Technical note

Caio Mattos
Paulo N. Bernardino
Bruna Stein
Gabriela Prestes Carneiro
Julia Tavares
Adriane Esquivel-Muelbert
Silvio Barreto
André Braga Junqueira
Arie Staal
Marina Hirota

# Protecting Indigenous Territories is Critical to Water and Food Security in Much of Brazil

Caio Mattos[1,9] , Paulo N. Bernardino[2,9] , Bruna Stein[3,9] , Gabriela Prestes Carneiro[4,9] , Julia Tavares[5,9] , Adriane Esquivel-Muelbert[6,9] , Silvio Barreto[7,9] , André Braga Junqueira[7,9] , Arie Staal[8] , Marina Hirota[1,9]

1. Department of Physics, Federal University of Santa Catarina, SC, Brazil
2. Cary Institute of Ecosystem Studies, Millbrook, NY, United States
3. Cedeplar, School of Economic Sciences, Federal University of Minas Gerais, Brazil
4. French National Museum of Natural History, France
5. Department of Ecology and Genetics, Uppsala University, Sweden
6. School of Geography, Earth and Environmental Sciences, University of Birmingham, United Kingdom
7. Academic Ecology and Indigenous Ecology Dialogue Network, Serrapilheira Institute
8. Copernicus Institute of Sustainable Development, Utrecht University, Utrecht, Netherlands
9. Tropical Ecology Research Group of the Serrapilheira Institute

**This document is endorsed by:**

1. Carlos A. Nobre, Institute for Advanced Studies, University of São Paulo
2. Paulo Artaxo, Institute of Physics, University of São Paulo
3. Manuela Carneiro da Cunha, Department of Anthropology, University of São Paulo and University of Chicago
4. Ronaldo Seroa da Motta, Faculty of Economic Sciences, Rio de Janeiro State University
5. Mercedes Bustamante, Department of Ecology, University of Brasilia

1 The Amazonian Indigenous Territories play a crucial role in generating the rainfall that supports 80% of Brazil's agricultural activities. This occurs through "flying rivers", where moisture recycled in the forests of these lands is transported through the atmosphere and falls as rain in other regions of Brazil.

2 **Brazil's crop and livestock farming heavily depend on water resources,** making rainfall a critical factor in their success. In 2021, the states that benefit most from the rainfall produced by Amazonian Indigenous Territories generated **R$338 billion** in agricultural income, **or about 57% of Brazil's total agricultural income.**

3 **Family farming contributes** more than half of the **total value of agricultural production** in many states that receive this rainfall**.** This means that the rainfall generated by **Indigenous Territories directly supports national food security** since a significant portion of the output of these **small-scale farmers** is consumed domestically.

4 Deforestation and forest degradation in Indigenous Territories reduce rainfall and **pose significant risks to Brazil's water, food, energy, and economic security. Preserving** these forests is vital not only for national water and food security but also for the agribusiness production chain and, thus, for the economic production of a considerable part of the national economy. Paradoxically, **Rondônia and Mato Grosso, two states heavily dependent on this rainfall, are among the nine states with the highest deforestation rates since 1985.**

# Introduction

Indigenous Territories (ITs) are crucial for conserving biodiversity and providing environmental services in Brazil and globally. The more than **450 ITs** (ISA, 2024) cover about 23% of the legal Amazônia and are home to about **403,600 people** (IBGE, 2024). They have historically served as a critical barrier to deforestation (Gonçalves-Souza et al., 2021). Data confirms that of the 4.4 million hectares deforested in the Amazônia biome between 2019 and 2023, **only 3% (130,200 hectares) occurred within ITs** (Mapbiomas, 2024a).

These figures are low because Indigenous communities often integrate their activities with the ecosystem. Their land management practices are diverse and don't always require the **removal of native vegetation** (Gonçalves-Souza et al., 2021; Levis, et al., 2024). This is evidence of the intrinsic link between **protecting Indigenous Peoples' territories and conserving ecosystems.**

In addition to the conservation of native biomes, the historical use and management of land and ecosystems by Indigenous Peoples has resulted in diverse landscapes home to a wide variety of tree species and other cultivated plants. As such, Indigenous Peoples contribute to the biodiversity and ecosystem diversity of the Amazon (Junqueira et al., 2010; Levis et al., 2017; Coelho et al., 2021; Levis et al., 2024).

While Indigenous Peoples and their territories are essential to the conservation of Brazil's socio-biodiversity, Indigenous Territories that have already been demarcated, as well as those in the process of demarcation or future demarcation, are under threat. Proposals to remove protections for Indigenous Territories and open them up to economic exploitation and infrastructure projects, as well as the Temporal Framework Thesis (Law 14.701/2023), undermine

Indigenous land rights. These initiatives disregard the longstanding presence of Indigenous Peoples and their history of exclusion and marginalization, jeopardizing their way of life and survival (Rocha et al., 2014; 2021; Neves, 2022).

**The Indigenous Territories of the Brazilian Amazônia comprise 27.5% of mature forests of Amazônia**, or about 90 million hectares (MapBiomas 2024b), and are essential for regulating the water cycle at the local, regional, and continental levels (Flores et al., 2024). Preserving these territories and strengthening demarcation efforts—in the Amazônia biome and beyond—is critical. This will protect Indigenous Peoples' land rights and the water supply essential for human survival, energy production (Pinto et al., 2024), industry, and agriculture in Brazil and other South American countries.

This technical note **quantifies the contribution of Amazonian Indigenous Territories to the moisture (water vapor) that generates rainfall in Brazil's agricultural zones.**

**The Amazônia effectively "irrigates" much of Brazil** via atmospheric water transport, producing rainfall in Brazil's central and southern regions (Arraut et al., 2012). Evaporation from the Atlantic Ocean brings rain to the eastern Amazônia. This moisture infiltrates the soil and is pumped back into the atmosphere by trees, a process known as **moisture recycling** (Nobre et al., 1991; Aragão, 2012). The processes that sustain moisture recycling in the Amazônia (Fig. 1) include:

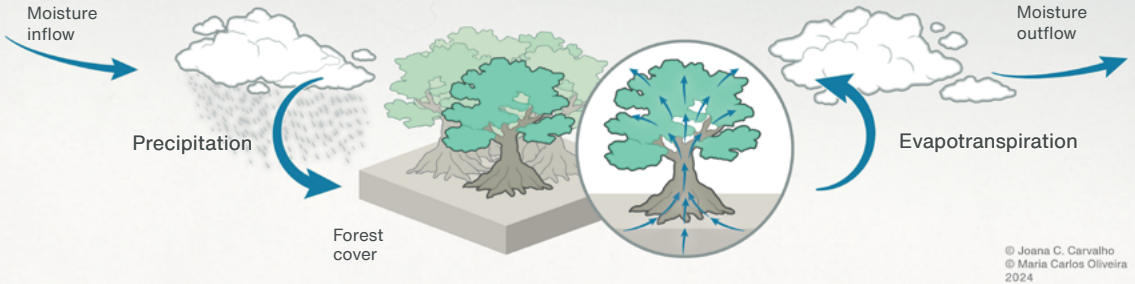
- → On a local scale, trees pump water from the soil and release it into the atmosphere as water vapor. This water vapor rises, forms clouds, and produces local rainfall.
- → Trade winds carry excess moisture westward, allowing cloud formation and rainfall over the further inland Amazonian forests.

- → This recycling process (atmosphere - soil - atmosphere) is repeated until the winds hit a barrier: the Andes.
- → Upon reaching the Andes, these winds shift south/southeast, carrying atmospheric moisture in a flow comparable to the volume of the Amazonas River—a phenomenon known as "flying rivers."
- → This moisture flow generates rainfall that naturally "irrigates" areas far beyond Amazônia, including the Pantanal, the Rio de La Plata Basin, and southeastern South America.

ON NEXT PAGE → **Fig. 1** - Trade winds carry moisture across the atmosphere in an east-west flow. When these winds hit the Andes, they are deflected to the south-southeast and thus affect central-western and southern Brazil. This atmospheric moisture flow, similar to that of the Amazonas River but in the sky, is known as a "flying river."

# Indigenous Lands in the Amazônia “irrigate” a large part of Brazil


## Water recycling and transport



Protecting native forests is essential for rainfall generation, as they pump moisture into the atmosphere. However, rising global temperatures have led to more frequent and intense droughts (e.g., 2015-16, 2023-24 in various regions of Amazônia), reducing the water available for moisture recycling (Marengo et al., 2021; IPCC, 2021). Thus, the escalation of deforestation (leading directly to a reduction in tree cover) combined with global warming (indirectly reducing water availability) could **disrupt this recycling**, potentially causing **forest collapse** in Amazônia's interior and **significantly diminishing moisture flow** to other South American countries and regions of Brazil (Zemp et al., 2017; Staal et al., 2018, 2023).

Rain-fed agriculture in Brazil currently faces a significant **water deficit, averaging 37%**, **preventing full-cycle production**. Alarmingly, 30% of this deficit occurs during critical crop growth stages (ANA, 2020). With agribusiness expected to contribute 21.8% to Brazil's GDP in 2024 (Confederation of Agriculture and Livestock of Brazil, CNA, 2024), the Amazônia's role in rainfall generation is crucial. Conservation of Amazônia is therefore essential not only for water and food security but also for the economic stability of the agribusiness sector, which is a significant part of the national economy.

Given the vital role of native forests in regulating water services and the importance of Indigenous Territories (ITs) in conserving these forests, this technical note aims to answer three main questions:

1 What proportion of Brazil's rainfall comes from moisture generated within the Amazonian Indigenous Territories?

2 What proportion of Brazilian agricultural production depends on rain-fed irrigation from Indigenous Territories?

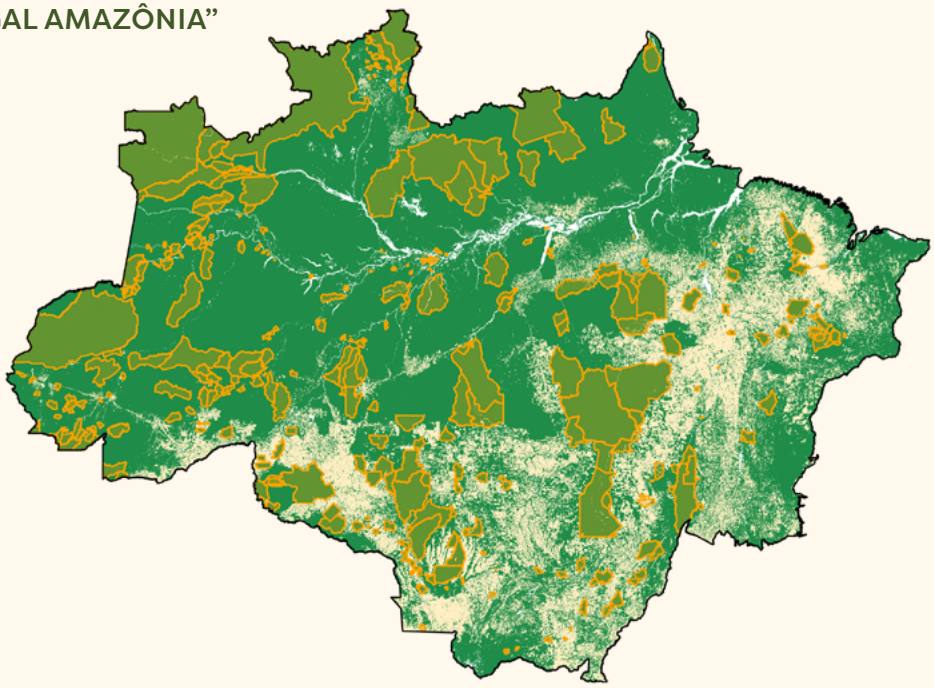
3 In terms of agricultural activities, which states benefit the most from the rainfall generated by the moisture recycled within the Amazonian Indigenous Territories?

## Methods

Moisture fluxes were calculated using the UTrack atmospheric moisture tracking model (Tuinenburg and Staal, 2020; Tuinenburg et al., 2020), a widely accepted tool in scientific studies of atmospheric water transport and recycling (e.g., Hoek Van Dijke et al., 2022). The model assumes a monthly evapotranspiration rate of 100 mm for mature forests (Shuttleworth, 1989; da Rocha et al., 2004; von Randow et al., 2004). The UTrack model simulates the dispersion of water molecules in the air column, representing tree evapotranspiration, and tracks their wind-driven trajectory until they fall as rain (Fig. 1). The model identifies the "point of interest" (e.g., an Indigenous Territory) where the water molecules originate and delineates its "area of influence" by tracking where those molecules fall as rain. In this analysis, the model was applied to each Indigenous Territory in "Legal Amazônia", using geospatial boundary data from FUNAI (accessed October 25, 2024) (Fig. 2) to determine their total contribution to Brazil's potential rainfall supply.

Average annual precipitation (1991-2020) was calculated using ERA5 reanalysis data (Hersbach et al., 2020), integrating various sources with climate models. These data, combined with rainfall volumes originating from Indigenous Territories, enabled the estimation of the percentage of annual rainfall generated by Amazonian Indigenous Territories in Brazil.

## INDIGENOUS TERRITORIES IN "LEGAL AMAZÔNIA"



→ Fig. 2 - Indigenous territories in "Legal Amazônia" are outlined in orange (source: https://www.gov.br/funai/pt-br/atuacao/terras-indigenas/geoprocessamento-e-mapas, accessed October 25, 2024). Areas shaded green represent native vegetation, while light yellow indicates agricultural land use, according to MapBiomas Collection 9 (2024).

Agricultural areas affected by rainfall from Indigenous Territories were identified using land cover and land use maps from MapBiomas Collection 9 (http://www.mapbiomas.org). These data allowed areas to be classified as agricultural land (including agriculture, livestock, planted forests, and mosaics of uses) or other uses (e.g., native vegetation and urban areas). By overlaying the rainfall influence area of the Indigenous Territories with the map of agricultural areas, we determined which agricultural areas were influenced by rainfall from the Indigenous Territories.

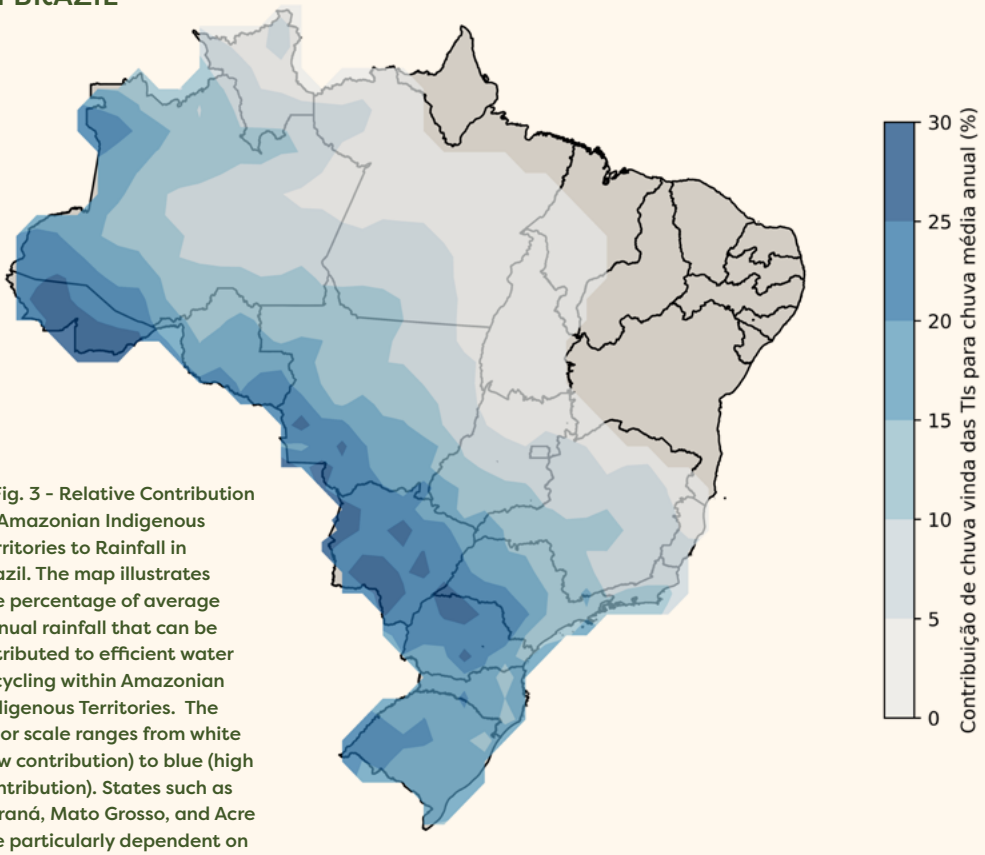
# Results and discussion

**What proportion of Brazil's rainfall comes from moisture generated within the Amazonian Indigenous Territories?**

Our results show that a considerable part of Brazil benefits from rainfall originating in the forests of Amazonian Indigenous Territories to a lesser or greater extent. This rainfall, generated by atmospheric water recycling and transport (Fig. 2), partially or totally affects **18 states and the Federal District** (Fig. 3).

The contribution of rainfall from water recycling in Indigenous Territories to total rainfall varies across the country, following a clear pattern: greater in the west and along the western border than in the east (consistent with water recycling). In regions within Acre, Mato Grosso, Mato Grosso do Sul, and Paraná, **rainfall from water recycling by forests in Amazonian Indigenous Territories can represent up to a third of the total annual rainfall.**

## RELATIVE CONTRIBUTION OF AMAZONIAN INDIGENOUS TERRITORIES TO RAINFALL IN BRAZIL




→ Fig. 3 - Relative Contribution of Amazonian Indigenous Territories to Rainfall in Brazil. The map illustrates the percentage of average annual rainfall that can be attributed to efficient water recycling within Amazonian Indigenous Territories. The color scale ranges from white (low contribution) to blue (high contribution). States such as Paraná, Mato Grosso, and Acre are particularly dependent on this source of rainfall.

Importantly, these results reflect only the contribution of Indigenous Territories, which cover **only 23%** of the total area of the "Legal Amazônia". The contribution of all Amazonian forests is potentially much greater. Therefore, conservation of the Amazônia forest has a **significant impact** on Brazil's water supply. Deforestation and degradation **seriously threaten water security and the provision of essential water-related services.**

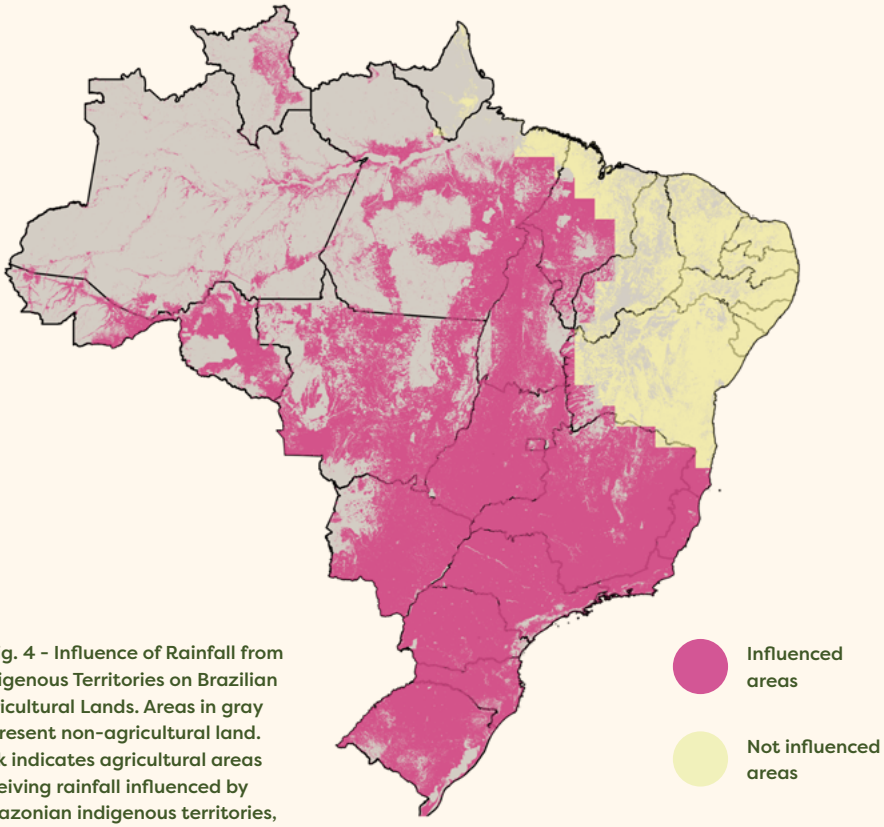
## What proportion of Brazilian agricultural production depends on rain-fed irrigation from Indigenous Territories?

According to the Environmental Economic Accounts for Water (CEA-A), Brazil consumed 306.1 billion cubic meters of water in 2020, with agriculture, livestock, forestry, fisheries, and aquaculture accounting for 97.1% of total consumption (IBGE, 2023).

The agricultural sector is highly dependent on rainfall for rain-fed and irrigated agriculture, making it highly vulnerable to climatic and hydrological variability (ANA, 2020). In 2018, 2019, and 2020, the agricultural sector, forestry production, and fisheries and aquaculture consumed 931 liters/R$, 939 liters/R$, and 684 liters/R$ of rainwater, respectively (considering only rainwater use). Even when focusing only on irrigated agriculture, the sector remains the largest consumer of water, exceeding 104 liters/R$ in 2018 and 78 liters/R$ in 2020. In addition, the data show a cumulative decrease in rainfall of almost 9.1% between 2018 and 2020, exacerbating the growing water deficit of the agricultural sector (IBGE, 2023).

The analysis shows that **approximately 80% of the Brazilian agricultural area benefits from rainfall influenced by water recycled within the Indigenous Territories of Amazônia** (Fig. 4).

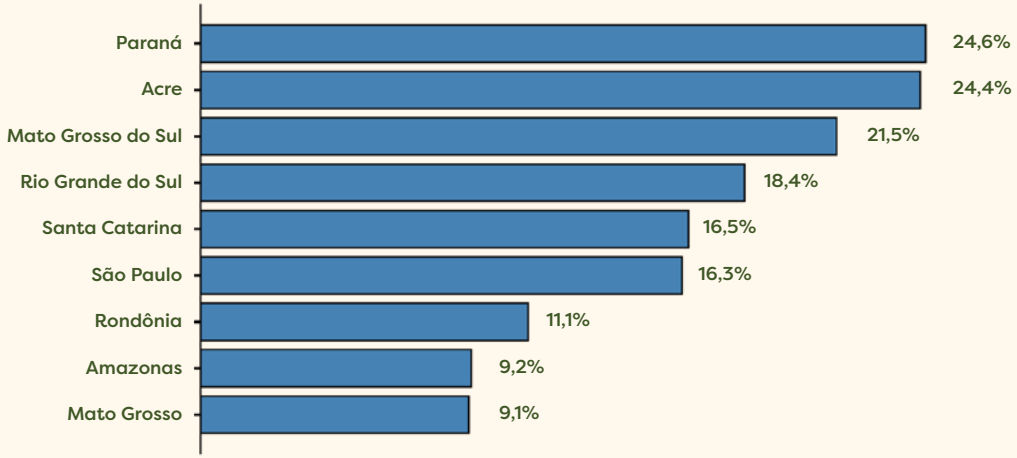
## INFLUENCE OF RAINFALL FROM INDIGENOUS TERRITORIES ON BRAZILIAN AGRICULTURAL LANDS




→ Fig. 4 - Influence of Rainfall from Indigenous Territories on Brazilian Agricultural Lands. Areas in gray represent non-agricultural land. Pink indicates agricultural areas receiving rainfall influenced by Amazonian indigenous territories, while yellow indicates agricultural areas without such influence (MapBiomas, Collection 9).

**In terms of agricultural activities, which states benefit the most from the rainfall generated by the moisture recycled within the Amazonian Indigenous Territories?**

The states most dependent on moisture recycling and rainfall generation from indigenous Amazonian territories are concentrated in the South, Central-West, and North regions (Fig. 5). The Southern Region shows a particularly high dependence: Paraná (24.6%), Rio Grande do Sul (18.4%) and Santa Catarina (16.5%) are among the top five states in terms of influence. Mato Grosso do Sul (21.5%) leads in the Central-West, while Acre (24.4%) leads in the North, and São Paulo (16.3%) leads in the Southeast.




→ Fig. 5 - Contribution of Indigenous Territories in the Brazilian Amazonian to average annual rainfall in the nine most-influenced Brazilian states (%)

In 2021, the nine states most dependent on moisture from Indigenous territories (Figure 5) generated an estimated R$338 billion in agricultural Gross Value Added (GVA),[1] **representing 57% of the sector's total GVA and 3.8% of Brazil's GDP** (IBGE, 2023).

**Family farming plays an important role in Brazilian agriculture, representing 76.8% of all rural farms** and employing 66.3% of the sector's labor force, despite occupying only 23% of agricultural land, according to the 2017 Agricultural Census. In states that benefit significantly from rainfall associated with Indigenous Territories, **family farms contribute significantly to the share of the agricultural production value** in each state: Amazonas (67%), Acre (52%), Santa Catarina (51%), Pará (39%), Rondônia (38%), Rio Grande do Sul (37%), Paraná (27%), Minas Gerais (25%), São Paulo (11%), Goiás (10%), Mato Grosso do Sul (6%) and Mato Grosso (6%) (IBGE, 2019).

The diversified production of **family farms** and their integration into local and regional markets **contribute significantly to Brazil's food supply and food security**. However, climate change poses a threat to this vital sector. Projected declines in the productivity of staple crops such as cassava, corn, and beans due to **global warming increase the vulnerability of family farming and threaten the nation's food security** (Tanure, 2020). Conserving native vegetation in Indigenous Territories helps mitigate these threats by supporting rainfall generation, safeguarding agricultural productivity, and **contributing to food security**.

1 Gross Value Added (GVA) is the value generated by each sector of an economy. It's calculated by subtracting the value of intermediate consumption (goods and services used in the production process) from the gross production value. By aggregating the GVA of all sectors and adjusting for taxes and subsidies, we arrive at Gross Domestic Product (GDP). Thus, GVA serves as a primary indicator of economic performance at the sectoral level.

# Conclusion

Amazonian Indigenous Territories are critical in ensuring Brazil's water, food, and socio-economic security. Our findings show that up to 30% of the average rainfall in the country's agricultural areas is directly linked to the efficient water recycling within these territories and the "flying rivers" that transport moisture south of the Amazônia. Paradoxically, **Rondônia and Mato Grosso, two of the nine states highly dependent on this rainfall, are also among those with the highest deforestation rates since 1985,** having lost 34% and 32% of their forests, respectively (MapBiomas, 2024b). This underscores the urgent need for forest conservation, particularly in Indigenous Territories, to maintain vital environmental services.

The vulnerability of family farming to climate change, coupled with its critical role in national food production, underscores **the importance of preserving native forests. Preserving these forests for water and climate regulation is essential to ensure national food security.**

This analysis has focused specifically on agricultural areas that benefit from water recycled within Amazonian Indigenous Territories. However, other sectors critical to the national economy, such as hydroelectric power generation (e.g., Pinto et al., 2024), industry, and public water supply, also rely on this water regulation. **Therefore, the results presented here likely underestimate the full economic benefits, which could be significantly higher than the percentages reported.**

**Protecting and demarcating Indigenous Territories is crucial and urgent for the conservation of the Amazônia.** These territories represent ancestral lands vital to the identity and way of life of the Indigenous Peoples who inhabit them. Our findings are consistent with other studies that underscore the importance of preserving this biocultural diversity and upholding Indigenous rights. Protecting Indigenous Territories and the Amazônia is essential for Brazil's water, food, socioeconomic, and biodiversity security, a cause that requires support from all sectors of society.

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