



Supplement of

From insufficient rainfall to livelihoods: understanding the cascade of drought impacts and policy implications

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S1. Drought impacts monitoring data

Observers collected the first dataset as part of their job routine. In addition to their various tasks, they regularly complete monthly questionnaires for each municipality, providing information on drought impacts and other relevant information. Employed by Ematerce, these observers are based across the state, with most offices overseeing two or three municipalities, covering 184 municipalities.

The questionnaire consists of four multi-choice questions addressing drought conditions, rainfall occurrence, agriculture, and water accessibility. Additionally, there is one open question asking for information on any impacts. The observers in each state may add additional locally relevant questions. In the final question, observers are free to express any pertinent information they consider important at the time. This means the reported impacts extend beyond just those related to drought. Especially considering this open question, it stands out globally as a rare and valuable example of monitoring drought impacts through the perspectives of people "on-the-ground" who directly experience the impacts. Therefore, in this research, the analysis focuses primarily on the responses to this open-ended question. We refer readers to Table S1 for the complete questionnaire used by observers. Further details on the data collection and analysis of this dataset can be found in Walker et al. (2024).

S1.1 Analysis of drought impacts monitoring data

We analyzed the open question on the reporting of impacts (question 5) using inductive reasoning and thematic analysis as a method to identify and analyze recurring patterns or themes within the dataset. This type of analysis is particularly suitable for areas lacking empirical research and provides a rich description of predominant themes across the dataset (Braun & Clarke, 2006). The analysis consisted of 3 main steps.

Step 1 Coding responses: Question 5 responses were manually coded through inductive reasoning to identify within the qualitative data. We leveraged our expertise in the field to search for patterns in relation to drought impacts occurrence. To conduct this analysis, we employed the qualitative analysis program Atlas.ti (version 22), where 3641 reports completed by observers were uploaded. We created distinct groups to organize our analysis, by Ematerce offices, periods and questions. The "codes" function within Atlas.ti was used to label identified drought impacts within the reports. This process resulted in the identification of 204 different codes (Table S2).

To reduce subjectivity in the definition of codes, samples of the data were individually coding by four authors, initially without guidance from the lead coder, to ensure cohesion. Any coding discrepancies were subsequently discussed and resolved through multiple rounds of review. Newly agreed upon codes or amended codes were then deductively searched for within the entire already coded dataset for inclusion or adjustment.

Step 2 data validation with observers: To reduce biases, we interviewed 29 observers, representing over 40 municipalities. These interviews aimed to clarify specific questions regarding the observers' reasoning while completing the questionnaires. These interviews revealed that the

questionnaires were completed based on observations and discussions with farmers and communities while conducting their routine tasks. These tasks involve visits to a wide area of municipalities, and farmers also visit their offices from across the region. Consequently, observers consider their reports comprehensive summaries of the conditions and impacts for the whole month and the entire municipality.

Step 3 impact homogenization: We were interested in finding a common terminology to unify the understanding of local impacts observations. For instance, individuals may express the same concepts with different words, while some wrote "Water trucks necessary in rural communities", others wrote, "Water trucks necessary in some communities", yet others, "Water trucks necessary in some rural communities". We combined all these as 'water trucks necessary in some communities'.

With this step, we achieved simplicity and manageability of data, to add clarity and focus on the most common patterns, and to increase readability. The outcome of this effort was the identification of 14 distinct impact types (Table S3), which were then classified into impacts due to drought impacts classification, i.e. hydrological, agricultural, and socio-environmental-economic impacts of drought.

S2. Fieldwork interviews data

The final dataset includes fieldwork notes and interviews carried out at various locations in Ceará during July 2019, November and December 2021, and April 2022. During these field visits, 60 smallholder farmers were interviewed, some by one researcher and others by two researchers. Questions were formulated to encourage participants to describe the drought risks, impacts, and factors increasing or decreasing the likelihood of impactful drought over time in the study area. The interviewees were randomly chosen. Some were more in-depth interviews that lasted an hour, in other cases a short conversation, depending on the person's availability. All the interviewees provided consent before being interviewed. The interviews were not recorded, but fieldwork notes were either written up while the interview was ongoing or written up immediately afterwards.

S2.1 Analysis of fieldwork interviews data

Following each full day of interviews, the research team convened for a debriefing session. During this session, fieldwork notes were transcribed, impressions were cross-checked, and understanding of each case was refined. Subsequently, the fieldwork notes dataset was uploaded to Atlas.ti (version 22) for further analysis, focusing on excerpts where farmers alluded to both public policies and the impacts of drought. For more information on the data collection and analysis of this dataset, see (Kchouk et al., n.d.).

S3 Policy documents data

Another dataset consisted of policy documents, which we gathered to acquire information about the objectives and strategies of specific policies or programs implemented in the area. The selected documents were about the public policies reported by both farmers and observers in the interviews. Furthermore, we consulted other researchers who conduct studies in the region to ensure that we had included all the policies implemented in the area. Our choice to include only public policies established through formal acts in laws, regulations, decrees, court decisions, executive orders, etc., which are typically observed within legally authorized decision-making arenas, such as legislatures, courts, and bureaucracies. This ensures their implementation happens irrespective of the government currently in power. We refer readers to Table S4.

S3.1 Analysis of policy documents data

Policy documents were added to Atlas.ti (version 22) and coded or some basic descriptive information, i.e. goal, instrument, year and organizations responsible for managing the policy. One limitation is that policy documents may not always accurately reflect the actual implementation or impact of a policy. To overcome this limitation, we also used our fieldwork experience and interviews to understand the nuances about the implementation of policies and their influences on livelihoods on a local level.

S4. Identification of key impact cascades

We use the different types of drought impacts as an analytical framework by categorizing and evaluating the diverse impacts associated with each type of drought. We used the classification as hydrological, agriculture, and socio-environmental-economic impacts of drought.

The identification of key sequential impacts followed a two-step procedure. First, we had all the data collected by observers, which was further analyzed as described on the section above (Analysis of drought impacts monitoring data). After, we used deductive reasoning to categorize the three types of impacts of drought. With this framework, we started to elaborate the different cascades in relation to the most common impacts recognized in our field work campaigns.

This methodological decision was made to illustrate cascading effects using human reasoning following our trial to conduct the data analysis using 'sequential pattern mining'. Unfortunately, the limited quantity of data was insufficient for the algorithm to find patterns within the analyzed dataset.

S4.1 Relationship between drought impacts monitoring data and policy documents data

The last step of analysis was to compare the drought impacts with policies, to understand how policy responses evolve to alleviate the cascade of drought impacts. We compiled all existing policies in the region as a basis for delineating each policy's placement within the various directions of the cascade of drought impacts. The public policies implemented in the region encompass various sectors and can be summarized as policies for social development, agriculture, food security and health.

Municipality:				
Month:				
DROUGHT				
1. Considering the drought situation in the municipality, compared to the previous month, would				
you say that:				

Table S1: Drought monitoring form

There was an improvement (1)
There was a worsening (2)
No change (3)
There is no drought (4)
RAINFALL
2. How would you rate the rainfall in your municipality in the last month?
a) In terms of the rainfall observed:
No rain (1)
Little rain (2)
Fair (3)
A lot of rain (4)
b) Regarding the temporal distribution of rainfall this month:
No rain (1)
Veranico of up to 10 days (2) Veranica haterean 10 and 15 days (2)
Veranico between 10 and 15 days (3)
veranicos over 15 days (4)
C) Regarding the spatial distribution of rainfall that month: It rained up to 25% (1)
It rained up to 25% (1) It rained between 25% and 50% (2)
It rained between 50% and 75% (3)
Rainfall above 75% (4)
CROPS
3. How would you describe the situation regarding rainfed crops such as beans, maize and
manioc in the municipality?
It's not planting season (1)
It's in season, but planting hasn't started due to lack of rain (2)
Planting has taken place and no losses have been recorded (3)
It has been planted, but losses have been recorded (4)
WATER ACCESS
WATER ACCESS
4. While regard to access to water in the municipality, please tick.
Levels are low, but there is no problem with access to water (2)
Levels are low, but there is no problem with decess to water (2) Levels are low and some uses are being affected (3)
Water systems are collapsing and water shortages are widespread (4)
a) In relation to the volume of water for HUMAN consumption?
Volume up to 25% (1)
Volume between 25% and 50% (2)
Volume between 50% and 75% (3)
Volume above 75% (4)
b) In relation to the volume of water for ANIMAL consumption?
Volume up to 25% (1)
Volume between 25% and 50% (2)
Volume between 50% and 75% (3)
Volume above 75% (4)

c) Regarding the volume of water for IRRIGATION? Volume up to 25% (1) Volume between 25% and 50% (2) Volume between 50% and 75% (3) Volume above 75% (4)

REPORT THE TYPES OF PROBLEMS HERE

5. If you wish, please use the space below to specify what kind of water access problems you have experienced in your municipality and/or report other drought-related impacts that are currently being observed in your region:

,				
Codes	Aggravating factor			
	o boreholes drilled due to empty reservoirs have saline			
• Cisterna levels are low	groundwater			
• Cisternas full	• broken water infrastructure			
• Cisternas replenished	• communities located a long distance from reservoirs			
• Crop development poor	 conditions unsuitable for replanting 			
• Crop losses	○ constant drought (aridity?)			
• Crop losses due to excessive rainfall	\circ crop losses due to low rainfall at critical crop growth stage			
• Crop losses high	◦ crop losses due to pests			
• Crop losses low	◦ deforestation			
• Crop planting reduced or delayed	\circ excessive rains at critical crop growth stage			
• Crop production only sufficient for family				
consumption	• excessive rains crop harvest			
	• farmer insecurity to investment due to irregular rainy			
• Crops developing well	season			
• Dairy production reduced	○ fear of covid			
• Drought condition improving	• high costs of electricity, diesel oil, butane			
• Drought condition worsening	• high costs of rice, meat, corn and soy derivatives for animal feed			
• Rainfall localised	• high production costs			
• Rainfall low	• insufficient seeds			
• Rainfall plentiful	• insufficient water infrastructure in some communities			
• Rainfall well distributed	• insufficient water trucks to serve all communities			
• Reduced economy	○ lack of rainfall monitoring			
Reservoir levels good	• livestock (cattle, sheep, goats and poultry) facing serious			
• Keservoir levels low	o investock farmers unprepared for lack of native forage			
• Reservoir losses due to excessive evaporation	○ low reservoir levels in external municipality water source			
• Reservoirs almost empty	• marketing bottleneck for producers			
• Reservoirs dried up	\circ no community initiatives to alleviate drought impacts			

Table S2: List of codes from the 1st step of analysis from observers reports using Atlas.ti (version 22)

• Reservoirs full	\circ no reforestation policy
• Reservoirs little replenished	\circ no water sources in some locations
• Reservoirs ok	• no water storage policy in wet season
	• planting in low-lying and poorly drained soils vulnerable
• Reservoirs overflowing	to heavy rain
• Reservoirs replenished	\circ poor road network and damaged infrastructure
• Reservoirs: localised replenishment	○ poor water management
• Risk of wildfires	\circ poor water quality in new boreholes
• River flow good	\circ preceding conditions unfavourable (already dry)
	\circ provided seeds from HORA DE PLANTAR programme
• River stopped flowing	are poor
• Seca verde	o public reservoirs only for human consumption and irrigation use prohibited
	• reported opposition of some farmers to using rooftop
• Silage production low	rainwater harvesting
• Small reservoirs full	• reservoirs not big enough
• Social impacts	• saline groundwater so cannot drill boreholes
• Soil moisture condition good	\circ sandy soils mean it is difficult to construct reservoirs
• Soil moisture low	• saturated soils prevents soil preparation
• Some regions suffering drought impacts, others not	\circ there is no irrigation programme
• State of emergency due to heavy rain and some dams	o undre la ne ningarion programme
broke	\circ waiting availability of a tractor to prepare soil
Survey questions	Alleviating factor
• Urban water supply difficulties	• (planned?) perennialisation of rivers using reservoir water
• Veranico occurred	\circ boreholes drilled
• Very high temperature	○ cisterns being supplied/built
 Very high temperature Water access difficulties in some isolated 	○ cisterns being supplied/built
 Very high temperature Water access difficulties in some isolated communities 	 cisterns being supplied/built groundwater used for supply
 Very high temperature Water access difficulties in some isolated communities Water access is at low levels 	 cisterns being supplied/built groundwater used for supply guidance provided on seed storage and planting (HORA DE PLANTAR programme)
 Very high temperature Water access difficulties in some isolated communities Water access is at low levels 	 cisterns being supplied/built groundwater used for supply guidance provided on seed storage and planting (HORA DE PLANTAR programme) increase in participation of agricultural and insurance
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• Water reserves for animals are good	• reservoir water prioritised for human and animal use so no irrigation
• Water reserves for humans are good	• reservoir working in accordance with particula regulatory framework
	• there are (only?) small irrigation schemes supplied by
• Water reserves for irrigation is good	groundwater
• Water reserves for shrimp farming	Extra information
\circ Water scarcity for rural families in some areas	○ % planted area
• Water scarcity in mountain areas	○ advice
• Water scarcity: critical	○ affected localities
• Water scarcity: localised	◦ comment on questionnaire
• Water supply rationing	\circ crop losses but not registered on database
• Water trucks necessary	\circ crop types provided
• Water trucks necessary in mountain areas	• different water sources
• Water trucks necessary in rural communities	• harvesting timing
• Water trucks necessary in some communities	\circ irrigation type and area
• Water trucks necessary in some rural communities	\circ it was not necessary to pay the Garantia Safra
• Water trucks not needed	\circ named author of report
• Water Hucks not needed	• named dution of report
• Wildfires	• no veranicos occurred
• whenes Prediction provided	• planting timing
• crop production will be good	• proportion of municipality affected
• crop production will be pormal	• proportion of multicipanty affected
• if current rains continue then supply will be guaranteed	• quantified crop losses
• increasing number of communities will require water	
trucks	 quantified rainfall
 rains will be plentiful 	 quantified reservoir level/capacity
• sparse rains will harm crops	\circ quantified river flow
\circ sufficient water volume accumulated during wet	
season	• quantity of communities served by water trucks
• supply not guaranteed unless much more rain falls	• quantity of water trucks
• there will soon be water scarcity	○ rainfall or season timing
• water trucks will soon be required	 related to past conditions
• when pasture will run out	○ seed distribution timing
• when water will run out	\circ source of water trucks
\circ will be a difficult year for producers due to losses	• veranico length
	• Farmers experiencing decreasing capital
	• Fish farm production reduced
	• Forage developing well
	• Forage diminishing
	• Forage is poor
	• Groundwater level dronning
	• Groundwater levels good
	• Groundwater levels improved
	Crowndwater levels improved
	\circ Groundwater levels low

• Harvest better than expected
○ Harvest good
 Insufficient water for irrigation
• Livestock farmers suffering
◦ Livestock in good health
◦ Livestock in poor health
• Livestock: conditions improved for livestock
◦ Localized flooding
◦ Loss of income
• Migration of rural producers to cities
• No crop losses
\circ No problems due to drought
○ No rainfall
• No social impact (due to social programmes)
• No water access problems due to drought
• No water access problems due to drought in rural
communities
• Pasture developing well
○ Pasture poor

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Hydrological drought impacts				
Water trucks necessary in some communities	Even though this is a response, it shows that there is insufficient water.	1		
Localized water shortage	The common response that some areas of the municipality have water problems and other areas have no problems.	2		
Insufficient water for human consumption	This option only considers water for humans and not for animals or irrigation.	3		
Low reservoirs levels	This category groups the many possible responses that refer to low reservoir levels, such as: "reservoirs not recharged", "water levels low", "reservoirs almost empty", etc. Because reservoirs have multiple uses, this is a separate option to 3 and 5.	4		
Insufficient water for production	This option considers both water for animals and for irrigation.	5		
Low groundwater levels	This option refers only to groundwater and mention of low water levels in wells and boreholes. Because groundwater has multiple uses, this is a separate option to 3 and 5.	6		
Agricultural Impacts				
Crop losses due to excessive rainfall	This option refers both to crop losses due to waterlogging and due to unexpected rains during harvest time.	7		
Crop losses due to pests	This option considers all types of pests, which may be aggravated by too wet conditions, drought conditions, or may be unrelated to rainfall.	8		

Crop losses due to insufficient rainfall	Crop losses due to drought, veranicos, or insufficient rain at critical times.	9		
Crop development impacts	This is commonly reported early in the growing season when crops are not developing well but the losses are not yet known.	10		
Livestock impacts This option includes responses about livestock ill-health and deaths, low dairy and fish farm production, as well as insufficient forage, pasture and silage.				
Socio environmental economic drought impacts				
Wildfires	Reports of fires in both natural vegetation or agricultural land.	12		
High production costs	Price increases in agricultural inputs like fertilizer, seeds, livestock feed, fuel or higher costs of services like renting equipment and transportation.	13		
Socioeconomic impacts	Examples include reduced income, unemployment, migration to cities, impacts on physical and mental health, etc.	14		

Table S4: Policy documents analyzed using Atlas.ti (version 22)

Policy in Portuguese	Description	Law	Institution	Year	Source
PRONAF	PRONAF, the National Program for Strengthening Family Farming, was created in 1995 as a rural credit line. Nowadays, it involves a set of actions aiming to increase the productive capacity, generate employment and raise the income of family farmers, with the aim of promoting development in rural areas.	Decreto nº 1.946, de 28 de junho de 1996	Ministry of Agrarian Development and Family Agriculture	1996	https://www.gov.br/pt- br/servicos/acessar-o- programa-nacional-de- fortalecimento-da- agricultura-familiar-pronaf
Garantia Safra	The Garantia-Safra aims to guarantee minimum livelihood conditions for family farmers in municipalities that are often affected by severe crop losses due to drought or excess water.	Lei nº 10.420, de 10 de abril de 2002	Ministry of Agriculture and Livestock	2002	https://www.gov.br/pt- br/servicos/acessar-o- beneficio-garantia-safra
Bolsa Família	Bolsa Família is Brazil's largest cash transfer program, internationally	Medida Provisória nº 1.164, de 2		2003	https://legislacao.presidenci a.gov.br/atos/?tipo=MPV& numero=1164&ano=2023&

	recognized for helping millions of families overcome hunger. The Federal	de Março de 2023			ato=fa6ITWE10MZpWTa6 2
	Government has relaunched the program with more protection for				
	families, with a model of payment that takes into account family size				
	and characteristics. Families with three or more people will now receive more than a				
	single person. In addition to guaranteeing basic				
	living in poverty, the Bolsa Família Program seeks to integrate public				
	policies, strengthening families' access to basic rights such as				
	health, education and social assistance.				
РАА	The Food Acquisition Program (PAA, in Portuguese) has two goals to promote access to food and to support small holder famers.	Created by Article 19 of Law No. 10,696 of July 2, 2003	Ministry of Agrarian Development and Family Agriculture	2003	https://www.gov.br/mds/pt- br/acoes-e- programas/inclusao- produtiva-rural/paa
Domestic Cistern or 1 st water cistern	The Cisterns Program aims to promote access to water for human consumption by implementing simple, low-cost social technologies.	Lei Nº 12.873/2013	Ministry of Development and Social Assistance, Family and Combating Hunger.	2013	https://www.gov.br/mds/pt- br/acesso-a- informacao/carta-de- servicos/desenvolvimento- social/inclusao-social-e- produtiva-rural/programa- cisternas-2013-agua-para- beber-e-para-agricultura
Production Cistern or 2 nd water cistern	The Cisterns Program aims to promote access to water for food production by implementing simple, low-cost social technologies.	Lei Nº 12.873/2013	Ministry of Development and Social Assistance, Family and Combating Hunger.	2013	https://www.gov.br/mds/pt- br/acesso-a- informacao/carta-de- servicos/desenvolvimento- social/inclusao-social-e- produtiva-rural/programa- cisternas-2013-agua-para- beber-e-para-agricultura
PNAE	The National School Nutritional Program (PNAE) consists of a	Lei nº 11.947, of 16/6/2009	National Education Development Fund	2010	https://www.planalto.gov.b r/ccivil_03/_ato2007- 2010/2009/lei/111947.htm

	supplementary		under the Ministry		
	transfer of federal		of Education		
	financial resources to				
	assist students. At				
	least 30% of food				
	products must be				
	purchased directly				
	from family farmers				
	and rural family				
	entrepreneurs or their				
	organizations, giving				
	priority to agrarian				
	reform settlements,				
	traditional indigenous				
	communities and				
	quilombola				
	communities.				
	Estratégia Saúde da				https://www.planalto.gov.b
	Família (ESF) is part				r/ccivil_03/leis/18080.htm
	of the Unified Health				
	(System Sistema				
	Único de Saúde,				
	SUS), the largest				
	public health system				
	in the world, which				
	assists more than 190				
	million people every				
	year in Brazil, fully				
	and free of charge.				
	Is not of animous				
	is part of primary				
	care in the country, in	Lai nº 8 080			
Estratégia	torms of the SUS	$\frac{10}{10} \frac{10}{10} 10$			
Saúde da	The FSE is developed	setembro de	Health Ministry	1990	
Família	by integrated care	1990			
	practices aimed at the	1770			
	population of the				
	territory and by				
	qualified				
	management, and is				
	led by a multi-				
	professional team				
	composed of a doctor				
	and a nurse,				
	preferably specialists				
	in Family Health; a				
	nursing assistant				
	and/or technician and				
	a community health				
	agent.				

Operação Carro-Pipa Federal	Operação Carro-Pipa is an emergency action by the federal government to bring drinking water to mainly rural communities in the Brazilian semi-arid region affected by drought, using water trucks to transport water from selected sources.	Portaria Interminister ial nº 1, de 25 de julho de 2012 do MI/MD.	Ministries of National Integration and Defense	2012	http://www.defesacivil.ba.g ov.br/wp- content/uploads/2015/02/P ORTARIA- INTERMINISTERIAL- No- 1MIMD_25_07_2012.pdf
Hora de Plantar	The Programa Hora de Plantar aims to strengthen family farming, using seeds and seedlings of high genetic potential and providing increased production and productivity of crops and improving the income level of the beneficiaries	Lei n°17.534, 2206/2021	Agrarian Development Secretary – Ceará State	2021	https://www.pge.ce.gov.br/ wp- content/uploads/sites/47/20 21/10/Edital-pag-11-a-24- 1.pdf