

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

S. 1 – Comprehensive data collection and analysis

1. 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 1 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).

1.1 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 2).

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

42 **Step 2 data validation with observers:** To reduce biases, we interviewed 29 observers,
43 representing over 40 municipalities. These interviews aimed to clarify specific questions regarding
44 the observers' reasoning while completing the questionnaires. These interviews revealed that the
45 questionnaires were completed based on observations and discussions with farmers and
46 communities while conducting their routine tasks.. These tasks involve visits to a wide area of
47 municipalities, and farmers also visit their offices from across the region. Consequently, observers
48 consider their reports comprehensive summaries of the conditions and impacts for the whole month
49 and the entire municipality.

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

56 With this step, we achieved simplicity and manageability of data, to add clarity and focus on the
57 most common patterns, and to increase readability. The outcome of this effort was the identification
58 of 14 distinct impact types (Table 3), which were then classified into impacts due to drought impacts
59 classification, i.e. hydrological, agricultural, and socio-environmental-economic impacts of
60 drought.

61 **2. Fieldwork interviews data**

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

71 **2.1 Analysis of fieldwork interviews data**

72 Following each full day of interviews, the research team convened for a debriefing session. During
73 this session, fieldwork notes were transcribed, impressions were cross-checked, and understanding
74 of each case was refined. Subsequently, the fieldwork notes dataset was uploaded to Atlas.ti

75 (version 22) for further analysis, focusing on excerpts where farmers alluded to both public policies
76 and the impacts of drought. For more information on the data collection and analysis of this dataset,
77 see (Kchouk et al., n.d.).

78 **3 Policy documents data**

79 Another dataset consisted of policy documents, which we gathered to acquire information about
80 the objectives and strategies of specific policies or programs implemented in the area. The selected
81 documents were about the public policies reported by both farmers and observers in the interviews.
82 Furthermore, we consulted other researchers who conduct studies in the region to ensure that we
83 had included all the policies implemented in the area. Our choice to include only public policies
84 established through formal acts in laws, regulations, decrees, court decisions, executive orders, etc.,
85 which are typically observed within legally authorized decision-making arenas, such as
86 legislatures, courts, and bureaucracies. This ensures their implementation happens irrespective of
87 the government currently in power. We refer readers to Table 4.

88 **3.1 Analysis of policy documents data**

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

95 **4. Identification of key impact cascades**

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

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

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

108 **4.1 Relationship between drought impacts monitoring data and policy documents data**

109 The last step of analysis was to compare the drought impacts with policies, to understand how
110 policy responses evolve to alleviate the cascade of drought impacts. We compiled all existing
111 policies in the region as a basis for delineating each policy's placement within the various directions
112 of the cascade of drought impacts. The public policies implemented in the region encompass

113 various sectors and can be summarized as policies for social development, agriculture, food
 114 security and health.

115 Table 1: Drought monitoring form

Municipality:	
Month:	
DROUGHT	
1. Considering the drought situation in the municipality, compared to the previous month, would you say that:	
<ul style="list-style-type: none"> 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:	
<ul style="list-style-type: none"> No rain (1) Little rain (2) Fair (3) A lot of rain (4) 	
b) Regarding the temporal distribution of rainfall this month:	
<ul style="list-style-type: none"> No rain (1) Veranico of up to 10 days (2) Veranico between 10 and 15 days (3) Veranicos over 15 days (4) 	
c) Regarding the spatial distribution of rainfall that month:	
<ul style="list-style-type: none"> 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?	
<ul style="list-style-type: none"> 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	
4. With regard to access to water in the municipality, please tick:	
<ul style="list-style-type: none"> There is no problem with access to water (1) Levels are low, but there is no problem with access 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:

116
117 Table 2: List of codes from the 1st step of analysis from observers reports using Atlas.ti (version
118 22)

Codes	Aggravating factor
<input type="radio"/> Cisterna levels are low	<input type="radio"/> boreholes drilled due to empty reservoirs have saline groundwater
<input type="radio"/> Cisternas full	<input type="radio"/> broken water infrastructure
<input type="radio"/> Cisternas replenished	<input type="radio"/> communities located a long distance from reservoirs
<input type="radio"/> Crop development poor	<input type="radio"/> conditions unsuitable for replanting
<input type="radio"/> Crop losses	<input type="radio"/> constant drought (aridity?)
<input type="radio"/> Crop losses due to excessive rainfall	<input type="radio"/> crop losses due to low rainfall at critical crop growth stage
<input type="radio"/> Crop losses high	<input type="radio"/> crop losses due to pests
<input type="radio"/> Crop losses low	<input type="radio"/> deforestation
<input type="radio"/> Crop planting reduced or delayed	<input type="radio"/> excessive rains at critical crop growth stage
<input type="radio"/> Crop production only sufficient for family consumption	<input type="radio"/> excessive rains crop harvest
<input type="radio"/> Crops developing well	<input type="radio"/> farmer insecurity to investment due to irregular rainy season
<input type="radio"/> Dairy production reduced	<input type="radio"/> fear of covid
<input type="radio"/> Drought condition improving	<input type="radio"/> high costs of electricity, diesel oil, butane
<input type="radio"/> Drought condition worsening	<input type="radio"/> high costs of rice, meat, corn and soy derivatives for animal feed
<input type="radio"/> Rainfall localised	<input type="radio"/> high production costs
<input type="radio"/> Rainfall low	<input type="radio"/> 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 health problems and disease
○ Reservoir levels low	○ livestock 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	○ no community initiatives to alleviate drought impacts
○ Reservoirs full	○ no reforestation policy
○ Reservoirs little replenished	○ no water sources in some locations
○ Reservoirs ok	○ no water storage policy in wet season
○ Reservoirs overflowing	○ planting in low-lying and poorly drained soils vulnerable to heavy rain
○ Reservoirs replenished	○ poor road network and damaged infrastructure
○ Reservoirs: localised replenishment	○ poor water management
○ Risk of wildfires	○ poor water quality in new boreholes
○ River flow good	○ preceding conditions unfavourable (already dry)
○ River stopped flowing	○ provided seeds from HORA DE PLANTAR programme are poor
○ Seca verde	○ public reservoirs only for human consumption and irrigation use prohibited
○ Silage production low	○ reported opposition of some farmers to using rooftop rainwater harvesting
○ Small reservoirs full	○ reservoirs not big enough
○ Social impacts	○ saline groundwater so cannot drill boreholes
○ Soil moisture condition good	○ sandy soils mean it is difficult to construct reservoirs
○ Soil moisture low	○ saturated soils prevents soil preparation
○ Some regions suffering drought impacts, others not	○ there is no irrigation programme
○ State of emergency due to heavy rain and some dams broke	○ 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	○ boreholes drilled
○ Very high temperature	○ cisterns being supplied/built
○ Water access difficulties in some isolated communities	○ groundwater used for supply
○ Water access is at low levels	○ guidance provided on seed storage and planting (HORA DE PLANTAR programme)
○ Water access problems alleviated	○ increase in participation of agricultural and insurance programmes
○ Water access problems in rural areas	○ later planting
○ Water for animal consumption: low availability	○ low rainfall but previous months saw plentiful rain
○ Water for human consumption has low availability in some communities	○ meeting requested with CMDS about Garantia Safra
○ Water for human consumption has low availability in some rural communities	○ municipality and competent bodies trying to mitigate drought impacts

○ Water for human consumption has poor water quality for rural populations	○ problems with water supply system are fixed
○ Water for human consumption has poor water quality for some communities	○ replanting
○ Water for human consumption: low availability	○ there is some irrigation
○ Water levels good	○ water supply from another municipality
○ Water levels low	○ water supply infrastructure installed
○ Water levels reasonable	Alleviating/aggravating factor
○ Water quality poor	○ crop losses not sufficient enough for Garantia Safra payment
○ Water reserves decreasing	○ no restrictions on reservoir use
○ 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 particular regulatory framework
○ Water reserves for irrigation is good	○ there are (only?) small irrigation schemes supplied by groundwater
○ Water reserves for shrimp farming	Extra information
○ 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	○ crop losses but not registered on database
○ Water trucks necessary	○ 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	○ irrigation type and area
○ Water trucks necessary in some rural communities	○ it was not necessary to pay the Garantia Safra
○ Water trucks not needed	○ named author of report
○ Wells dried up	○ no veranicos occurred
○ Wildfires	○ period of water scarcity
Prediction provided	○ planting timing
○ crop production will be good	○ proportion of municipality affected
○ crop production will be normal	○ quantified cisterna level
○ 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	○ quantified river flow
○ 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	○ source of water trucks

o will be a difficult year for producers due to losses	o <i>veranico</i> length
	o Farmers experiencing decreasing capital
	o Fish farm production reduced
	o Forage developing well
	o Forage diminishing
	o Forage is poor
	o Groundwater level dropping
	o Groundwater levels good
	o Groundwater levels improved
	o Groundwater levels low
	o Harvest better than expected
	o Harvest good
	o Insufficient water for irrigation
	o Livestock farmers suffering
	o Livestock in good health
	o Livestock in poor health
	o Livestock: conditions improved for livestock
	o Localized flooding
	o Loss of income
	o Migration of rural producers to cities
	o No crop losses
	o No problems due to drought
	o No rainfall
	o No social impact (due to social programmes)
	o No water access problems due to drought
	o No water access problems due to drought in rural communities
	o Pasture developing well
	o Pasture poor

119

120 Table 3: Impact homogenization

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.	11
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

121

122 Table 4: 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 recognized for helping millions of families overcome hunger. The Federal 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 income for families 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.	Medida Provisória nº 1.164, de 2 de Março de 2023		2003	https://legislacao.presidencia.gov.br/atos/?tipo=MPV&numero=1164&ano=2023&ato=fa6ITWE10MZpWta62
PAA	The Food Acquisition Program (PAA, in Portuguese) has two goals to promote access to food and to support small holder farmers.	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-productiva-rural/paa
Domestic Cistern or 1 st water cistern	The Cisterns Program aims to promote access to water for human consumption by implementing	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-

	simple, low-cost social technologies.				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 N° 12.873/2013	Ministry of Development and Social Assistance, Family and Combating Hunger.	2013	https://www.gov.br/mds/pt-br/aceso-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 supplementary transfer of federal 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 <i>quilombola</i> communities.	Lei n° 11.947, of 16/6/2009	National Education Development Fund under the Ministry of Education	2010	https://www.planalto.gov.br/ccivil_03/_ato2007-2010/2009/lei/111947.htm

<p>Estratégia Saúde da Família</p>	<p>Estratégia Saúde da Família (ESF) is part 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.</p> <p>Is part of primary care in the country, in accordance with the terms of the SUS. The ESF is developed by integrated care practices aimed at the 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.</p>	<p>Lei nº 8.080, de 19 de setembro de 1990</p>	<p>Health Ministry</p>	<p>1990</p>	<p>https://www.planalto.gov.br/ccivil_03/leis/18080.htm</p>
<p>Operação Carro-Pipa Federal</p>	<p>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.</p>	<p>Portaria Interministerial nº 1, de 25 de julho de 2012 do MI/MD.</p>	<p>Ministries of National Integration and Defense</p>	<p>2012</p>	<p>http://www.defesacivil.ba.gov.br/wp-content/uploads/2015/02/PORTARIA-INTERMINISTERIAL-No-1MIMD_25_07_2012.pdf</p>

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 nº17.534, 2206/2021	Agrarian Development Secretary – Ceará State	2021	https://www.pge.ce.gov.br/wp-content/uploads/sites/47/2021/10/Edital-pag-11-a-24-1.pdf
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