstract

Water scarcity and climate variability pose significant challenges to sustainable cashew cultivation in rainfed regions of India. This study assesses the water footprint (WF), crop water requirement (CWR), and water deficit in cashew plantations of Gajapati and Rayagada districts of Odisha. Using the Water Footprint Assessment framework, green and blue water components were estimated based on crop evapotranspiration and effective rainfall, while field data were collected through farmer surveys and focus group discussions. Results indicate that cashew cultivation in the study area is entirely rainfed, with negligible blue and grey water footprints. The average water footprint was estimated at 15 m^3 kg^{-1} for raw nuts and 50 m^3 kg^{-1} for shelled kernels, with processing significantly increasing total water use. Water deficit analysis revealed increasing deficits with plantation age, ranging from 143-293 mm in Gajapati and 153-306 mm in Rayagada. Crop water requirement varied seasonally, peaking during flowering and fruiting stages (January-May). The study highlights the critical role of in-situ soil and water conservation (SWC) measures-such as contour trenching, mulching, and terracing-in reducing runoff, improving soil moisture, and enhancing productivity. Adoption of these interventions is essential to improve water use efficiency, mitigate climate risks, and sustain cashew-based livelihoods in water-limited regions.

Key words : Cashew cultivation; Water footprint; Crop water requirement; Water deficit; SWC interventions.

Cashew (*Anacardium occidentale* L.), native to Brazil (Jusna Mariya, 2009), was introduced to India by Portuguese explorers in the sixteenth century (Achaya, 2017) and has since adapted to diverse agro-climatic conditions (Warren, 2015). It is primarily cultivated in coastal states such as Maharashtra, Goa, Karnataka, Kerala, Tamil Nadu, Andhra Pradesh, Odisha, and West Bengal (Hegde, 2022), mostly on marginal and degraded lands under rainfed conditions. Beyond livelihood support, cashew contributes to soil conservation and wasteland development (Nair and Nair, 2021; Prabhakaran and Nedumaran, 2022), and plays a significant role in export earnings (Tola and Mazengia, 2019).

India cultivates cashew over about 10.30 lakh hectares, producing nearly 9.98 lakh metric tons annually (Nayak and Paled, 2018). Increasing demand due to its nutritional value has supported expansion (Jeyavishnu *et al.*, 2021). The sector is labour-intensive and supports smallholders, though productivity remains comparatively low (Kamble, 2023). In Odisha, cashew covers around 183,000 hectares (6% of national area) with a production potential of 93,000 metric tons (DCCD, 2023). Initiated under soil conservation programs in 1954-55, it remains a major livelihood source, particularly in districts like Gajapati and Rayagada, where farmers face water scarcity, soil erosion, and climate variability.

Water resources are increasingly stressed due to declining availability, competing demands, pollution, and low efficiency (Kaur and Gauttam, 2022). Limited irrigation access further constrains productivity (Saha *et al.*, 2023), while climate change exacerbates water deficits through rising temperatures and erratic rainfall

(Pant *et al.*, 2024). In cashew, uneven rainfall-especially from January to May-induces moisture stress during critical stages, reducing yield (Paul, 2023). In this context, in-situ soil and water conservation (SWC) practices are essential for improving moisture availability, reducing erosion, and enhancing productivity in cashew-based systems (Borah *et al.*, 2024).

To address these issues, the Watershed Organisation Trust (WOTR) implemented targeted SWC interventions in selected villages of Gunupur and Gumma blocks. These interventions can bridge yield gaps, enhance farmer incomes, and strengthen India's position in the global cashew market (Ramteke *et al.*, 2024). Accordingly, this study evaluates the water footprint, crop water requirements, and water deficits in cashew cultivation and assesses the role of SWC interventions in improving productivity.

Study Area : The study was conducted in Gajapati and Rayagada districts of Odisha, located in the Eastern Ghats, characterized by hilly terrain and forest cover. These regions face soil erosion and seasonal water scarcity (Swamy, 2018). Four villages-Tada, Gade, Guleijung, and Kudinguda-Sanamunisingi-were selected to represent typical conditions for assessing water constraints and soil-water conservation impacts. The details of the study villages are given in Table 1.

Data Collection : Field data were collected through focus group discussions (FGDs), field observations, and structured questionnaires. Long-term gridded weather data (1980–2023), including rainfall and temperature, were obtained from the Indian Meteorological Department (Pai *et al.*, 2014; Srivastava *et al.*, 2009).

Methodology : This section describes methods to quantify water footprint and crop water requirements of cashew, including data collection, analysis, and assumptions for evaluating water use, deficits, and balance.

Water Footprint (WF) : The water footprint (WF) quantifies freshwater use relative to agricultural output, capturing both direct and indirect consumption. For crops, it is expressed as water volume per unit yield (e.g., m^3 ton^{-1} or liters kg^{-1}). WF comprises three components: green (rainwater), blue (surface and groundwater), and grey (pollution assimilation). These are measured against different units such as crop yield, population, area, or products, depending on the analysis. Assessing WF helps evaluate water-use efficiency by linking water consumption to production, integrating both consumptive use (green and blue) and pollution-related impacts (grey). In this study, blue and grey WF of cashew were estimated using primary data and participatory methods. Focus group discussions and farm-level surveys captured irrigation, input use, and management practices. Additionally, field visits to processing units assessed water use during processing. All estimations followed the Water Footprint Assessment (WFA) framework (Hoekstra *et al.*, 2011) to ensure consistency and reliability.

Table 1. Details of study villages

Name of district	Name of block	Study village	Longitude	Latitude	Area (Hectare)
Rayagada	Gunupur	Tada	83.950 E	19.009 N	498.7
		Gade	83.921 E	19.033 N	295.2
Gajapati	Gumma	Guleijung	83.989 E	18.984 N	110.1
		Kudinguda-Sanamunisingi	83.924 E	19.010 N	156.9

Green Water Footprint (WFgreen) : The green water footprint (WFgreen) quantifies rainwater stored in the soil and consumed through evapotranspiration during crop growth, expressed per unit yield. It reflects effective use of soil moisture, excluding runoff and deep percolation. Green crop water use (CWUgreen) is estimated from crop evapotranspiration (ETc) and effective rainfall (ER), considering the minimum of the two over the growth period. The cumulative green crop water use is calculated as:

$$CWUgreen = 10 * \Sigma Min(ER, ETc)$$

Here, the summation is performed over the entire crop growth period. The factor of 10 is used to convert water depth (mm) into volumetric units (m^3 ha^{-1}).

Crop evapotranspiration (ETc) is estimated using the crop coefficient approach :

$$ET_c = ET_O * Kc$$

where ET_O is the reference evapotranspiration (mm), and Kc is the crop coefficient, which varies with the growth stages of cashew plantations in the study region.

Effective rainfall (ER) is estimated as a fraction of total rainfall, following the empirical relationship suggested for Indian conditions (Dastane, 1974):

$$ER = R * 0.70$$

Where R represents the average seasonal rainfall during the cropping period.

Finally, the green water footprint (WFgreen) is obtained by dividing the total green crop water use by the corresponding crop yield:

$$WFgreen = CWUgreen\ (m^3)/Crop\ Yield\ (tons)$$

This formulation provides a measure of rainwater use efficiency in cashew production systems by linking soil moisture consumption to crop output.

Blue Water Footprint (WFblue) : The blue water footprint (WFblue) measures surface and groundwater used during crop growth per unit yield, indicating reliance on irrigation. Blue crop water use (CWUblue) is the total irrigation applied over the crop period, excluding effective rainfall. It is calculated as the cumulative irrigation depth, converted into volumetric units using an appropriate conversion factor:

$$CWUblue = 10 * \Sigma IR$$

Here, the summation is carried out over the crop growth period, and the factor of 10 converts water depth (mm) into volume per unit area (m^3 ha^{-1}).

The blue water footprint (WFblue) is then determined by relating the total blue water use to the crop yield:

$$WFblue = CWUblue\ (m^3)/Crop\ Yield\ (tons)$$

This provides an estimate of irrigation water use efficiency in terms of output produced per unit of blue water consumed.

The total water footprint (WF) of the crop is obtained by summing the green and blue components:

$$WF = WFgreen + WFblue$$

This combined measure offers a comprehensive assessment of total freshwater use in crop production by integrating both rainfall-derived and irrigation-based water consumption.

Grey Water Footprint (WFgrey) : The grey water footprint (WFgrey) quantifies the volume of freshwater required to dilute pollutants and maintain acceptable water quality standards, serving as an indicator of environmental impact. Introduced by Hoekstra and Chapagain (2008) and later refined to include background concentrations (Hoekstra *et al*., 2009), it reflects pollution-related water use. Systems with minimal chemical inputs, such as organic farming, may have negligible WFgrey. In this study, WFgrey was not estimated due to negligible fertilizer use in cashew plantations across Gunupur and Gumma blocks, resulting in insignificant pollutant loads. Similarly, the blue water footprint (WFblue) was considered zero, as farmers rely entirely on rainfall without irrigation. However, crop water requirement was assessed to estimate potential irrigation demand under improved conditions. The analysis is limited to field-level water use and excludes supply chain components such as input production, processing, and transport.

Crop Water Requirement (CWR) : Crop water requirement of cashew depends on canopy, evapotranspiration, spacing, and plantation age, estimated per plant and scaled to hectare level using plant population. The daily crop water requirement per plant is estimated as:

$$CWR = ET0 \times Kc \times WA \times CS$$

CWR = Crop Water Requirement (litre plant^{-1} day^{-1}), ET0 = Reference Crop Evapotranspiration (mm day^{-1}), Kc = Crop coefficient (dimensionless, varies with crop stage), CS = Crop spacing (m^2 plant^{-1}, based on row-to-row and plant-to-plant distance) and WA = Wetted area fraction (depends on canopy size and plant age).

The total water requirement for a given plot is obtained by multiplying the per-plant water requirement by the total number of plants per unit area. Reference evapotranspiration (ET_0) is the evapotranspiration rate from a well-watered standard surface, typically a uniform, actively growing grass. It is estimated using FAO-56 methods (Allen *et al*., 2002; 2005). This study used the Hargreaves-Samani method due to limited data availability.

Crop Coefficient (Kc) : The crop coefficient (Kc) is used to estimate crop evapotranspiration (ETc) from reference evapotranspiration (ET_0), reflecting crop type, growth stage, and canopy. In this study, stage-wise Kc values were of Vengurla 36/3 variety used and applied to Odisha varieties. These values were converted into daily Kc for accurate, continuous estimation of ETc across growth stages.

Results and Discussion

This section analyzes the water footprint and crop water requirements of cashew in Rayagada and Gajapati, assessing water use components, deficits, and implications for improved management and productivity.

Water Footprint of Cashew Plantation: The water footprint of an agricultural product represents the total volume of freshwater consumed and polluted across all stages of production, including cultivation, processing, and value addition, thereby indicating the pressure exerted on water resources. Based on focus group discussions (FGDs) with farmers in Gunupur and Gumma blocks, cashew cultivation in the study area was found to be entirely rainfed, with no external irrigation or synthetic fertilizer use across plantation stages and age groups. Farmers mainly depend on rainfall and follow low-input or organic practices. Consequently, the blue water footprint (irrigation-related) and grey water footprint (pollution-related) are negligible and considered zero under field conditions. However, post-harvest processing contributes significantly to water use. Field observations from cashew processing units show that about 3 liters of water are required to produce 1 kg of shelled kernels. Since only 20–30% of raw nut weight is

FGD with Tada villagers

FGD with Gade villagers

FGD with Guleijung villagers

FGD with Kudinguda villagers

FGDs with cashew Farmers in study villages

Shri Krishna Cashew Industry

Shri Narayana Cashew Industry

Visit to the cashew industries

converted into kernels, the effective water footprint of shelled cashews becomes three to four times higher than that of raw nuts. This emphasizes the need to include both field and processing stages in total water footprint assessment.

Table 2 shows average raw and shelled

cashew production and corresponding water footprints across different plantation age groups in Gajapati and Rayagada districts of Odisha. Results indicate that nut yield increases with plantation age up to a certain stage, resulting in a lower water footprint per unit output due to higher productivity. However, after about 15-20 years, yields gradually decline, leading to an increase in water footprint. Comparative analysis reveals slightly higher water footprint values in Rayagada than in Gajapati, mainly due to differences in green water contribution linked to higher effective rainfall in Rayagada, which increases total water use.

Water Requirements of Cashew Plantation : Accurate estimation of crop water requirement is essential for efficient irrigation and water resource management in cashew. Unlike annual crops, cashew water demand is governed by its perennial growth cycle and varies with plantation age. Young trees with limited canopy require less water, while mature trees need higher amounts due to greater transpiration and ground cover. A distinct dry period before flowering is also crucial for phenological development. Additionally, crop geometry, including plant spacing and wetted area, influences water demand by determining plant population. These factors collectively regulate total water requirement and must be considered for precise estimation and management.

Month-wise water requirement for cashew cultivation in Gajapati District : To estimate the average water requirement of cashew plantations across different age groups, reference evapotranspiration (ET_0) was computed using the Hargreaves–Samani method. Crop evapotranspiration (ETc) was then derived using daily cashew-specific crop coefficient (Kc) values. Based on these estimates, month-wise water requirement (liters day^{-1} tree^{-1}) was calculated for plantations of varying ages and spacings in the Gajapati district of Odisha. The results (Fig. 5-7) provide a detailed representation of seasonal water demand, supporting effective irrigation planning and scheduling throughout the year.

The analysis shows that no external irrigation is required during June-September, as monsoon rainfall meets crop water needs. Water demand increases during early growth and peaks during the flowering, fruiting, and early harvesting stages, then gradually declines towards the end of harvest, completing the annual phenological cycle. Mature plantations (>10 years) show the highest demand, especially from January to May, reaching about 120 L day^{-1} tree^{-1} under wider spacing (7m x 7m), whereas younger plantations require comparatively less water due to smaller canopies and lower transpiration. The absence of irrigation demand during the monsoon highlights opportunities for water

Table 2. Water footprint of cashew plantation in Gajapati and Rayagada districts of Odisha

Name of district	Age of plantation (in years)	Av. raw cashew production (kg ha^{-1})	Av. shelled nut cashew production (kg ha^{-1})	Total (includes Green, Blue, and Grey) water footprint of raw cashew (m^3 kg^{-1})	Total (includes Green, Blue, and Grey) water footprint of shelled nut cashew (m^3 kg^{-1})
Gajapati	1-4	375	112.50	25.04	83.47
	5-10	875	262.50	10.73	35.77
	Above 10	1125	337.50	8.35	27.83
Rayagada	1-4	375	112.50	25.49	84.98
	5-10	875	262.50	10.93	36.42
	Above 10	1125	337.50	8.50	28.33

conservation. Overall, the study provides key insights for optimizing irrigation scheduling and improving water use efficiency in cashew systems.

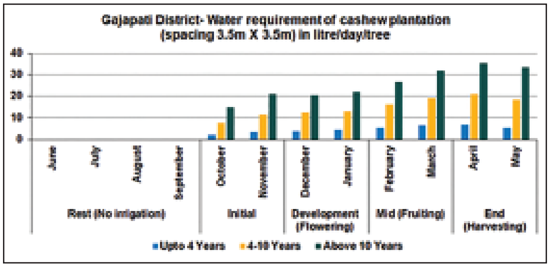

Fig. 5. Monthly water requirement of different-aged cashew plantations spaced at 3.5m x 3.5m for the Gajapati district of Odisha.

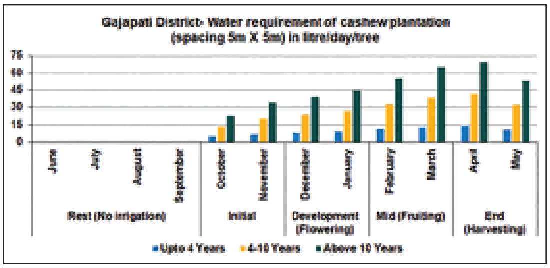

Fig. 6. Monthly water requirement of different-aged cashew plantations spaced at 5m x 5m for the Gajapati district of Odisha.

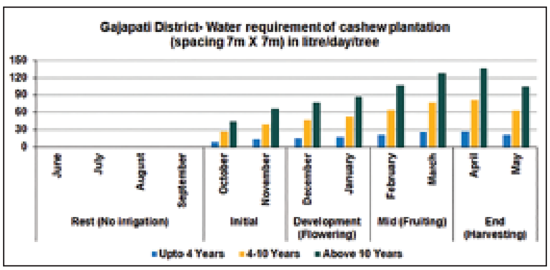

Fig. 7. Monthly water requirement of different-aged cashew plantations spaced at 7m x 7m for the Gajapati district of Odisha.

Month-wise water requirement for cashew cultivation in Rayagada District : Figures 8-10 present month-wise water requirements (L day^{-1} $tree^{-1}$) of cashew across growth stages and planting geometries in Rayagada district, Odisha, providing a clear basis for seasonal irrigation planning. Water demand varies with plantation age and spacing: younger (≤4 years) and mid-aged (4–10 years) plantations show lower requirements due to limited canopy and transpiration, while mature plantations (>10 years) exhibit the highest demand, particularly from January to May. In wider spacing (7m x

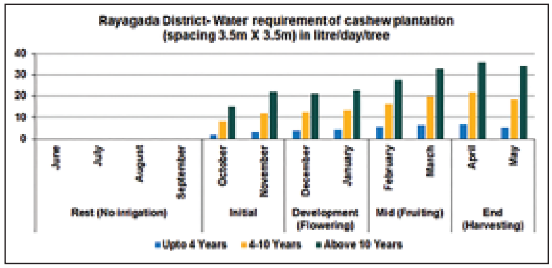

Fig. 8. Monthly water requirement of different-aged cashew plantations spaced at 3.5m x 3.5m for the Rayagada district of Odisha.

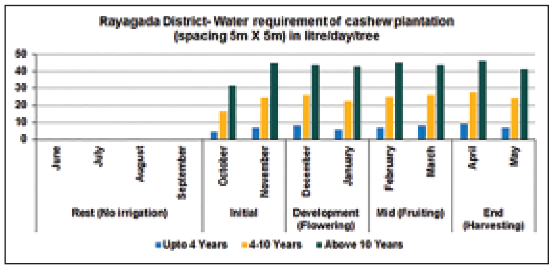

Fig. 9. Monthly water requirement of different-aged cashew plantations spaced at 5m x 5m for Rayagada district of Odisha.

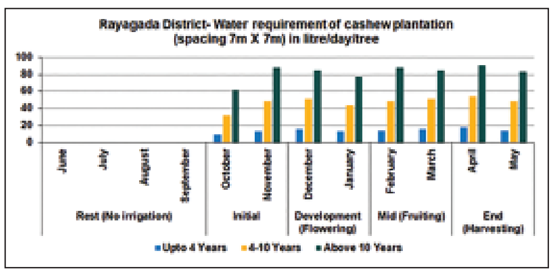

Fig. 10. Monthly water requirement of different-aged cashew plantations spaced at 7m x 7m for the Rayagada district of Odisha.

7m), demand may reach ~105 L day^{-1} $tree^{-1}$. As in Gajapati, no irrigation is needed during the June-September monsoon, highlighting opportunities for water conservation and efficient scheduling.

Water Deficit in Cashew Plantation : A water deficit occurs when crop evapotranspiration (ETc) exceeds available precipitation over a given period, making it a critical constraint under changing climatic conditions. Such deficits arise when crop water loss surpasses uptake capacity, causing physiological stress that adversely affects plant growth, yield, and product quality (Wang and Frei, 2011). In some crops, water stress also reduces starch accumulation while increasing protein content (Wang and Frei, 2011; Thitisaksakul *et al*., 2012).

In cashew cultivation, estimating per-hectare water deficit across plantation age groups provides a scientific basis for planning in-situ soil and water conservation (SWC) measures. These 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. These interventions enhance soil moisture retention and ensure adequate water supply across growth stages. Evapotranspiration losses vary with plantation age and location (Table 3). While effective rainfall remains similar within a location, differences in canopy development and water demand across age groups result in varying deficits. Older plantations, therefore, experience higher water stress due to greater evapotranspiration. In Gajapati, water deficit increases from ~143 mm in younger plantations (1–4 years) to ~293 mm in mature plantations (>10 years), while in Rayagada it rises from ~153 mm to ~306 mm. This indicates increasing water stress with age, driven by higher transpiration demand.

These findings highlight the need for site- and age-specific SWC measures such as trenching, mulching, and terracing to improve soil moisture, reduce runoff, and sustain productivity under varying climatic conditions in both districts.

Conclusions

The water footprint analysis indicates substantial water use in cashew cultivation, averaging about 15 m^3 kg^{-1} for raw nuts and 50 m^3 kg^{-1} for shelled kernels. However, significant

Table 3. Average annual crop evapotranspiration (ETc) and water deficit in the cashew plantation for the Gajapati and Rayagada districts of Odisha

Average annual water deficit in cashew plantations					
Name of district	**Age of plantation (years)**	**Crop ETc (mm)**	**Total/Green water use (Effective rainfall in mm)**	**Water deficit (mm)**	**Water deficit (m^3 ha^{-1})**
Gajapati	1-4	1082	939	143	883
	4-10	1171		232	956
	Above 10	1232		293	1006
Rayagada	1-4	1108	956	153	905
	4-10	1199		244	979
	Above 10	1261		306	1029

water deficits persist, with averages of 223 mm (948 m^3 ha^{-1}) in Gunupur and 224 mm (971 m^3 ha^{-1}) in Gumma, highlighting a clear mismatch between crop water demand and available moisture.

Soil and water conservation (SWC) practices are therefore critical. Measures such as CCT, GT, SCT, SET, CST, WAT, CBT, RT, MCB, TBT, CHB, larger pits, and mulching effectively improve soil moisture retention and reduce runoff. These interventions also enhance soil structure, reduce erosion, and support groundwater recharge due to higher infiltration in cashew systems compared to open land.

Overall, adopting suitable SWC strategies is essential for improving water use efficiency, sustaining productivity, and strengthening the resilience of cashew-based systems under water-limited conditions.

Recommendations and Way Forward

In the absence of assured irrigation and under increasing climate variability, the adoption of scientifically designed soil and water conservation (SWC) measures is essential for sustainable cashew cultivation. Practices such as contour trenching, mulching, terracing, and other moisture conservation structures should be systematically implemented to reduce runoff, enhance in-situ soil moisture retention, and minimize soil erosion. These interventions improve soil water availability during critical growth stages, thereby reducing water deficits and stabilizing yield levels. Integrating SWC measures within existing plantation systems enhances water use efficiency and strengthens the resilience of cashew-based farming systems against climatic variability and moisture stress.

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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 organisations.

Financial Interests

The authors declare no financial conflicts of interest.

Credit Author Statement

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

Marcella D'Souza: Conceptualization and supervision.

Vijay Solanky: Analysis for soil erosion.

Faraz Rupani: Data collection, review, and editing.

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