CLIMATE VULNERABILITY ANALYSIS IN ILHA DO MARAJÓ / PA

PRODUCT A.1

Diagnosis of the Study Region

Developed by:
H2O Company

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SOCIOECONOMIC DIAGNOSIS

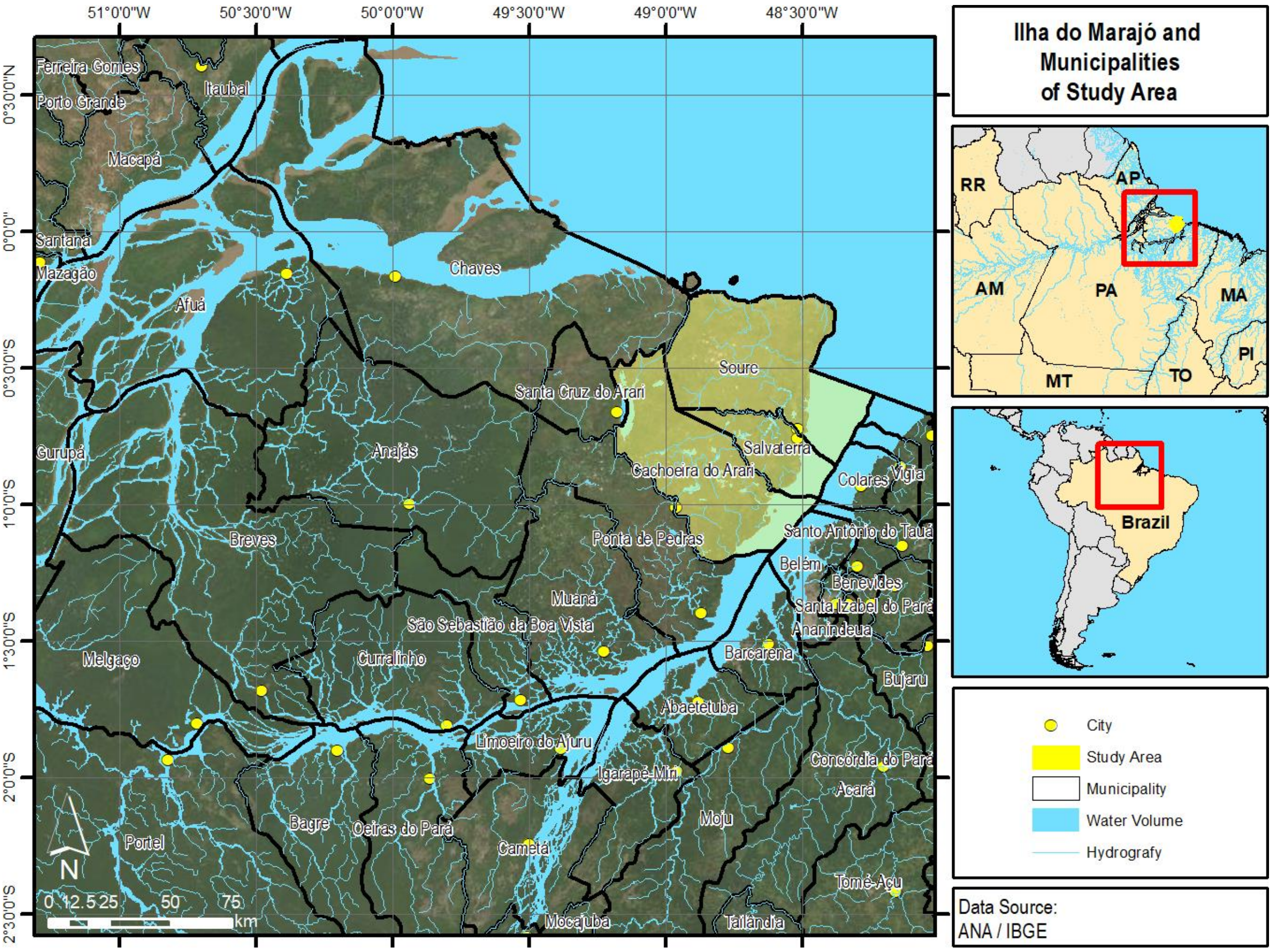
This section presents the diagnosis of the social and economic aspects of interest to the Marajó Archipelago, with focus on the target municipalities of the study.

LOCATION

The Marajó Archipelago is located in the state of Pará and is considered the largest fluviomarine territory in the world. Its territory is divided between islands (40.6 thousand km²) and a part of the mainland (54.5 thousand km²), totaling 95.1 thousand km². The archipelago is composed of 16 municipalities, with the continental fraction referring to the municipalities of Bagre and Portel (BRAZIL, 2020). Its insular portion is limited to the north by the Atlantic Ocean, to the south by the Pará River, to the east by the Marajó Bay and to the west by the Amazon River.

The archipelago is 87 km from the city of Belém, capital of Pará, and it is only possible to get there by river transport (boat, ship and ferry) or by plane. Figure 1 shows the location of the Marajó Archipelago, highlighting the study's target municipalities (Soure, Salvaterra and Cachoeira do Arari).

Figure 1: Location of the Marajó Archipelago



Source: Elaborated by the authors.

SOCIAL ASPECTS

The analysis of social aspects of the study region aims to characterize the conditions of the Marajoara population and describe the reality of the territory.

POPULATION

In 2021, the population of the Marajó Archipelago was estimated to be more than half a million people (577,790 inhabitants), which represents about 6.58% of the population of the state of Pará. The most populous municipality in the region is Breves, with 104,280 inhabitants, and the least populous is Santa Cruz do Arari, with 10,496 inhabitants. Table 1 presents population data (2010 and 2021), area and demographic density of Marajó's municipalities, highlighting the municipalities of Cachoeira do Arari, Salvaterra and Soure.

Table 1: Urban and rural estimated populations for the Marajó Archipelago municipalities

Municipality	Estimated 2021	2010 Census (IBGE)			Area (km^2)	Demographic Density ($inhab/km^2$)
	Population	Population	% Urban	% Rural		
Breves	104,280	92,860	50	50	9,567	10.9
Portel	63,831	52,172	48	52	25,385	2.5
Muaná	41,454	34,204	42	58	3,763	11.0
Afuá	39,910	35,042	27	73	8,338	4.8
Curralinho	35,530	28,549	38	62	3,617	9.8
Gurupá	34,127	29,062	33	67	8,570	4.0
Ponta de Pedras	32,007	25,999	48	52	3,364	9.5
Bagre	31,967	23,864	45	55	4,397	7.3
Anajás	30,091	24,759	38	62	6,914	4.4
Melgaço	28,121	24,808	22	78	6,774	4.2
São Sebastião da Boa Vista	27,302	22,904	43	57	1,632	16.7
Soure	**25,752**	**23,001**	**91**	**9**	**2,857**	**9.0**
Salvaterra	**24,392**	**20,183**	**63**	**37**	**919**	**26.6**
Cachoeira do Arari	**24,355**	**20,443**	**36**	**64**	**3,100**	**7.9**
Chaves	24,175	21,005	12	88	12,535	1.9
Santa Cruz do Arari	10,496	8,155	49	51	1,077	9.7
Marajó	**577,790**	**487,010**	**43**	**57**	**95,100**	**6.1**
Pará	**8,777,124**	**7,581,051**	**68**	**32**	**1,245,871**	**7.0**
Brazil	**213,317,639**	**190,755,799**	**84**	**16**	**8,510,346**	**25.1**

Source: IBGE, 2021; IBGE, 2010.

The three municipalities studied have small and very similar populations, with Soure housing the largest number of people (25,752 inhabitants), followed by Salvaterra (24,392 inhabitants) and Cachoeira do Arari (24,355 inhabitants). These three municipalities correspond to 13% (77,499 inhabitants) of the archipelago's total population. Regarding territorial extensions, Salvaterra is the smallest municipality in Marajó (919 km²), while at the other extreme is Portel (25,385 km²). Cachoeira do Arari (3,100 km²) and Soure (2,857 km²) are also among the cities with the smallest geographic area.

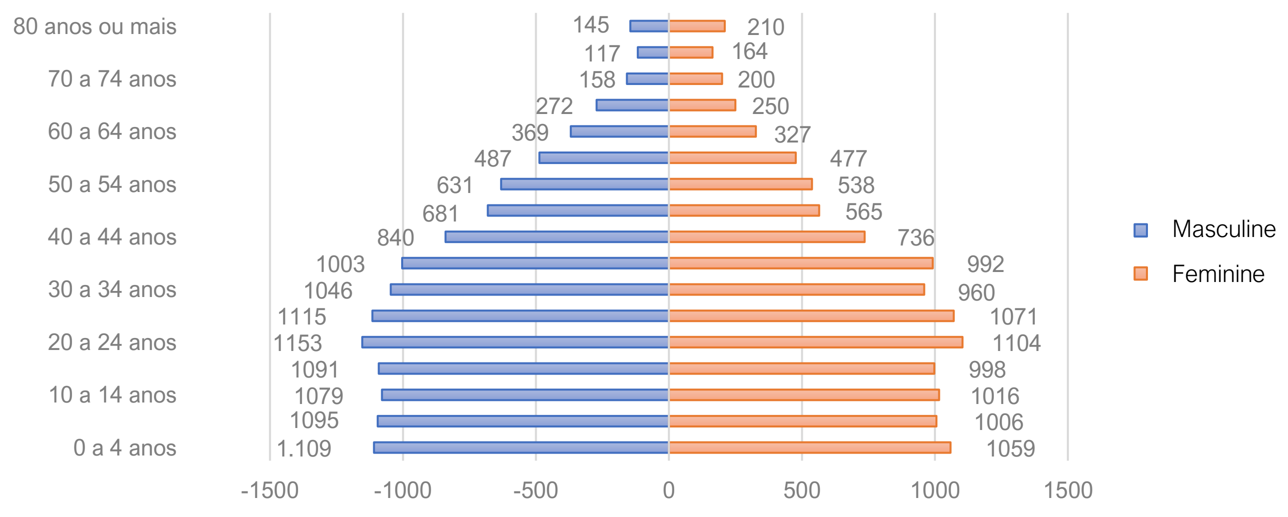
Due to the reduced area, Salvaterra is the municipality with the highest population density in Marajó, with 26.6 inhab/km². This is higher than the population density of Brazil, estimated at 25.1 inhab/km².

It can be observed that in 2010, the Marajoara population was predominantly rural, with the exception of the cities of Salvaterra and Soure. For the state of Pará, and for Brazil, the population in that same year lived mostly in urban areas.

GENDER AND AGE GROUPS

Graphs 1 to 3 present the population distribution, according to age group and gender, for the municipalities of Cachoeira do Arari, Salvaterra and Soure, respectively.

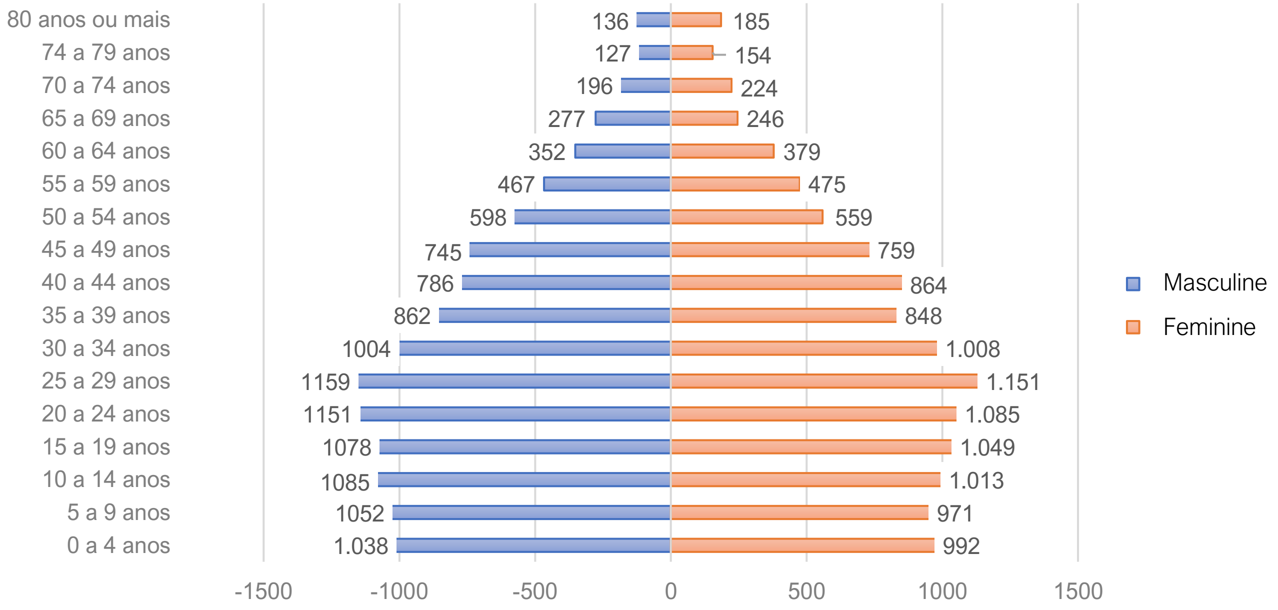
Graph 1: Age pyramid for the municipality of Cachoeira do Arari



Source: DATASUS, 2021. Elaborated by the authors.

Cachoeira do Arari maintains high birth rates and low infant mortality rates. An increase is noted in the ranges of young and adult populations — the economically active population — with higher values for the 20–24 interval. The male population remains larger than the female population until the age of 69, when there is an inversion of this pattern, which indicates greater life expectancy among women. The narrow top of the pyramid indicates low life expectancy in the elderly population, which may be linked to low quality of life.

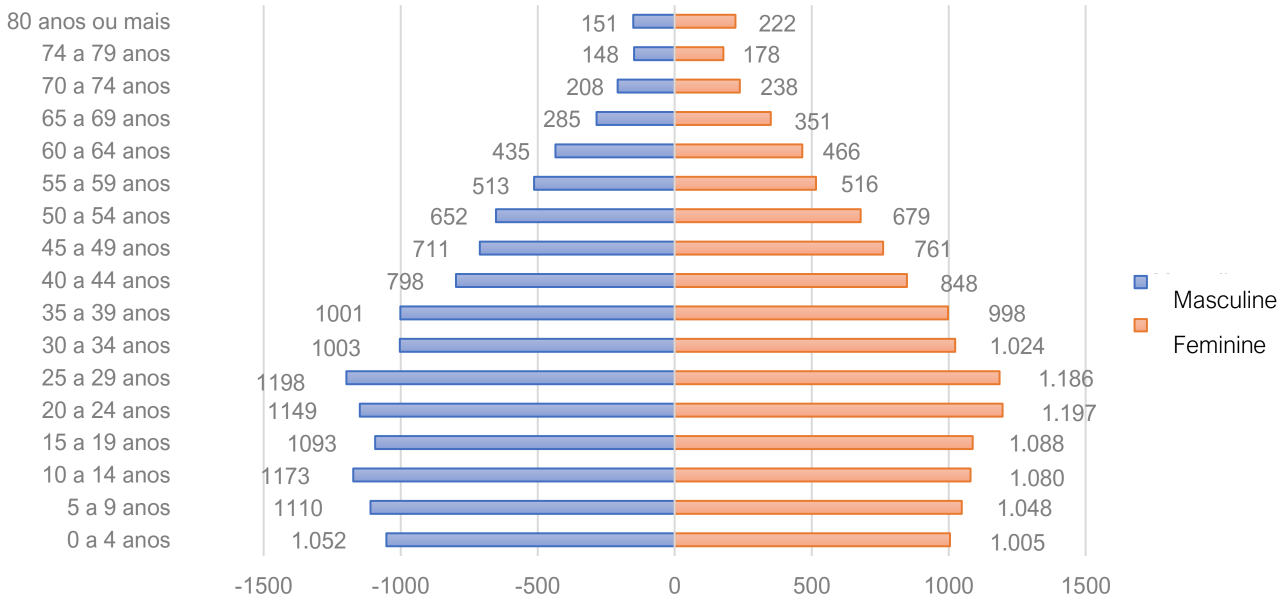
Graph 2: Age pyramid for the municipality of Salvaterra



Source: *DATASUS, 2021. Elaborated by the authors.*

The pattern verified for the municipality of Salvaterra is very similar, preserving a wide pyramid base, which indicates high birth rates, and a significant population of children and young people. It is worth noting that in this case, most of the population is in a higher age group than in Cachoeira do Arari, between 25 and 29, indicating slightly better living conditions, which may be associated with a higher rate of urbanization in the city.

Graph 3: Age pyramid for the municipality of Soure



Source: DATASUS, 2021. Elaborated by the authors.

More men than women are born in Soure, too, and the municipality has a low infant mortality rate. Of note is the reduced number of individuals of both genders between 15 and 19 years old. A possible explanation is the departure of young people from the municipality in search of new opportunities, mainly related to education, in municipalities with greater opportunities, such as Belém. In addition, of the three cities analyzed, Soure has the largest population over 80. Several factors can influence this achievement, such as better public policies in health, education, security, sanitation or even the profile of economic activities carried out in the territory.

FORMAL EMPLOYMENT

In 2019, Salvaterra was among the 20 cities in Pará with the lowest average monthly income, occupying the 18th position. In that year, the formal worker was paid an average of around R$1,658.27/month, the lowest value among the three analyzed municipalities, approximately 38% below the remuneration calculated for the state, and 44% lower than that of the country. In Cachoeira do Arari and Soure, salaries are a little higher, the latter having the best result with R$1,929.31. Table 2 presents the average monthly remuneration of formal workers in each municipality evaluated.

Table 2: Average monthly remuneration of formal workers

Municipality	Average monthly remuneration (R$)
Soure	1,929.31
Cachoeira do Arari	1,831.36
Salvaterra	1,658.27
Pará	**2,653.59**
Brazil	**2,975.74**

Source: CEMPRE, 2019.

Aside from presenting a higher average monthly income, Soure also possesses a higher number of formal jobs among the municipalities analyzed, followed by Salvaterra and Cachoeira do Arari, as shown in Table 3.

Table 3: Formal employment ties by major sector

Municipality	Sex		Major sector				
	M	F	Industry	Civil construction	Commerce	Service	Agriculture
Soure	712	627	8	-	211	1,025	95
Salvaterra	634	563	47	15	128	988	19
Cachoeira do Arari	530	562	38	-	68	948	38

Source: FAPESPA, 2019.

Soure was the sixth Marajoara municipality that generated the most registered jobs in 2019. A common point among the cities listed in Table 3 is the greater concentration of jobs in the service, commerce and agriculture sectors, a reflection of the economic activities developed in those territories. This same trend is verified for Marajó and for the state of Pará.

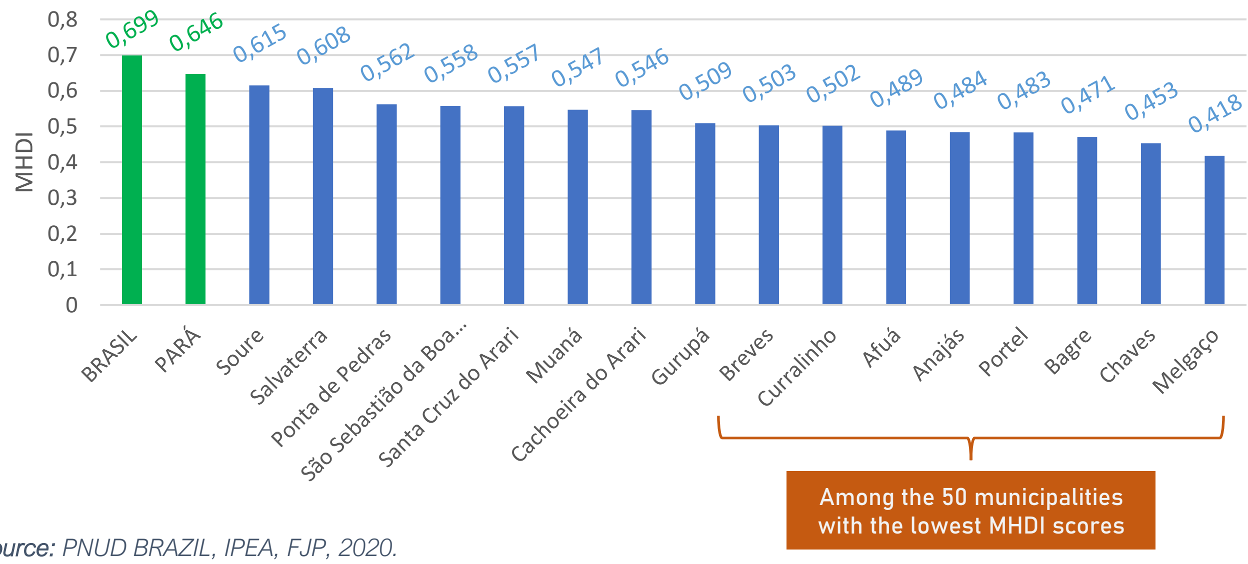
MUNICIPAL HUMAN DEVELOPMENT INDEX — MHDI

The municipalities of the Marajó Archipelago have some of the lowest MHDI scores in Brazil. Among the 16 municipalities that make up Marajó, eight have among the 50 lowest MHDI scores in the country. They are: Breves, Curralinho, Afuá, Anajás, Portel, Bagre, Chaves and Melgaço. Cachoeira do Arari's MHDI score falls in the range of low human development, and Salvaterra and Soure present average performance.

Graph 4 presents the MHDI of the municipalities of Marajó, as well as the average for Brazil and the state of Pará.

> The MHDI is a composite measure of indicators of three dimensions of human development: longevity, education and income (PNUND, 2021). The index varies on a scale from 0 to 1. The closer to 1, the greater the human development.

Graph 4: Municipal Human Development Index of the municipalities of the Marajó Archipelago



Source: PNUD BRAZIL, IPEA, FJP, 2020.

HIGHLIGHTS

Cachoeira do Arari is the least populous municipality and the only one whose population is mostly rural. It was the one that least created registered jobs, but the one that most employed women. The city was also the one with the worst performance in the HDI. Salvaterra is the smallest and most populated municipality in Marajó, with a considerable degree of urbanization of its population. It presents the lowest remuneration of formal workers, and most jobs are concentrated in the service sector. Soure is home to the largest population, mostly concentrated in urban areas, and has the highest life expectancy. The city also possesses the highest number of formal jobs, a large part also linked to the service sector, and offers the best salaries. Such factors contribute to Soure registering the best position in the HDI.

DEVELOPMENT CHALLENGES

From the brief social profile outlined so far, it is clear that there are elements that challenge the strengthening of adaptive capacities of smallholders to better cope with climate impacts. A significant part of the population of the municipalities under study is currently dispersed in rural areas, especially riverside and traditional communities. This dispersion makes it difficult to offer goods and services to the population, increasing the degree of vulnerability of these social groups. The deficit in access to public services and infrastructure can impact the health, education and economy of a region, leading to developmental delay. Such a relationship can be demonstrated by the Municipal Human Development Index (MHDI). Although Soure and Salvaterra present the highest values in Marajó, and Cachoeira do Arari the seventh highest, their performance is still below the state and national average.

Among the indicators evaluated to calculate the MHDI is income. If we consider the population over 16 years old indicated in the age pyramids presented, whose potential labor can be considered by the productive sector, and compare it with the amount of formal employment relationships verified, it is clear that a considerable part of the population is unemployed or acting informally, as is the case of artisanal fishers, smallholders and extractivists. The absence of standardization or formalization in work or production relationships can lead to the formation of asymmetrical, non-transparent and inconstant commercial relationships, as is the case with small producers. As they do not have direct access to the consumer market, they depend on intermediary negotiators, known as *atravessadores*, to sell their production. Thus, *atravessadores* have great bargaining power over producers, as they determine prices and payment terms.

Another aspect evaluated by the HDI-M is longevity. The three municipalities analyzed have high fertility rates, however, there is a low life expectancy and evidence of a possible process of emigration of the younger population to other locations.

The implementation of actions to contribute to the reduction of the climate vulnerability of smallholders in the study region must take into account the complexity of working in a vast territory such as the Amazon biome, with a dispersed population, with low access to services and infrastructure that promote socioeconomic development.

ECONOMIC ASPECTS

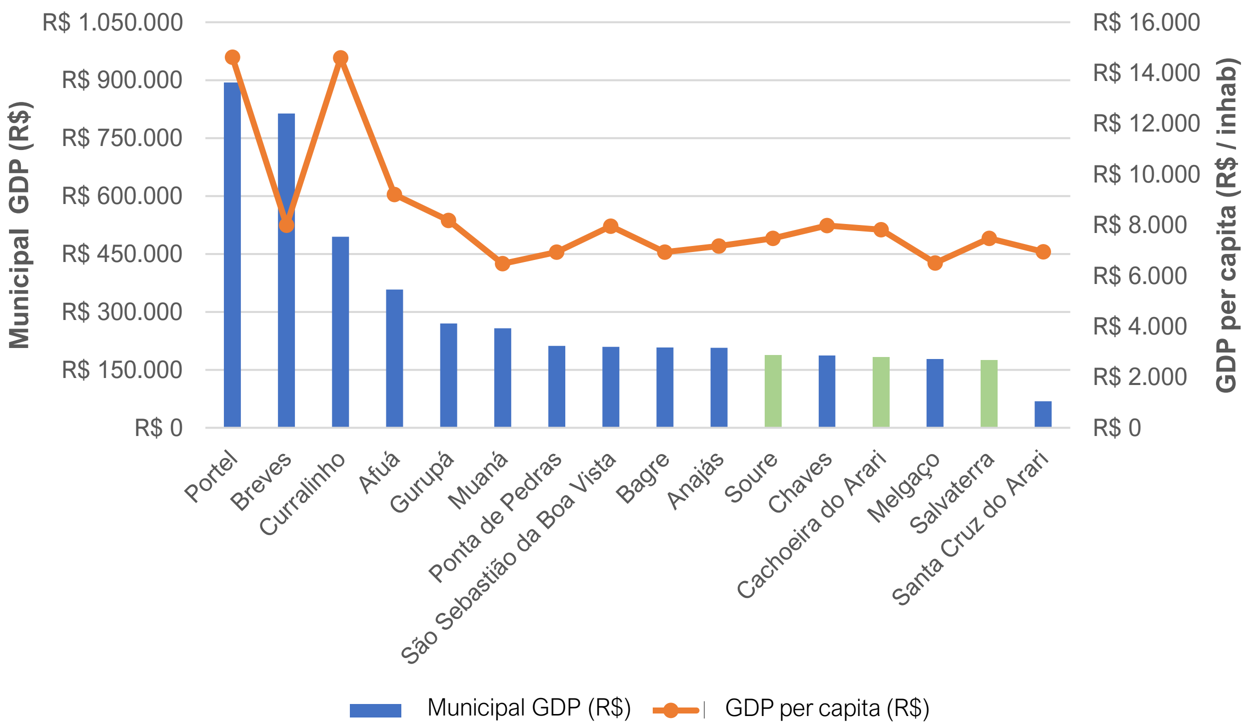
In relation to the Gross Domestic Product (GDP) of the Marajoara municipalities, Portel stood out in 2018 as the largest economy, contributing 18% of the region's total performance whereas the city of Santa Cruz do Arari had the worst indicator, with a share of only 1%. The three municipalities in the study also showed low economic performance, with the GDP of each municipality representing about 4% of the Archipelago's result.

Soure, Salvaterra and Cachoeira do Arari present a very similar municipal GDP and per capita GDP, as presented in Graph 5. The studied municipalities are highlighted in green.

An analysis of the GDP per capita shows that the value for Marajó (R$8,801.00) is almost four times lower than the national (R$33,593.82) and well below what is verified at the state level (R$18,952.00).

Graph 5. The studied municipalities are highlighted in green.

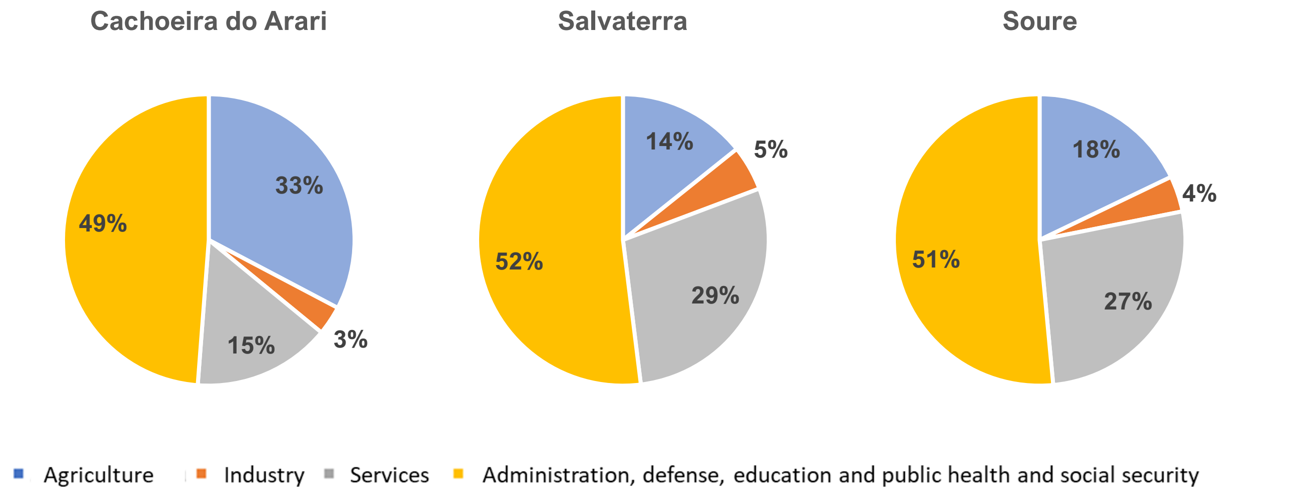
Graph 5: Municipal and GDP per capita of the Marajó Archipelago municipalities



Source: IBGE, 2018; FAPESPA, 2019; IBGE, 2021; FAPESPA, 2021.

While evaluating the profile of the economic activities developed in the three territories, it is verified in Graph 6 that the public administration possesses relevant contribution to the results, which demonstrates a considerable dependence on the public sector by the municipalities. If we exclude this activity from the analysis, the most prominent sector for Cachoeira do Arari was agriculture, followed by service and industry. As for the municipalities of Salvaterra and Soure, this order is reversed, the main one being services, followed by agriculture and finally, industry.

Graph 6: Gross value added of the economic activity sectors



Source: IBGE, 2018.

PRODUCTIVE ACTIVITIES

The official public data available on agricultural activities carried out in the municipalities of Soure, Salvaterra and Cachoeira do Arari do not reflect the reality of the entire population, especially small producers and the fishing and extractive population.

There are no official data associated with extractive production, such as fish, crab and shrimp, as well as non-timber forest products. This absence of data was confirmed in the field by several actors, such as representatives of EMATER, ICMBIO and municipal governments, in addition to the residents of the communities visited. However, these resources represent important sources of livelihood and small income surpluses for the most vulnerable communities.

SOURE

Located in the municipality of Soure is the Marine Extractive Reserve (Resexmar), which houses 1.298 families distributed in 6 communities, totally or partially within the conservation unit (Araruna, Barra Velha, Pesqueiro, Céu, Caju-úna and Pedral), and in 9 urban neighborhoods outside the Resexmar limits (Centro, São Pedro, Matinha, Umirizal, Pacoval, Macaxeira, Bom Futuro, Bairro Novo and Tucumanduba) (ICMBIO, 2018).

These families survive mainly on fishing resources, such as fish, crab, shrimp, crabs and shellfish (ICMBIO, 2018). The shrimp harvesting is an alternative activity during the fishing closed season. Some families also make a living from the capture and sale of crabs, an activity that involves the whole family: men and some women collect, and women process, then sold processed. The sale is made to intermediaries.

To complement the source of income and for their own consumption, there is exploitation of non-timber forest resources (natural oils and fruits, especially açaí, coconut, bacuri, andiroba and tucumã oil), breeding small animals (chickens, ducks and pigs), as well as the sale of handicrafts and natural products, and activities related to the tourism sector (tours, bar and restaurant services, accommodation, among others). The east coast region of Marajó is among the main tourist destinations in the Brazilian Amazon, making the Resexmar Soure one of the most visited federal conservation units (150.000 visitors/year). (ICMBIO, 2018).

The income of families in Resexmar de Soure is concentrated between half and 1 minimum wage per month (CARDOSO, 2018). Table 4 presents the contribution of each economic activity to Resex families, and the most representative products.

Table 4: Economic activities of families living in the Soure Marine Extractive Reserve

Productive Activities	Representativeness	Main products
Fishing	81,34%	Crab, shrimp, turu, bagre, acari, sarda, tainha, cação and filhote
Extractive production	37,94%	Açaí, coconut, andiroba and tucumã almond/oil
Small animals breeding	6,03%	chickens, ducks and pigs
Agriculture	2,58%	Vegetables, banana and maxixe

Source: ICMBIO, 2018; CARDOSO, 2018.

In the community of Vila do Pesqueiro there are about 120 families, with approximately 367 people. During the fishing season they live in the community and when it closes, they migrate to the city. Regarding changes associated with fishing activity, some representatives of Vila do Pesqueiro reported a reduction in the amount of fish available, and the disappearance of species such as 'Xaréu' and 'Tainha' in fisheries, while others currently predominate, such as 'Pratiqueira', 'Tambaqui' and 'Tucunaré'. They associate such changes with industrial fishing and also with the effects of climate change.

A study by the Peabiru Institute on the fisheries value chain corroborates the information that some fish species have already been overexploited by industrial commercial fisheries in the Amazon estuary. The fishermen of Marajó Island point out that in recent years fish has become scarce as a result of overfishing by industrial fishing vessels that practice pair trawling in the Amazon estuary. Industrial fishing, in addition to reducing fish stocks, resulting in overfishing and scarcity of species consumed by artisanal fishing, generating a series of consequences for the social environment that depends on this stock and for the environment. (INSTITUTO PEABIRU, 2017)

Fishermen have observed an increase in tidal and river levels and the drying up of rivers, lakes and dams. Changing water regimes impair species cycles and cause failures in the species' food chain and fisheries production, often felt several years later. (CONSELHO PASTORAL DOS PESCADORES, 2016).

There is a range of small producers in the municipality, who seek to diversify activities for their maintenance. For example, two properties were visited that already practice production in an Agroforestry System, with a consortium of fruit and non-wood species (açaí, cupuaçu, taperebá, bacuri). These producers have explored the production with greater added value, through pulps, jellies and other forms. Processing has a worrying factor in energy, as it requires storage of perishable products and, as reported, there is some instability in the energy supply in the region.

Regarding the most vulnerable communities in Soure, the community of Pedral was visited, which brings together about 82 families with a profile to work with Agroforestry Systems, as a strategy for climate resilience and food security. The land is around 1 hectare on average and there are some unoccupied areas that could be used for some type of system for collective use. The community has already received a community garden project, however, there was a lack of planning about the types of crops and how to access markets for sale. The project is maintained without guidance by the communities themselves.

It is evident the need for a plan and management of the system, that is, how the system should be managed on a daily basis by the community. There is no production and marketing plan, defining what should be grown and how these products could be marketed.

SALVATERRA

In the municipality there are 16 quilombola communities, in addition to some communities that are organized around family farming. The municipality of Salvaterra is the one with the greatest aptitude for family farming, according to reports from the population and what was observed in the field in relation to the structure of small rural properties, which always have backyards (1 to 3 hectares) for agricultural production.

Bacabal was one of the first quilombola communities in Salvaterra to begin the process of land tenure. The families that live there maintain their livelihood from the cultivation and sale of cassava, pineapple, in addition to fishing. Some families also raise small animals such as ducks and swines for own consumption (SENA et al, 2021).

In the Boa Vista community, the main source of income is the cassava plantation, raw material for the production of common flour, tapioca flour, tucupi, gum (used in the preparation of tacacá) and maniva (manioc leaves, main ingredient of maniçoba). The fishing and small animals breeding serve as a basis for food for families, in addition to constituting a source of income (SENA et al, 2021).

A very similar model can be verified in the Pau Furado community. In this quilombola community, the production of cassava, watermelon and tomato was observed. They also produce pineapple, but for this crop they reported difficulty in transport and storage. They are gradually replacing pineapple with cassava, as they already had prior knowledge. They commented that if there was knowledge, they would also plant other cultures. They have a partnership with a flour factory belonging to a large producer in the region, which also encouraged the transition to planting cassava. In this property, it was reported that recently it has felt the need to irrigate the crops, due to the reduction of rainfall. They reported that the extraction of açaí and bacuri has reduced because of the effects of climate change and overexploitation.

Visiting the Quilombola community of Caldeirão and talking to local leaders, it was reported that the area has been suffering from the fragmentation of its territory due to owners outside the community. The properties have, on average, 1 to 3 hectares, being suitable for the implementation of agroforestry systems. Fishing is pointed out by most residents as the main economic activity, followed by agriculture.

The community of Bairro Alto is organized into seven large sites: São Luiz, Santa Maria, Vila Galvão, Valentim, Marinquara, Bairro Alto and Cocal Island. The management of bacuri is one of the main extractive activities in the community, followed by açaí and the extraction of coconut and tucumã to produce oil (SENA et al, 2021).

Table 5 presents the most representative products in some quilombolas communities of Salvaterra.

Table 5: Economic activities of smallholders living in Salvaterra

Productive Activities	Pau Furado	Bairro Alto	Boa Vista	Bacabal	Caldeirão
Extractive production	Açaí, bacuri	Bacurí, Açaí, tucumã oil, coconut	-	-	-
Fishing	Acará, Tucunaré, Bacu, Traíra	Fish	Aracu, Piranha, Acará, Traíra	Acará, Bacu, Traíra	Fish
Agriculture	Cassava, watermelon, Tomato, pineapple	Cassava, pineapple	Cassava	Cassava, pineapple	-
Small animals breeding	Chicken, swine and quati	-	Chicken, swine	Duck, swine, chicken	-
Livestock	-	-	-	Cattle	-

Source: SENA et al, 2021; H2O Company (field visit), 2022

In Salvaterra, a visit was made to the cooperative of family farmers CAFAS, made up of 21 families. The women at the head of the initiative (they are predominant in the cooperative) began to organize themselves to raise funds in projects and participate in bids for the National School Feeding Program (PNAE). With resources from projects from the Pará Development Agency – ADEPARÁ, they equipped the fruit processing environment and today have processing and storage capacity.

The cooperative recently acquired a new area, covering about 1.5 hectares, and they plan to diversify production. Currently, they purchase products from their own cooperatives and from third parties, for processing and commercialization of products such as cupuaçu, bacuri, taperebá, açaí, pineapple, among others. They reported that there is a noticeable variation in the availability of fruits as a function of climatic conditions. As an example, they note that the production of cupuaçu decreased in the last

When one of the cooperative members was asked what the forest represents, she replied: "*For me, the forest represents support because we are extractivists and the forest gives us piquiá, pupunha, cupuaçu, graviola, native açaí...*"

summer, which was rainier in the months of October, November and December, in addition to reporting an increase in the thermal sensation (temperature).

CACHOEIRA DO ARARI

The municipality of Cachoeira do Arari has a good part covered by a landscape of flooded fields, in which the recent rice production has been installed, which already occupies a good part of the central region of the municipality. The fields come close to the banks of the streams and the Arari River, on the western edge. The riparian vegetation intersperses forests and open areas.

In conversation with a representative of EMATER in the municipality, it was reported that the main activity in the municipality is livestock. When crossing from Salvaterra to Cachoeira do Arari, one travels around 60 km in a landscape of flooded natural fields where the expressive presence of buffalo livestock on the properties can be seen, and more recently the introduction of cattle. It was reported that about 80% of the territory is associated with large farms with livestock activity, with a predominance of landscapes of natural fields.

Artisanal fishing is very strong among the most vulnerable population of the municipality, serving basically for subsistence. EMATER develops fish farming work with 15 families in the municipality. The main native crops in the municipality are açaí, cassava, corn, bacuri, taperebá and cupuaçu. EMATER develops açaí plantation management work in a floodplain area.

It was reported that most of the municipality where more vulnerable populations reside, such as extractive settlements (PAE Xipaia and PAE Urubuquara) and the quilombola community of Gurupá, are in floodplain areas, with little availability of firm land available for planting.

There are 2 settlements in the municipality of Cachoeira do Arari: the Xipaiá and Urubuquara Agroextractive Settlement Projects (PAE), and 1 remaining quilombolo community called Gurupá. In 2014, there were 350 families living in Urubuquara and the extractivism is one of the productive activities carried out by them, and is mainly focused on açaí. Next is fishing for different species of fish and shrimp. When fishing takes place in the bay, the most common species are: sarda, filhote, mapará, dourada, pescada branca and amarela, bagre, pacú, gurijuba, piramutaba, piaba, cação, arraia, chareu, tainha, camurim and pratiqueira. When fishing takes place in lakes, the following species stand out: pacú, piranha, sarapó, tamuatá, traíra and cachorrinho do padre. The ones found in the river that bathes the community are: pongó, mandií, pescadinha, anujá, sarapó, aracú, jundiá and ituí. The production is mainly destined to self-consumption, however, sporadically there is commercialization in the settlement (INSTITUTO PEABIRU, 2014).

Another productive activity developed by the families is the raising of small animals such as: chicken, duck and swine. This production is intended to guarantee the food security of the families, however, sporadically there is also commercialization in the settlement of chicken and pork. The activity is mainly developed by women and children (INSTITUTO PEABIRU, 2014).

The second community, Gurupá, is organized into eight micro-communities/sectors where 150 families live: i) Igarapé Bom Jesus or Toromba; ii) Igarapé da Roça; iii) Baixo Gurupá; iv) Tapera; v) Gurupá River (more specifically the left bank); vi) Campinho or Campo Alegre; vii) Aracajú and viii) Cabeceira. The economic base of the families is extractive production, mainly focused on açaí, but also related to other products such as Brazilian nut, bacuri and andiroba. There are also artisanal fishing and shrimp harvesting, agriculture, small animals breeding (chicken and swine) and livestock (buffalos and cattle) (RODIGUES et al, 2017).

In 2017, the average income of the families in Gurupá community was R$ 339.48/month. When considering income from other sources such as government income transfer programs (Bolsa-Família and Seguro Defeso), the average monthly income rises to R$ 420.44 (RODIGUES et al, 2017).

In the community, producers use upland areas to produce products such as: cassava (Manihot esculenta), cassava (Manihot palmata), macaxeira (Vigna unguiculata (L.) Walp.), corn (Zea mays), banana (Musa spp.), among others. The capoeira area is cultivated with species such as watermelon (Citrullus lanatus), maxixe (Cucumis angaria), quiabo (Abelmoschus esculentus) and pineapple (Ananas comosus), among others of food importance, which vary according to the choice of the producer.

Table 6: Economic activities of smallholders living in Cachoeira do Arari

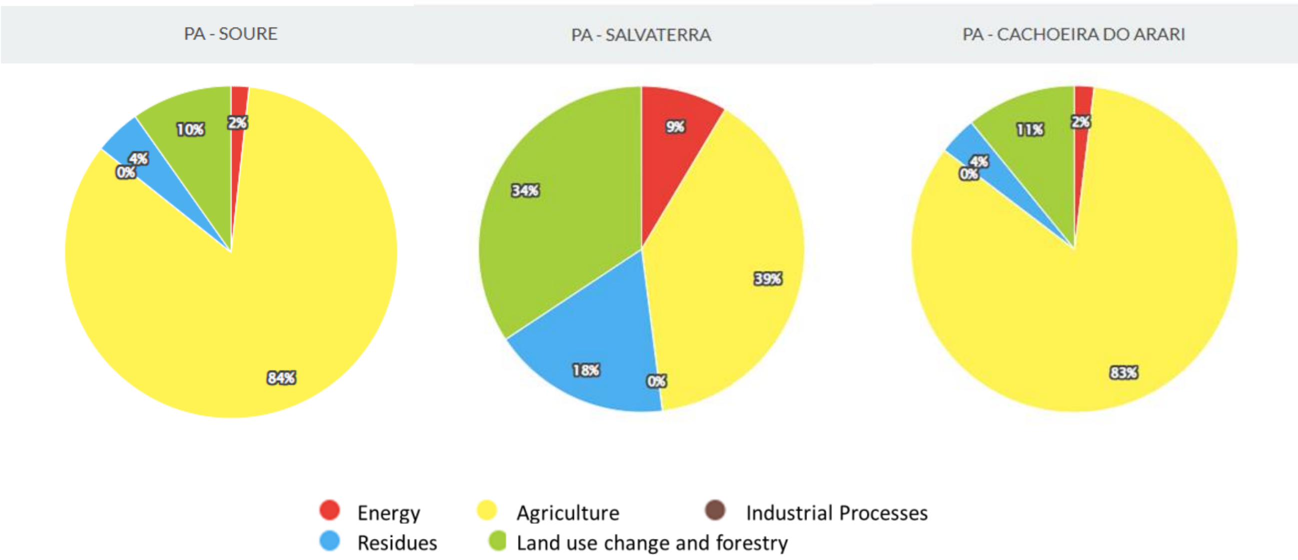
Productive Activities	PAE Urubuquara	Gurupá
Extractive production	Açaí, Brazilian nut, bacuri and andiroba	Açaí
Fishing	Fishes and shrimp	Fishes and shrimp
Agriculture	-	cassava, macaxeira, feijão-caupi, corn, banana, watermelon, maxixe, quiabo, pineapple
Small animals breeding	Chicken, duck and swine	chickens and swine
Livestock	-	Buffalos and cattle

Source: INSTITUTO PEABIRU, 2014

MUNICIPAL EMISSIONS PROFILE

The System for Estimating Greenhouse Gas Emissions (SEEG) has data on municipal emissions in 2018, by sector of activity. The participation of the main sources of emission of each studied municipality is presented below.

Graph 7: Sources of greenhouse gas emission in the municipalities of Soure, Salvaterra and Cachoeira do Arari



Source: SEEG, 2018.

The municipalities of Soure and Cachoeira do Arari present a very similar emission profile. The main source of emissions is the agriculture sector, with 84% in Soure and 83% in Cachoeira do Arari, followed by the Land Use Change and Forestry sector, with 10% and 11%, respectively. Salvaterra has a more balanced distribution, with 39% of its emissions associated with agriculture and 34% with Land Use Change.

LAND TENURE STRUCTURE

Information on the size of rural properties in the studied municipalities, as well as the existence of settlements and quilombos, are presented below.

SIZE OF RURAL PROPERTIES

According to Law nº 8,629/93, art. 4, rural property can be classified as:

- Small property: Area up to 4 fiscal modules[1]
- Medium property: Area between 4 and 15 fiscal modules
- Large property: Area above 15 fiscal modules

For the three studied municipalities, the value of one (01) Fiscal Module is 65 hectares.

In 2021, there were 176 properties declared in the municipality of Cachoeira do Arari, occupying an area of 283,308.21 hectares. The properties are divided into rural properties, settlements and areas occupied by traditional communities. On average, the small properties measure 24 hectares, the medium properties measure 532 hectares and the large properties measure 4,154 hectares. If we add up all registered small and medium properties, equivalent to 62% of the total, we see that they occupy only 5% of the entire area. This information was obtained by consulting the Rural Environmental Registry (CAR) database, a mandatory electronic registration, made in a declaratory way by the rural owner or possessor, and is presented in Table 7 and Table 8

Table 8Table 7: Classification of rural properties in Cachoeira do Arari

Type of property	Number of properties			
	Up to 4 FM	4 to 15 FM	Over 15 FM	TOTAL
Rural property	89	23	60	172
Settlement	-	-	3	3
Traditional communities	-	-	1	1
Total	**89**	**23**	**64**	**176**

Source: SICAR, 2021.

[1] *According to Law nº 6,746/79, art. 50, the fiscal module of each municipality, expressed in hectares, will be determined by taking into account the following factors: the predominant type of exploitation in the municipality; the income obtained from the predominant type of exploitation; other existing explorations in the municipality that, albeit not predominant, are significant in terms of income or area utilized; and the concept of "family property," defined in item II of article 4 of this law.*

Table 8: Area of rural properties in Cachoeira do Arari

Type of property	Area (ha)			
	Up to 4 FM	4 to 15 FM	Over 15 FM	TOTAL
Rural property	2,171.86	12,231.97	251,127.07	265,530.90
Settlement	-	-	7,593.23	7,593.23
Traditional communities	-	-	10,184.08	10,184.08
Total Area	**2,172**	**12,232**	**268,904**	**283,308**
Average Area	**24.40**	**531.82**	**4,154.75**	**1,609.71**

Source: SICAR, 2021.

The CAR database informs the existence of three settlements. However, in consultation of the projects created and recognized by the National Institute of Colonization and Agrarian Reform (INCRA), the federal agency responsible for carrying out agrarian reform and national land tenure regulation, there are only two records for the municipality of Cachoeira do Arari: the Xipaiá and Urubuquara Agroextractive Settlement Projects (PAE), created in 2006 and 2009, respectively. The main characteristics of these settlements are presented below.

Table 9: Characteristics of the registered settlements in the municipality of Cachoeira do Arari

Settlement	Area (ha)	Capacity of families	Settled families
PAE Ilha Xipaiá	1,261.25	117	96
PAE Ilha Urubuquara	3,168.11	530	482

Source: INCRA, 2021a.

Regarding the traditional peoples who inhabit Cachoeira do Arari, at the southern end of the municipality is the Gurupá community, certified in 2010 by the Palmares Cultural Foundation as a remaining quilombolo community. Its residents have started the process of land tenure regularization and titling with INCRA, the body responsible for this activity according to Decree Nº 4,887/2003 (BRAZIL, 2003). Nevertheless, they continue to wait for the process to conclude, which has caused conflicts of land possession with non-quilombolo people who seek to appropriate the land (PUBLIC DEFENDER'S OFFICE OF THE STATE OF PARÁ, 2021).

Table 10: Characteristics of the Gurupá Community in the municipality of Cachoeira do Arari

Community	Area (ha)	Number of families	Palmares Cultural Foundation Certificate		INCRA Registration	
			Ordinance N°	Ordinance date in the DOU	Ordinance in the DOU	Decree in the DOU
Gurupá	10,184.08	149	82/2010	2010/07/06	2014/12/18	2016/04/04

Source: FCP, 2021; INCRA, 2021b.

In Salvaterra, 148 rural properties were identified, most of them small (113 properties), with an average area of 30.17 hectares, followed by medium properties (22 properties) with approximately 434.50 hectares each. Among the analyzed municipalities, Salvaterra is the one with the lowest number of large properties (13 properties). The fact that the city is the smallest in the region in terms of territorial extension and also the most populated may contribute to this fact. About 75% of the territory (38,271 ha) is divided *into large properties whose areas reach, on average, 2,944 hectares.*

Table 11: Classification of rural properties in Salvaterra

Type of property	Number of properties			
	Up to 4 FM	4 to 15 FM	Over 15 FM	TOTAL
Rural property	113	22	13	148
Settlement	-	-	-	-
Traditional communities	-	-	-	-
Total	**113**	**22**	**13**	**148**

Source: SICAR, 2021.

Table 12: Area of rural properties in Salvaterra

Type of property	Area (ha)			
	Up to 4 FM	4 to 15 FM	Over 15 FM	Total
Rural property	3,408.92	9,558.78	38,270.63	51,238.33
Settlement	-	-	-	-
Traditional communities	-	-	-	-
Total Area	**3,409**	**9,559**	**38,271**	**51,238**
Average Area	**30.17**	**434.50**	**2,943.92**	**346.20**

Source: SICAR, 2021.

Once again, differences were identified between the databases consulted for land tenure characterization. While the CAR database reports the inexistence of traditional peoples, the Palmares Cultural Foundation and INCRA databases have several records, as pointed out in Table 13.

Table 13: Characteristics of remaining communities of quilombos in the municipality of Salvaterra

Community	**Area (ha)**	**Number of families**	**Palmares Cultural Foundation Certificate**		**INCRA Registration**	
			Ordinance N°	Ordinance date in the DOU	Ordinance in the DOU	Decree in the DOU
Bacabal	516.24	55	15/2006	2006/07/28	2014/07/21	2015/06/23
Santa luzia	522.72	20	15/2006	2006/07/28	-	-
Rosário	3,721.00	77	29/2006	2006/12/13	-	-
Campina	-	-	19/2004	2004/06/04	-	-
Vila União	-	180	29/2006	2006/12/13	-	-
Boa vista	-	115	51/2007	2007/05/16	-	-
Deus ajude	-	65	162/2010	2010/12/27	-	-
Bairro alto	-	120	162/2010	2010/12/27	-	-
Caldeirão	-	210	162/2010	2010/12/27	-	-
Pau furado	-	55	162/2010	2010/12/27	-	-
São benedito da ponta	-	35	162/2010	2010/12/27	-	-
Siricarí	-	40	211/2011	2011/12/22	-	-
Providência	-	13	28/2016	2016/03/07	-	-
Mangueira	-	180	28/2016	2016/03/07	-	-
Salvá	-	10	28/2016	2016/03/07	-	-

Paixão	-	42	28/2016	2016/03/07	-	-

Source: FCP, 2021. INCRA, 2021b; FUNDAÇÃO AVINA, 2021.

In the case of Soure, the number of small properties is practically the same as that registered for large ones; however, while those cover only 1% of the territory (3,958 ha), the properties of more than 15 fiscal modules cover 95% of the municipality (255,881 ha). As seen earlier, the main economic activity of the municipality is the raising of buffalo, and the size of the farms dedicated to this purpose can vary considerably. Nevertheless, in some studies it is possible to identify a large representation of properties of less than 200 hectares involved in this type of activity, the equivalent of three fiscal modules, which would explain the pattern observed in the municipality (COELHO, 2019; OLIVEIRA, 2018).

It is worth mentioning that in comparing the average areas of small properties in the cities of Cachoeira do Arari (29.35 ha), Salvaterra (49.40 ha) and Soure (63.84 ha), the latter presents the highest value. The same occurs for medium properties, Soure with areas of around 589.59 hectares and the others with 455.18 hectares (Salvaterra) and 556 hectares (Cachoeira do Arari).

Table 14: Classification of rural properties in Soure

Type of property	Number of properties			
	Up to 4 FM	4 to 15 FM	Over 15 FM	TOTAL
Rural property	71	19	63	153
Settlement	-	-	-	-
Traditional communities	-	-	-	-
Total	**71**	**19**	**63**	**153**

Source: SICAR, 2021.

Table 15: Area of rural properties in Soure

Type of property	Area (ha)			
	Up to 4 FM	4 to 15 FM	Over 15 FM	Total
Rural property	3,958.34	10,612.58	255,881.13	270,452.05
Settlement	-	-	-	-
Traditional communities	-	-	-	-
Total Area	**3,958**	**10,613**	**255,881**	**270,452**

Average Area	**55.75**	**588.58**	**4,061.60**	**1,767.66**

Source: SICAR, 2021.

Despite not being included in the CAR database, INCRA recognizes the existence of one settlement project in this territory — the Soure Marine Extractive Reserve — presented in table 16.

Table 16: Characteristics of the registered settlement in the municipality of Soure

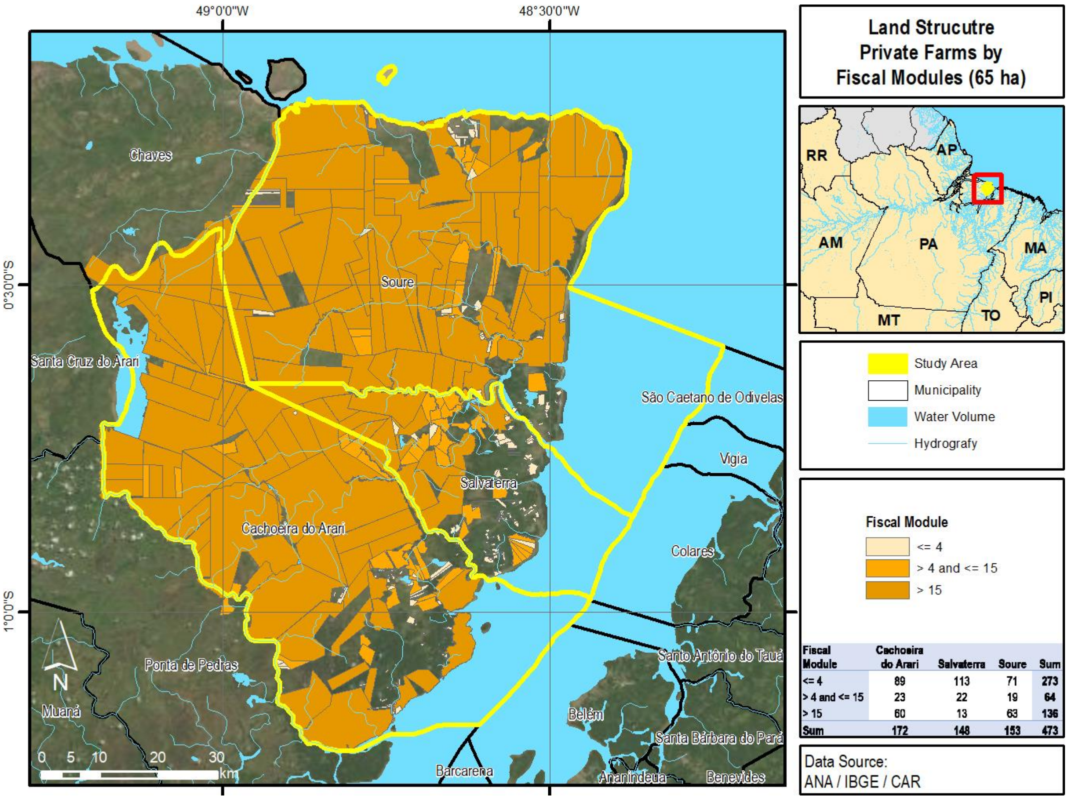
Settlement	Area (ha)	Capacity of families	Settled families
Soure Marine Extractive Reserve	27,463.58	2,200	2,187

Source: INCRA, 2021a.

Figure 2 presents the land tenure structure, according to the CAR polygons, showing the size of rural properties, according to the fiscal module (65 ha), for the three municipalities. The map in Figure 6 shows the areas of interest for the project, the Soure Marine RESEX, the 16 quilombola communities in Salvaterra, and the two Extractive Settlement Projects (PAE), as well as the quilombola community of Gurupá, in Cachoeira do Arari. For the municipality of Salvaterra, according to the INCRA database, only the quilombola communities of Bacabal and Rosário have defined and available area polygons (purple polygons on the map in figure 3). The other quilombola communities in the municipality do not have their polygons in the INCRA database, having only considered the indication of their locations within the municipality, through the red dots on the map in Figure 3.

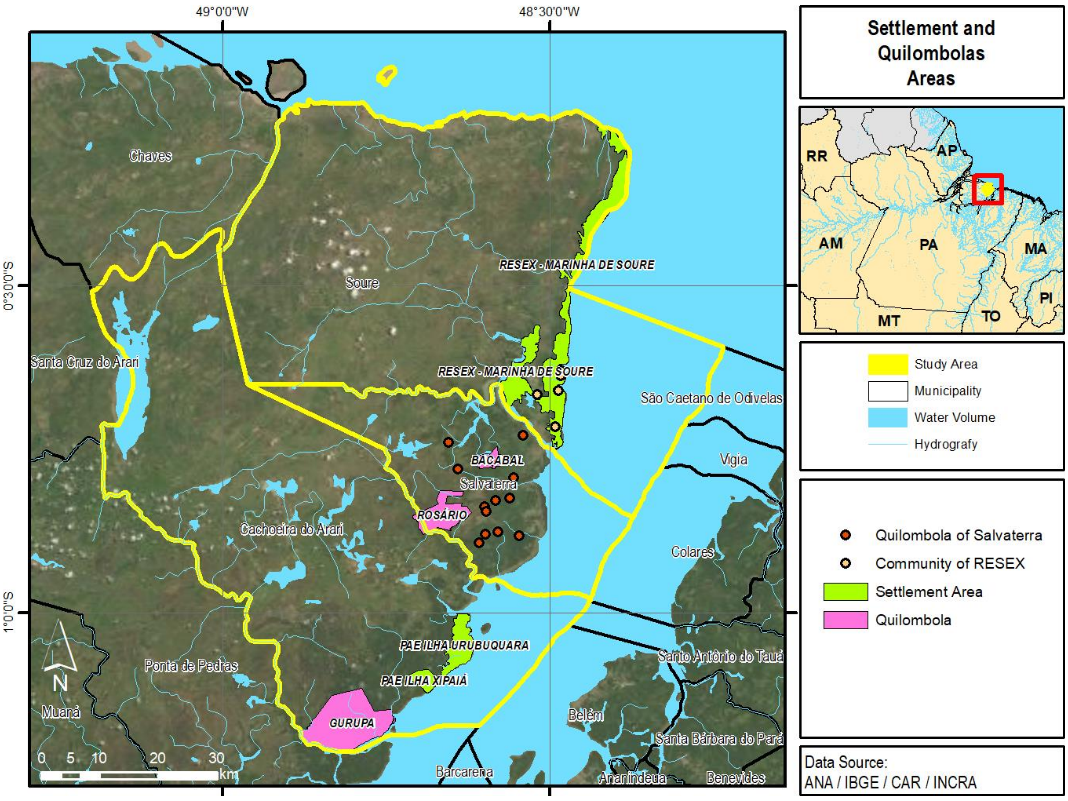
The identification of large and medium-sized properties will serve as an exclusion criterion for the analysis of climate vulnerability, since the objective of the project is to intervene in the areas of quilombola communities and small family farming properties. This is an alternative approach for identifying areas of interest, as these are not yet mapped.

Figure 2: Land structure private farms by fiscal modules



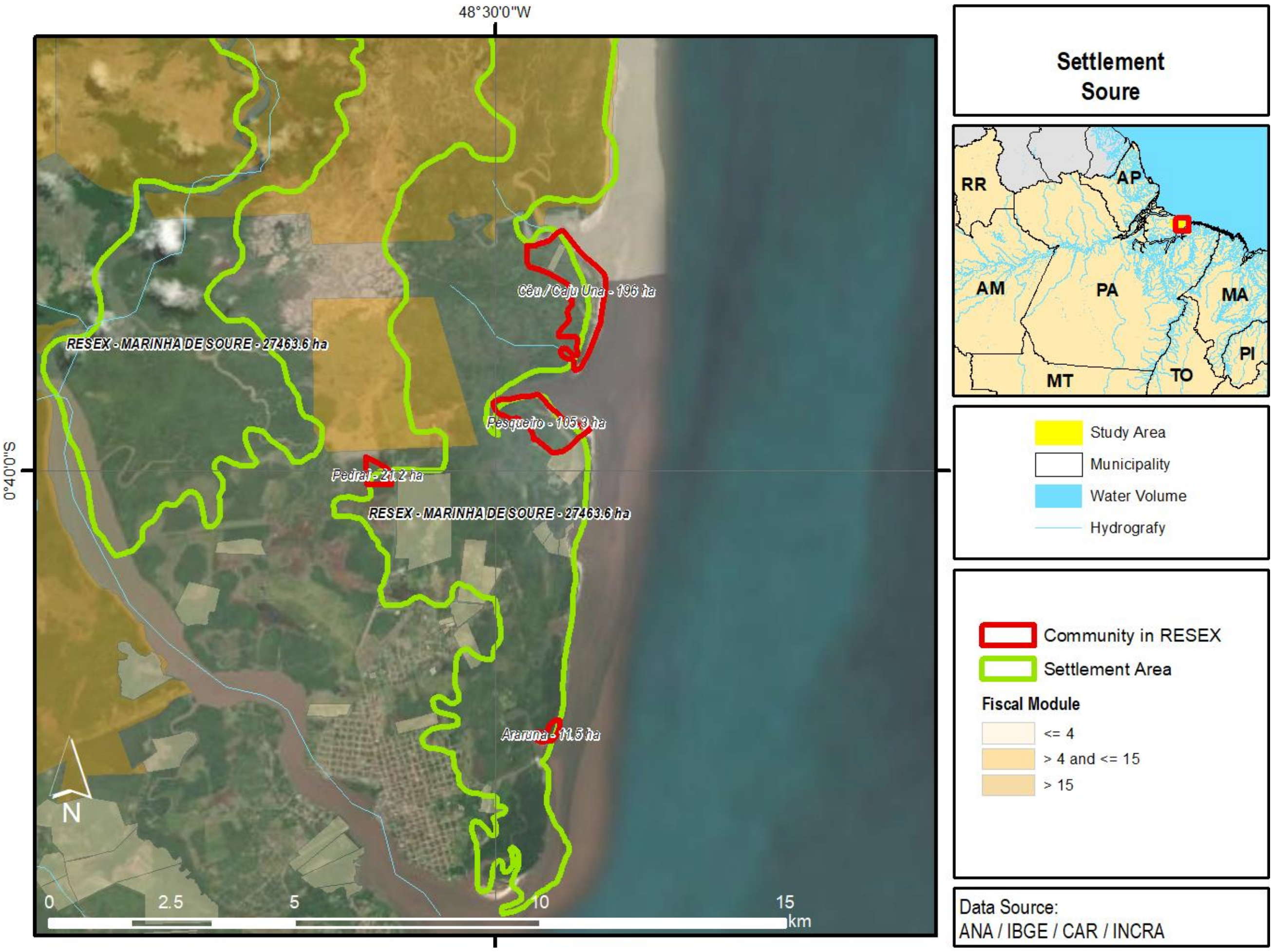
Fiscal Module	Cachoeira do Arari	Salvaterra	Soure	Sum
<= 4	89	113	71	273
> 4 and <= 15	23	22	19	64
> 15	60	13	63	136
Sum	172	148	153	473

Figure 3: Location of the quilombolo communities, settlements and Soure Marine Resex



For a better visualization of the target communities of the project, the map is presented below, by municipality, with the location of the communities of interest. In an attempt to identify possible areas of land conflict between the rural properties of the municipalities and the target communities of the project, overlapping regions of the properties declared in the CAR with the polygons of the communities of each municipality were identified. Figure 4 presents the communities of interest for the municipality of Soure.

Figure 4: Location of communities of interest in the municipality of Soure



In order to show the dimension of occupation of quilombola communities in the municipality of Salvaterra, based only on their punctual location, an area of approximately 600 hectares was estimated, whose delimitation was made with the identification of population and agricultural lands in the vicinity, following contours of roads, rivers and other geographic features. The delimitation is not precise, however, it is able to illustrate the occupation scenario in the area considering all the existing communities.

Figures 5 and 6 present the communities of interest in the municipalities of Salvaterra and Cachoeira do Arari, respectively.

Figure 5: Location of communities of interest in the municipality of Salvaterra

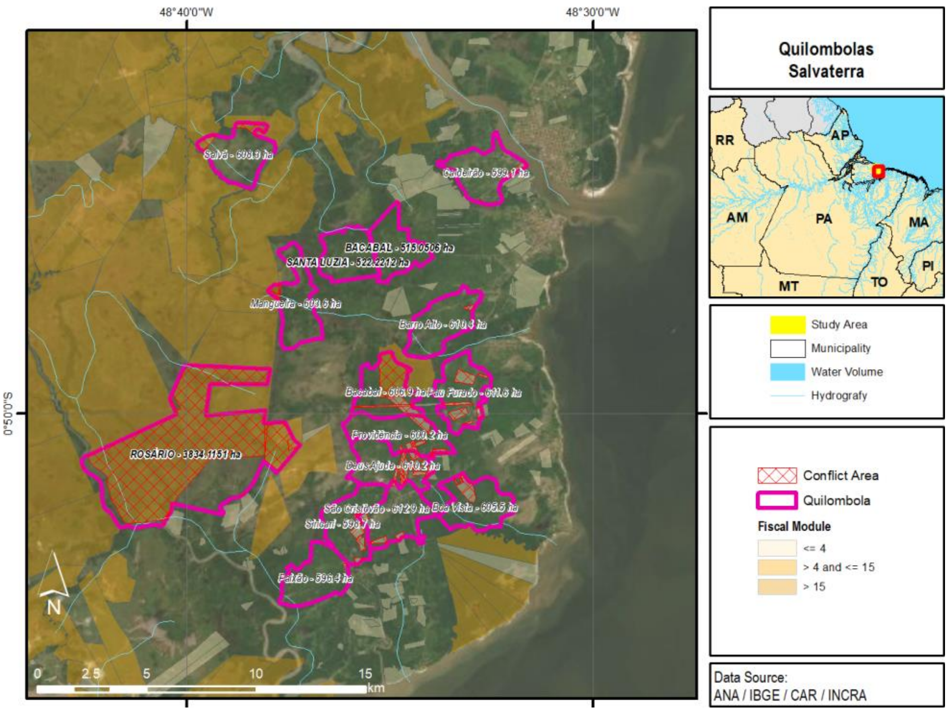
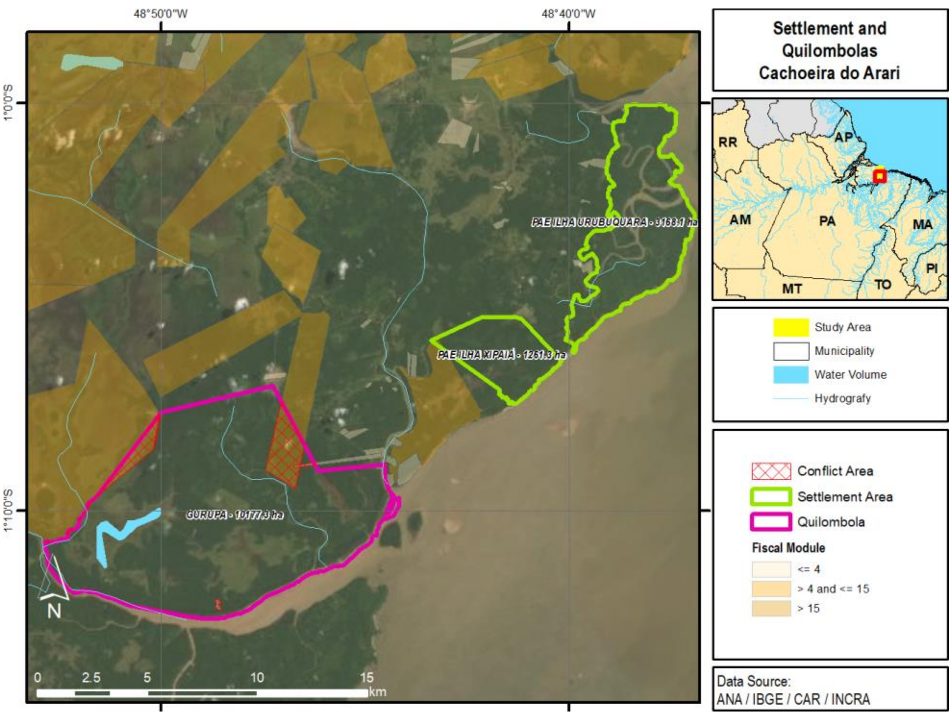


Figure 6: Location of communities of interest in the municipality of Cachoeira do Arari



PUBLIC POLICY AND LEGISLATION

This section presents the main laws, plans, programs and policies that demonstrate the potential to impact the development of adaptation solutions for the Marajoara territory and the communities that inhabit it in light of the effects of climate change. Such instruments were analyzed in search of mentions about adaptation, mitigation, and reduction of social, economic, environmental and climatic vulnerabilities in the region. In general, it can be seen that this issue is hardly contemplated by the municipal sphere, and that it gains more prominence and robustness in state and federal policies.

LAWS AND DECREES

Table 17 presents the main relationships between the State Policy on Climate Change in Pará to the aims of the present study.

Table 17: State Policy on Climate Change in Pará

Law / Decree	**Law Nº 9,048, April 29, 2020**
Topic	**State Policy on Climate Change in Pará**
Objectives	**Article 5:** **II —** Support research, development, dissemination and promotion of the use of technologies to face climate change and measures for adaptation and mitigation of the respective impacts on the climate; **XIV —** Protect, recover and expand carbon sinks through the use of conservation, recovery and sustainable practices for the use of natural capital; **XVI —** Carry out the monitoring of weather conditions, in order to predict possible extreme weather-related events and thus mitigate the impacts on the population;
Instruments	**I —** Sustainable public management; **II —** Instruments of education, research and innovation; **III —** Instruments of transparency and communication; **IV —** Economic, financial and fiscal instruments; and **V —** State Plan for Climate Change

Table 18 presents the decree establishing the Pará Forum on Climate Change and Adaptation. The forum is an instrument for promoting discussions between different actors in the region.

Table 18: Pará Forum on Climate Change and Adaptation

Law / Decree	State Decree Nº 254, August 08, 2019
Topic	**Institutes the Pará Forum on Climate Change and Adaptation**
Objective	**Article 1:** To promote cooperation and dialogue between the different sectors of society, with the aim of addressing problems related to climate change, adaptation and its socio-environmental and economic consequences.

One of the results of the Pará Forum on Climate Change and Adaptation was the document "Recommendations for a climate change mitigation and adaptation agenda in the State of Pará," published in 2015. Its content presents an overview of Pará's main work fronts related to climate change and of how proposals to structure and start the implementation of a state strategy on this topic are made. Twenty-nine recommendations, organized into 11 major areas, were made.

Table 19 shows the recommendations set forth on the themes of Adaptation and the Plan for Low Carbon Emission in Agriculture.

Table 19: Recommendations of the State Climate Forum for the Climate Change Agenda in the state of Pará

Topic	Recommendation
National Plan for Low Carbon Emission in Agriculture **(ABC Plan)**	Elaborate and implement a monitoring system, including measurement of emission reductions
Adaptation	Map the areas of greatest risk and vulnerability to climate change

	Bring an urban adaptation agenda to metropolitan regions, such as Greater Belém, and to regions with a low Social Progress Index, with more vulnerable populations
	Prioritize ecosystem-based adaptation approaches rather than exclusively adopting conventional engineering works
	Seek partnerships with federal government agencies that are working on the topic, such as the Ministry of the Environment (MMA)

Source: PARÁ FORUM ON CLIMATE CHANGE, 2015.

Table 20 presents the main points of the Policy for Integrated Action for Sustainable Territories.

Table 20: State Policy for Integrated Action for Sustainable Territories

Law / Decree	State Decree Nº 344, October 10, 2019
Topic	**Policy for Integrated Action for Sustainable Territories**
Objectives	**Article 3:** **III —** design measures for sustainable development and climate justice, considering their impacts on human rights — particularly of women, field laborers and children — and combating child and forced labor; **VI —** Carry out actions for the protection and maintenance of ecosystems and hydrological cycles to guarantee the continuity of ecosystem services, promoting the participation of traditional, indigenous and quilombolo peoples and communities, their traditional knowledge and their visions of harmonious development with nature while respecting their social, collective and cultural identity, customs, traditions and institutions.

DECREE Nº 1,684 DE 2021/06/29

It is estimated that 27% of the territory of Pará does not have its land tenure situation defined, which facilitates illegal land appropriation for private use, a fraudulent practice known as *grilagem* (IMAZON, 2022). One of the ways to regularize these appropriations is through the sale of properties, and State Decree Nº 1,684/2021 brings a revision of the reference table with the Bare Land Value (BLV) of already occupied rural areas in the state of Pará.

For the calculation, the minimum value of the BLV Tariff elaborated by INCRA was adopted as a reference. Based on this, the final values are defined according to the following criteria: (i) distance of the property in relation to the seat of the municipality, (ii) means of access, (iii) "ancientness," that is, how long the area to be regularized has been occupied, and (iv) dimension.

The decree presents reference values for 12 regions of integration in Pará, which are groups of municipalities with similar occupation, social levels and economic dynamism, defined by State Decree Nº 1,066/2008 (PARÁ, 2008), shows the current reference values for the Marajó region for different fiscal module ranges.

Table 21 shows the current reference values for the Marajó region for different fiscal module ranges.

Table 21: Bare Land Value (BLV) of reference by dimensions of the area according to State Decree Nº 1,684/2021.

Integration Region	BLV of reference (R$/ha)	BLV for 1 FM (R$/ha)	BLV for 1 to 4 FM (R$/ha)	BLV for 4 to 1,500 FM (R$/ha)
Marajó	487.00	48.70	146.10	243.50

Source: PARÁ, 2021.

The update of the BLV is part of the Amazon Now Plan, an initiative of the state government that aims to lead the state to zero net emissions in the Land Use Change and Forestry sector as of 2036, land regularization being one of the strategies (PARÁ, 2020). However, this initiative may generate the opposite effect, as indicated by an IMAZON study. In the study, the reference values of land established by the new decree were compared with those practiced by the previous state rule (Cepaf Resolution Nº 001/2015), by the minimum BLV of INCRA's Bare Land Value tariff schedule, as well as with market values.

It can be seen from the data in Table 22 that the new rule reduced the average value of land in the state of Pará by 40% compared to the 2015 rule. If we take market value into account, this difference grows to an impressive 75%. On the other hand, in the case of Marajó, the new decree increased the reference value of land in the region by around 14%, keeping it well above the average market price.

Table 22: Average reference value of hectare for land tenure regularization

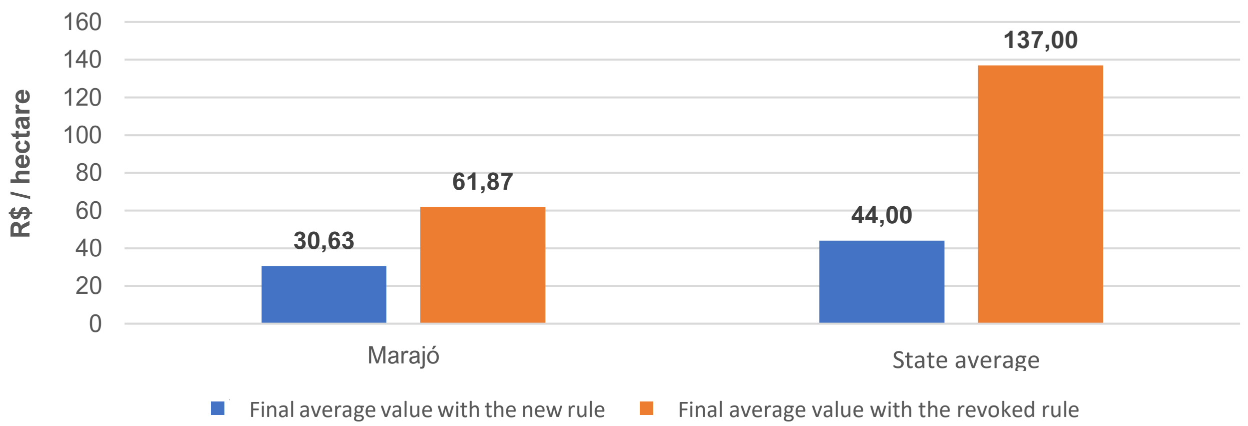
Integration Region	Reference value new state rule 2021 (R$)	Reference value revoked state rule (R$)	INCRA 2020 (R$)	Market (R$)
Marajó	487	426	487	265
State average	**549**	**923**	**618**	**3,684**

Source: IMAZON, 2022.

The apparent appreciation of land in Marajoara ceases to exist when analyzing the final price of the properties, obtained after applying the aforementioned criteria to the reference value.

The final value of the hectare in the archipelago drops from R$61.87 to R$30.63, equivalent to a reduction of 50%.

Graph 8: Average final value of the hectare in the Cepaf Resolution Nº 001/2015 and in the State Decree Nº 1,684/2021



Source: IMAZON, 2022.

The charging of low prices for public land encourages illegal occupation even more because after the properties are regularized, they will be resold by those invaders at market prices, generating a highly profitable business. To request the legalization of public land, it is necessary to prove the use of the property, which is most often simulated through the removal of vegetation cover and the exploitation of low-cost, low-productivity agricultural activities. Thus, the lowering of costs charged by the government for the sale of state land also encourages deforestation and all the negative environmental impacts associated with this activity.

MUNICIPAL MASTER PLANS

The Municipal Master Plan is the basic instrument of urban development and expansion policy, and it should promote dialogue between the physical/territorial and environmental aspects. According to § 3 of article 40 of the City Statute (Federal Law Nº 10,257, of July 10, 2001), the Master Plan must be reviewed at least every ten years (BRAZIL, 2001). A brief analysis of the content of the master plans of the studied municipalities is presented below. In general, there are no significant mentions of the climate change issue.

During the field visit, it was informed through the environmental secretaries of Soure and Salvaterra that these municipalities were charged by the Federal Public Ministry (MPF) to make adaptations to the master plans, including the issue of climate change.

SALVATERRA

Salvaterra's territorial development and management policy was implemented in accordance with its Municipal Master Plan, instituted by Complementary Law Nº 1,135, of October 10, 2006 (SALVATERRA, 2006). According the City Statute (Law Nº 10,257/2001), the Salvaterra planning instrument is already subject to reassessment.

The first chapter of the document brings the fundamental principles of territorial policy, and at this point, there is a mention of social, economic and environmental sustainability, which is understood as balanced local development, based on cultural values and political-institutional strengthening and aimed towards the continuous improvement of the quality of life for present and future generations. This definition is supported by several concepts presented in article 9, including social justice, a crucial concept in the debate on climate change. Extreme weather events affect marginalized and vulnerable populations more intensely. Therefore, reducing social inequality is fundamental to effectively combating climate change.

The general guidelines for municipal territorial management are presented next. Among them, the following stand out: (i) improvement of the quality of the urban environment through the recovery, protection, conservation and preservation of the natural, constructed and landscaped environments; (ii) promotion and strengthening of economic dynamics in a manner compatible with the standard of environmental sustainability; (iii) order and control of land use and occupation directed towards respecting and valuing soil permeability and the proper use of public spaces.

The plan also brings the concept of environmental vulnerability, present in article 34 § 1, which deals with the Municipal Health Policy. It establishes that the actions of the health system "will prioritize care for the population in situations of social, environmental and health vulnerability, taking into account the epidemiological profile of the population and the dimensions of gender, race and generation."

The Environmental and Sanitation Policy present in the plan also recognizes that "the environmental dimension is a global and strategic issue that must guide all interventions in urban and rural areas, guaranteeing proactive and preventive attitudes, to the detriment of corrective actions" (article 50). Among the aims of this policy are: (i) to guide investments and decisions that promote the recovery of the degraded environments, natural and constructed, especially in places where there is a threat to human security; (ii) and to control water and air pollution, and soil and subsoil contamination, and set pollution reduction targets.

Although climate change has not been directly mentioned in Salvaterra's Master Plan, it is possible to identify some guidelines that may contribute to the territory's adaptation to the effects of this phenomenon.

CACHOEIRA DO ARARI

Law Nº 045 of September 23, 2006, institutes the Municipal Master Plan of Cachoeira do Arari (CACHOEIRA DO ARARI, 2006). Established 16 years ago, this planning instrument is already subject to reassessment, according to the City Statute (Law Nº 10,257/2001). The plan's principles are: (i) sustainable development, (ii) universal access to public goods and equipment, (iii) socioeconomic inclusion of the citizens, (iv) preservation of the natural and constructed environment and (v) the democratization of the territorial management of the municipality.

Among the general guidelines, the plan emphasizes in article 6 that the regulation and control of land use must guarantee "the protection, preservation and recovery of the natural and constructed environment, of the cultural, historical, artistic, scenic and archaeological heritage." The environment is highlighted in Chapter II of the Sectoral Guidelines for Urban Policy, with article 20 first mentioning the guarantee of natural resources for future generations by defending the promotion of rational use, protection and recovery of water resources, maintaining their availability in sufficient quantity and quality for the current and future population.

It can be concluded from this that the provisions contained in the Master Plan for Cachoeira do Arari do not ensure effective actions in the face of the proposal to mitigate climate change.

SOURE

The Soure Municipal Master Plan was instituted in January 2019 by Complementary Law Nº 024. Among the principles set out in article 2 are (i) sustainable development, (ii) the socioeconomic inclusion of the citizens and (iii) the preservation of the natural and constructed environment. Although the plan is based on economic, social and environmental aspects, climate change is not included in its principles (SOURE, 2019).

Chapter II of the Sectoral Guidelines for Urban Policy is dedicated exclusively to dealing with the environment and is oriented towards the promotion of the rational use of natural resources, protection of springs and permanent preservation areas, implementation and consolidation of conservation units, recovery of degraded areas, education and environmental control measures, among others. Once again, there is a lack of explicit mention of climate change and of strategies that contribute to the adaptation of the municipality. In the chapters dedicated to sectorial guidelines, such as those referring to housing, economic development, and agriculture, neither are there guidelines that recognize and incorporate the theme (SOURE, 2019).

MARAJÓ TERRITORIAL DEVELOPMENT PLAN

The Marajó Sustainable Territorial Development Plan (STDP) was launched in 2007 and was prepared by the Interministerial Executive Group, created by presidential decree on July 26, 2006, and coordinated by the Civil House of the Presidency of the Republic, and the Executive Group of the State of Pará for the Marajó Plan, instituted by the State Decree of July 30, 2007, and coordinated by the State Secretariat for Regional Integration (BRAZIL, 2006; BRAZIL, PARÁ, 2007).

STDP is a strategic plan aimed at structuring and promoting development for the 16 municipalities of the archipelago, based on guidelines grouped into five thematic core elements. In light of the proposal of the present study, the "fostering sustainable production activities" one stands out, for which the guidelines and priority actions are presented in the table below. It highlights the production chains listed as priorities in public hearings, particularly those linked to family farming (pineapple, açaí and rice), as well as fishing, cattle, buffalo and rural tourism.

STDP STRATEGIC CORE ELEMENTS

- ✓ Territorial regulation, land regularization and environmental management;
- ✓ Promotion of sustainable production activities;
- ✓ Social inclusion and citizenship;
- ✓ Infrastructure for development;
- ✓ Institutional relations and plan

Table 23: Guidelines for the promotion of sustainable productive activities of the Marajó Territorial Development Plan

GUIDELINES
Reorganize, strengthen and create new fronts for economic expansion in the archipelago, as well as raise the importance of the local economy within the context of the economy of the State of Pará, taking advantage of the relative proximity to the large consumer market represented by the Metropolitan Region of Belém, Macapá, French Guyana and other markets
Support studies aimed at improving knowledge of the possibilities and socioeconomic potential of the Marajó Archipelago, observing the principles of sustainability
Strengthen food security and the creation of jobs and income through support for family agro-extractivism and solidarity-based economic enterprises, seeking to create mechanisms: diagnosis, training, infrastructure, institutionalization of groups, credit, commercialization and technical assistance
Promote the recuperation of agricultural activity
Promote the industrialization of fishing and other aquaculture products and the construction of fishing terminals
Promote the expansion of production and dissemination of Marajoara products and services
Stimulate development of industrial, commercial and service industries in the archipelago
Encourage the dairy, meat packing and processed food industries in general
Strengthen tourism activity, implementation of the MMA's PROECOTUR, the Ministry of Tourism programs, among others, and expansion to other municipalities

Promote the spread of forest management
Create programs and specific lines of credit for the development of productive activities in Marajó

Source: BRAZIL; PARÁ, 2007.

It was predicted that the investments and actions would be carried out between 2007 and 2011. However, the Association of Municipalities of the Marajó Archipelago reported that the plan had only a small part the intentions carried out by the established deadline (AMAM, 2011).

EMBRACE MARAJÓ PROGRAM

Established by Decree Nº 10,260, of March 3, 2020, the Embrace Marajó Program is an initiative coordinated by the Federal Government, through the Ministry of Women, Family and Human Rights, as a strategy for the socioeconomic development of the municipalities that make up the Marajó Archipelago. Its objective is to improve the Human Development Index of this territory by expanding the reach and access of the Marajoara population to individual, collective and social rights, pursuant to the provisions of art. 5 and art. 6 of the constitution.

Its Action Plan covers the period 2020–2023, although the program itself does not have a defined term. The document outlines 110 actions for the development of the region, grouped into four core elements.

The element "productive development" aims to valorize the regional product, verticalize production, improve the business environment, improve the quality of the regional products and expand local markets and productivity. The municipalities of Soure and Salvaterra stand out in the theme of tourism, since, as previously mentioned, both are already considered consolidated destinations in Marajó. The lines of action envisioned for this component of the plan are set out below.

Elements of the action plan for the program "Embrace Marajó"

- ✓ Productive development;
- ✓ Infrastructure;
- ✓ Social development;
- ✓ Institutional development.

Table 24: Lines of action for the productive development component of the Action Plan Embrace Marajó 2020–2030

Line of Action	Project/Activity/Initiative	Target Audience	Territorial Coverage
Eco-economic zoning	Eco-economic Zoning Establishment for Marajó	Municipal governments, Marajoara producers and entrepreneurs	Municipalities of Marajó
Land tenure regularization and territorial regulation	Land tenure regularization and territorial regulation initiatives in Marajó	Family farmers in Marajó	Municipalities of Marajó
	Digitalization of land tenure proceedings in Marajó registry offices	Municipal seats, local producers and the general Marajoara society	Municipalities of Marajó
	Quilombolo land tenure regularization	Quilombolo communities	Municipalities of Marajó
Production verticalization in Marajó	Verticalization program for local production	Extractivists, family farmers, açaí beaters, extension agents and other actors in the açaí production chain of Portel Curralinho, Anajás, Muaná and 60 Extractivist Settlement Projects	Portel, Curralinho, Anajás and Muaná
	House of Açaí Project in Marajó	Producers and local businesspeople	Municipalities of Marajó
	Açaí and Cupuaçu Production Chains: Small-scale sustainable powdered foods factory	Target audience: Marajoara population in general, in particular of the municipality of Portel	Portel

Productive Family Agriculture (Productive inclusion of the PCT of Marajó)	Structuring and valorization project for family production in Marajó	Farmers and extractivists from Marajó	Municipalities of Marajó
	Minimum Price Guarantee Policy for Sociobiodiversity Products (PGPM-BIO) — Event	Agricultural producers and extractivists from Marajó	Municipalities of Marajó
	Minimum Price Guarantee Policy for Sociobiodiversity Products (PGPM-BIO) — Visits	Agricultural producers and extractivists from Marajó	Municipalities of Marajó
The tourism chain in the archipelago (Regional tourism route)	Activation of the Code of Conduct for the Marajó region	Municipal administration, businesspeople and small entrepreneurs in the regional tourism chain	Soure and Salvaterra
	Development and positioning of products and tourist experiences in Marajó	Municipal administration, businesspeople and small entrepreneurs in the regional tourism chain	Soure and Salvaterra
Adequate and updated network of slaughterhouses	Financing program for slaughterhouses in Marajó	Cattle producers, consumers and municipal administrations in general	Municipalities of Marajó
Creative economy center in Marajó	Valorization of local handicrafts project	Artisans from the traditional peoples of Marajó	Municipalities of Marajó

Source: BRAZIL, 2020.

The program was presented at the 46th session of the United Nations Human Rights Council (HRC), however, despite its visibility and importance to the government, dozens of civil society organizations signed a public statement alleging the absence of the people's participation in the program's construction, economic and political conflicts of interest, and demanding the revision of Decree Nº 10,260/2020 and, consequently, the revision of the Action Plan (AGÊNCIA BRAZIL, 2021; OBSERVATÓRIO DO MARAJÓ, 2021).

THE AMAZON NOW STATE PLAN

In August 2020, the Government of Pará instituted the Amazon Now State Plan (PEAA), through Decree Nº 941/2020. The plan was created to coordinate the environmental policies on climate change that had been adopted by the state since 2019 and aims to achieve net zero emissions in the Land Use Change and Forestry sector as of 2036 in Pará. The Decree also defines two intermediate targets (PARÁ, 2020):

- By 2030, a reduction of 37% of greenhouse gas (GHG) emissions in Land Use Change and Forestry sector in relation to the average of emissions between the years 2014 and 2018;
- By 2045, a reduction of 43% of GHG emissions in the Land Use Change and Forestry sector in relation to the average of emissions between the years 2014 and 2018.

Structural components of the plan

- ✓ Inspection, Licensing and Monitoring;
- ✓ Land, Territorial and Environmental Planning;
- ✓ Low Emissions Socioeconomic Development;
- ✓ Long-Range Environmental Financing.

The PEAA possesses four structural components, among them the "socioeconomic development of low emissions in the state." To make it viable, the main instrument adopted is the Policy for Integrated Action for Sustainable Territories, instituted by State Decree Nº 344, of October 10, 2019. The construction of the structure and operation of this policy is under the responsibility of the Sustainable Territories Working Group (GTTS), created within the scope of the executive branch, linked to the Governor's Office, and coordinated by the State Secretariat for the Environment and Sustainability (SEMAS).

The Policy for Integrated Action for Sustainable Territories considers three regions of the state for priority actions — Xingu, Tapajós and Araguaia — which do not include the municipalities of Cachoeira do Arari, Salvaterra and Soure.

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CLIMATIC DIAGNOSIS

According to the World Meteorological Organization (WMO), the climate of a region in a specific period can be described in statistical terms, describing the central trends and variabilities of relevant elements of climatic conditions such as temperature and precipitation or through combinations of these elements such as humidity indices, evapotranspiration and others.

The WMO developed a Working Group that has elaborated indices that may be employed in the detection of climatic changes: The Working Group *Expert Team on Climate Change Detection and Indices* (ETCCDI), which considers 27 indices, comprising 16 of temperature and 11 of precipitation. The use of these indices is common in the analysis of historical series of these climatic variables, as with precipitation and temperature projections in future climatic scenarios, such as in the case of the IPCC RCP scenarios.

The climate exercises great influence on natural processes and on human life, making behavioral analysis of rain and temperature fundamental factors for climatic comprehension. The behavior of these climatic variables is even a determining factor for many social and economic activities.

The climatic diagnosis of the cities of Soure, Salvaterra and Cachoeira do Arari was performed through the behavioral analysis of precipitation and temperature variables, as well as some indices used by ETCCDI. In this way, we sought to characterize previously noted alterations in the series of historical data by characterizing the baseline for comparison with the climatic scenarios.

METEOROLOGICAL STATIONS IN THE REGION

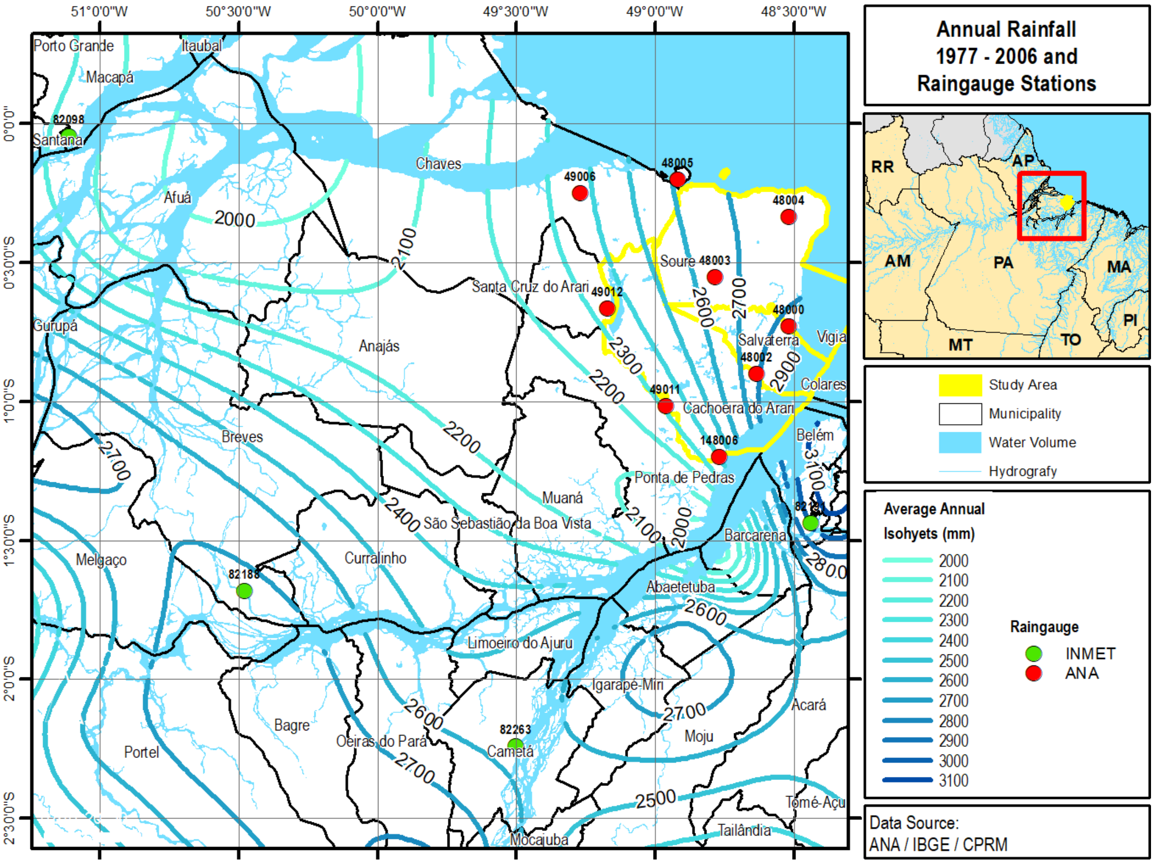
To gather the daily data of precipitation and temperature variables, a consultation of the institutions and official bodies that generate information, like the Brazilian National Institute of Meteorology (INMET) and the National Water Agency (ANA), was made through access to their databases. Nine ANA stations were identified within close proximity to the study region, and four INMET stations were located in more distant regions (Belém, Cametá, Breves and Macapá).

Table 1 presents the information of latitude, longitude, altitude and distance from the study region (distance in a straight line from the station to the polygon that envelops the municipalities of Soure, Salvaterra and Cachoeira do Arari). Figure 1 presents the spatial location of the identified meteorological stations, as well as the annual precipitation isohyets.

Table 25: Information on the meteorological stations near the study region

Code	Station	Base	State	Municipality	LAT	LONG	Alt. (m)	Distance (km)
48000	Soure	ANA	PA	Soure	-0.7278	-48.5158	12.6	0.0
48002	Câmara	ANA	PA	Cachoeira do Arari	-0.9000	-48.6333	7.0	0.0
48003	Fazenda Tapera	ANA	PA	Soure	-0.5500	-48.7833	8.0	0.0
48004	Fazenda Livramento	ANA	PA	Soure	-0.3333	-48.5167	8.0	0.0
49011	Santa Cruz do Arari	ANA	PA	Santa Cruz do Arari	-1.0158	-48.9597	0.0	0.0
148006	Santana do Arari	ANA	PA	Ponta de Pedras	-1.2000	-48.7667	8.0	0.8
49012	Cachoeira do Arari	ANA	PA	Cachoeira do Arari	-0.6653	-49.1711	0.0	3.2
48005	Mandube	ANA	PA	Chaves	-0.2000	-48.9167	0.0	3.9
49006	Fazenda Cajueiro	ANA	PA	Chaves	-0.2500	-49.2667	8.0	26.8
82191	Belém	INMET	PA	Belém	-1.4358	-48.4372	7.1	34.8
82263	Cametá	INMET	PA	Cametá	-2.2397	-49.4997	9.9	134.6
82188	Breves	INMET	PA	Breves	-1.6803	-50.4780	9.8	172.8
82098	Macapá	INMET	AP	Macapá	-0.0450	-51.1100	12.8	219.0

Figure 7: Map of meteorological station locations



DATA AVAILABILITY

The data availability of the 13 meteorological stations presented was evaluated for the period of 1961 to 2020, an interval of 60 years. The data availability is presented in the format of percentage of days with available data in each decade, calculated with the formula:

$$Data\ availability\ (\%) = \frac{Nº\ days\ with\ available\ data\ in\ 10\ years}{Nº\ days\ in\ 10\ years}$$

Tables 26 and 27 present the data availability for the variables of precipitation and temperature, respectively.

Table 26: Analysis of data availability for the precipitation variable in the selected stations

Station			1961–1970	1971–1980	1981–1990	1991–2000	2001–2010	2011–2020
Hidroweb	148006	Santana do Arari	-	97.8	19.0	-	-	-
Hidroweb	48002	Câmara	-	92.8	20.0	-	-	-
Hidroweb	48003	Fazenda Tapera	-	89.0	19.6	-	-	-
Hidroweb	48004	Fazenda Livramento	-	66.7	20.0	-	-	-
Hidroweb	48005	Mandube	-	33.0	11.1	-	-	-
Hidroweb	49006	Fazenda Cajueiro	-	67.7	10.0	-	-	-
Hidroweb	49011	Santa Cruz do Arari	-	-	-	12.9	99.0	94.1
Hidroweb	49012	Cachoeira do Arari	-	-	-	-	53.3	83.3
Hidroweb	48000	Soure	96.5	91.6	98.3	100.0	99.6	91.6
INMET	82191	Belém	77.5	100.0	99.2	100.0	100.0	100.0
INMET	82188	Breves	26.5	93.4	86.4	53.7	100.0	100.0
INMET	82263	Cametá	9.9	90.3	99.2	100.0	100.0	100.0
INMET	82098	Macapá	10.1	100.0	99.1	98.0	100.0	97.4

Table 27: Analysis of data availability for the temperature variable in the selected stations

Station			1961–1970	1971–1980	1981–1990	1991–2000	2001–2010	2011–2020
INMET	48000	Soure	93.2	90.0	76.2	94.8	96.6	77.0
INMET	82191	Belém	77.2	100.0	99.5	100.0	99.9	99.4
INMET	82188	Breves	3.3	92.8	69.2	52.5	99.8	99.8
INMET	82263	Cametá	6.7	88.3	89.9	79.2	99.9	94.5
INMET	82098	Macapá	30.7	98.3	99.2	86.9	100.0	94.8

The stations that were not listed in table 27 do not have measurements for temperature.

SELECTION OF THE REPRESENTATIVE STATION

The definition of the weather stations for analysis of the historical series followed these criteria:

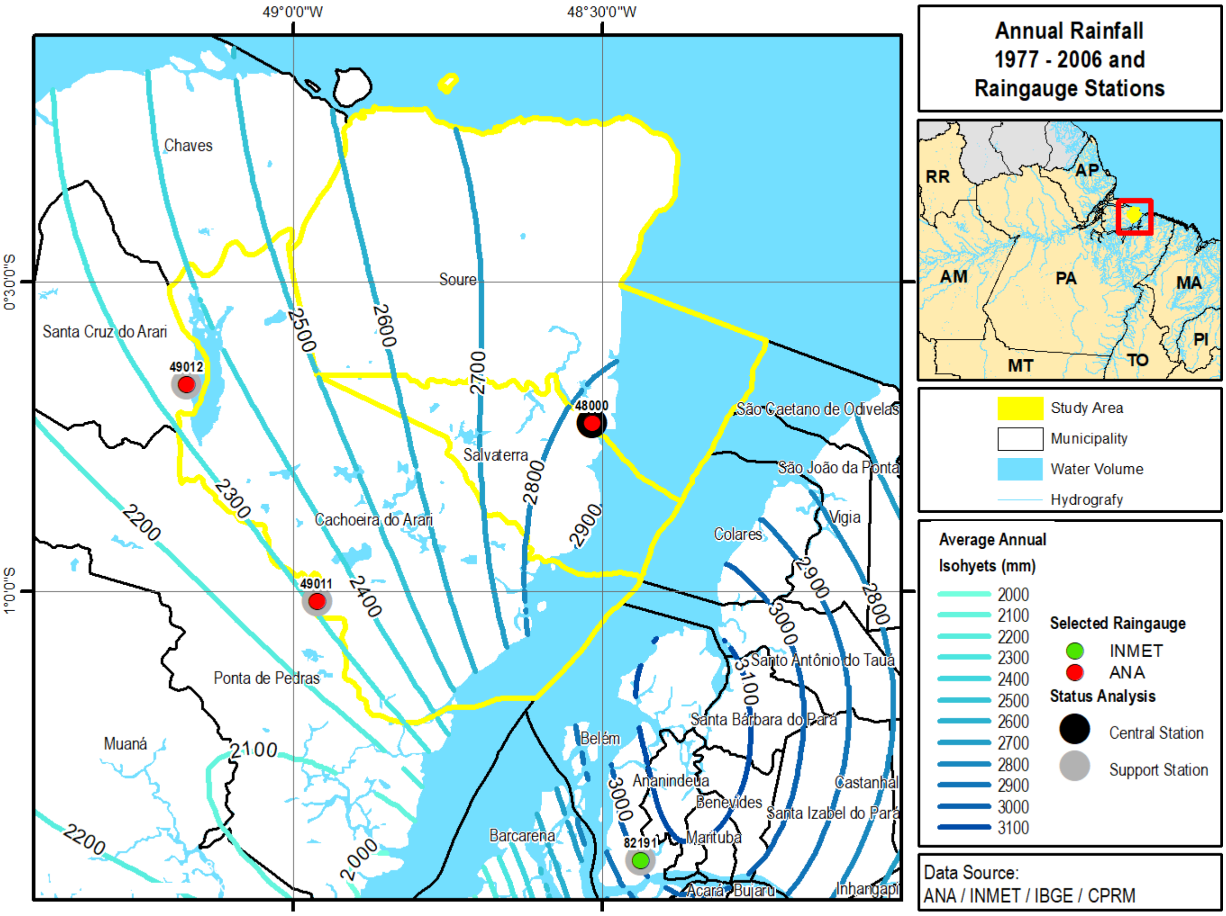
- Spatial proximity between a central station, considered for the analyses, and other adjacent stations (support stations);
- Historical series of greater extension and with few gaps for correction in the central station;
- Similar altitude of the station to be corrected and the support stations.

From these criteria, the Soure station was chosen as the central station for climatic analyses. The Belém station was chosen as a support station for gap correction since it presents series with few gaps for the entire period and proximity to the study region, with a distance of 34.8 km and an altitude difference of only 5.5 m.

The Cachoeira do Arari (49012) and Santa Cruz do Arari (49011) stations, two stations on the edge of the study region, were also considered as support stations. Both stations present data for periods smaller than 20 complete years, but they were considered for the validation of the analyses of the Soure station.

Figure 4 presents the stations selected for climatic analysis.

Figure 8: Identification of weather stations selected for analysis



DATA CORRELATION

To evaluate the possibility of characterizing the climate of the study region from the Soure station, a data correlation analysis was performed on this station with the stations located in the study region (Cachoeira do Arari and Santa Cruz do Arari). The same analysis was done between the Soure station and the Belém station to evaluate the possibility of using it for the correction of gaps in the central station of analysis.

For correlation analysis, the Pearson correlation coefficient was used. In descriptive statistics, this coefficient, also called "product-moment correlation coefficient," measures the degree of correlation between two quantitative variables.

Pearson's correlation coefficient is calculated with the formula:

$$r = \frac{\sum_{i=1}^{n} \quad (x_i \,.\, x).(y_i \,.\, y)}{(n-1).S_x S_y}$$

$$x = Sample\ average\ for\ first\ variable$$

$$S_x = Standard\ deviation\ for\ first\ variable$$

$$y = Sample\ average\ for\ second\ variable$$

$$S_y = Standard\ deviation\ for\ second\ variable$$

$$n = Number\ of\ series\ data$$

Pearson's correlation coefficient (r) varies from -1 to 1. The sign indicates positive or negative direction of the relationship, and the value suggests the strength of the relationship between the variables. Different methodologies were developed for classification of the Pearson's correlation coefficient, such as Cohen (1988), Hopkins (2000) and Dancey and Reidy (2005). Regardless of the methodology, it is of note that values above 0.7 are considered a strong correlation. For this study, the Hopkins classification was considered, presented in the following table.

Table 28: Classification of the Pearson correlation coefficient. Source: Hopkins, 2000.

Correlation Coefficient (r)	Classification
0.0 a 0.1	Very low
0.1 a 0.3	Low
0.3 a 0.5	Moderate
0.5 a 0.7	High
0.7 a 0.9	Very high
0.9 a 1.0	Almost perfect

With Soure meteorological station becoming the reference, a correlation calculation was performed on the historical series of data from the central station and the support stations.

Table 29: Pearson correlation coefficient between the stations Soure, Belém, Santa Cruz do Arari and Cachoeira do Arari.

Station	Soure station		
	Period	Pearson Correlation Coefficient (r)	Classification
Belém	January 1968 to August 2020	0.7749	Very high
Santa Cruz do Arari	September 1999 to June 2020	0.7761	Very high
Cachoeira do Arari	September 2005 to August 2020	0.7513	Very high

It is noted that the historical series of precipitation from the Belém, Santa Cruz do Arari and Cachoeira do Arari stations present a very strong relationship with the series from Soure station. These values of

Pearson's correlation coefficient corroborate the use of the Belém station to fill in the gaps of the Soure station, as well as validate the climatic diagnosis of the Soure station with the Santa Cruz do Arari and Cachoeira do Arari stations.

CLIMATOLOGICAL ANALYSIS

Following are the data analyses of the climatic variables for the baseline definition and the evaluation of already noted climatic alterations.

ANALYSIS PERIOD

The interval of the Soure station's series to be worked on was defined from the data interval that presented the lowest quantity of gaps to be filled in. Once the Belém station had been chosen as support station for the filling in of gaps from the Soure station, the aim became working with the most complete interval of data from the Belém station. Thus, the initial years of the decade 1960 — Belém station's period with the most gaps — were disregarded.

The interval of data to be considered for analysis was defined as 1968–2020. The Belém station possesses very few gaps within this interval and can serve as support to fill in the Soure station's gaps.

CLIMATOLOGICAL NORMAL

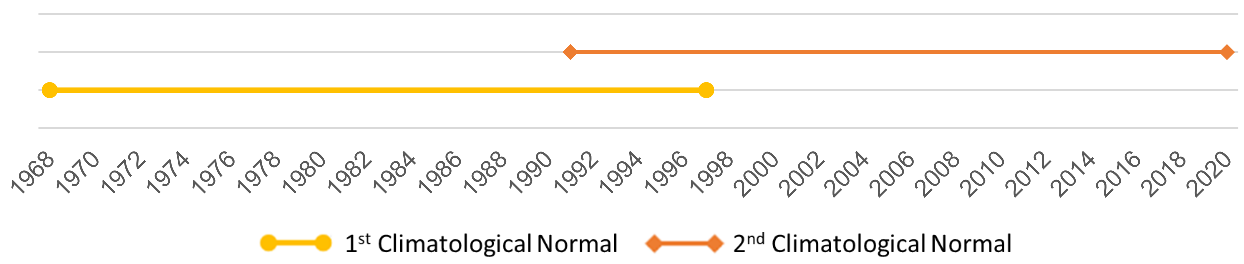
Once the data is available for a period of 53 years, it is possible to define two intervals for the construction of the climatological normals, and through the comparison of the normals of these two intervals, verify the alterations of the past and present climates.

INMET utilizes series of 30 years to construct climatological normals, and it adopts as intervals the periods of 1961–1990 and 1981–2010 in such a way that there is an overlap of the climatological normals over a period of 10 years. According to the available data series, the intervals of 1968–1997 and 1991–2020 were adopted for the construction of the normals, with an overlap of the normals over a period of seven years (1991 to 1997).

A climatological normal is a climatic element in a determined region, the average value correspondent to the number of years sufficient to be able to admit that it represents the predominant value of said element in the considered location. The World Meteorological Organization (WMO) has established 30 years as the interval for this purpose.

Figure 3 illustrates the contemplated period for each climatological normal constructed. The first climatological normal, in blue, represents the past climate, ended in 1997, and the climatological normal in orange represents the present climate, from 1991 to 2020.

Graph 9: Period of data for the characterization of climatological normal



PRECIPITATION VARIABLE

The statistical application of the data was based on parameters such as: measurements of central trend (average, maximum and minimum), measurements of dispersion, such as deviation in relation to the average and the elaboration of the Rainfall Anomaly Index (RAI), extracted from the total rainfall of the historical series (1968–2020).

Such elements were obtained from data processing in Excel spreadsheets, using the application of descriptive statistics, identifying the principal measurements related to the data, as well as their graphical representations.

> Among the atmospheric elements, rainfall attracts the largest public interest. Knowledge of rainfall behavior over time is indispensable for monitoring the impacts caused by excess or by the prolonged lack of rain and contributes to the development of a series of activities, as much in urban areas as in rural (SPECIAN e VECCHIA, 2014; NUNES et al., 2016).

DATA PROCESSING

Although the use of data produced by meteorological stations is important, it requires a certain caution and necessity of verification, including correctional procedures, through estimates due to the presence of gaps. From the daily precipitation data for the period of 1968 to 2020, the Soure station presented gaps in only 3.7% of the days. Even though the proportion of gaps in the historical series is low, the decision was made to fill in the gaps using the Belém station.

The Soure station gaps were filled in by two different techniques:

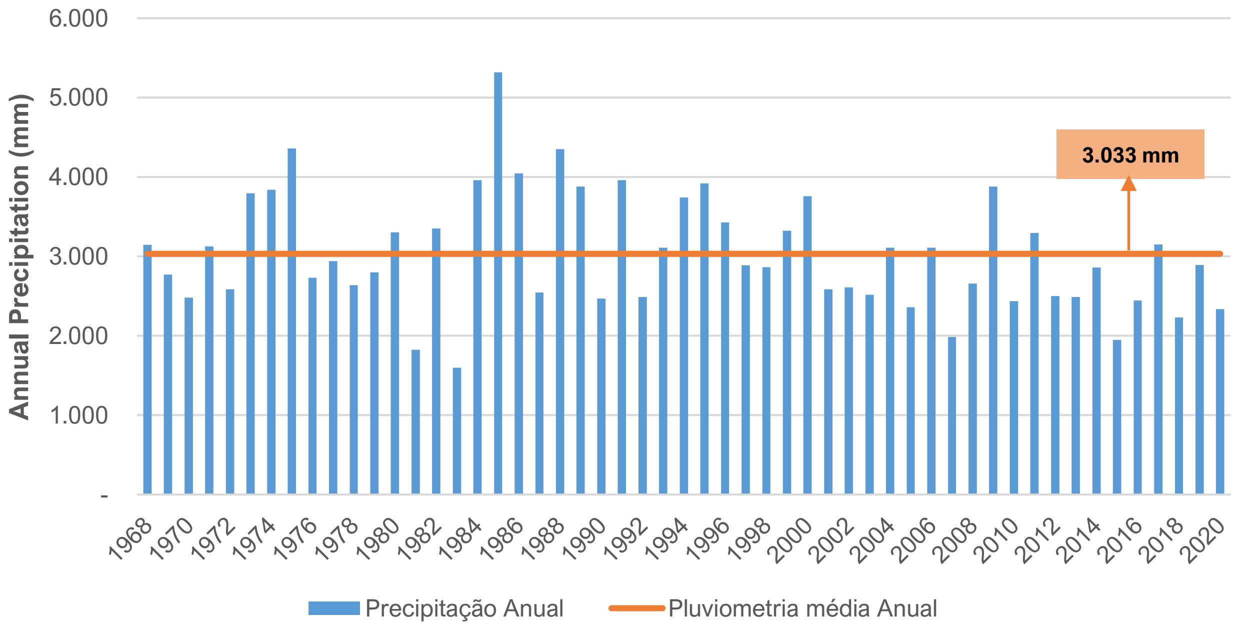
- Months with up to three days of gaps: Daily data were corrected through the calculation of the moving average of the last five days.
- Months with more than three days of gaps: The monthly precipitation data from the Soure station were disregarded, and the monthly precipitation value was estimated from linear regression with data from the Belém station.

Linear regression was made in a monthly form, or rather an equation was elaborated for each month of the year, estimating precipitation of the Soure station from the Belém station.

ANNUAL PRECIPITATION

Graph 10 presents the annual accumulated precipitation from the Soure station for the period of 1968 to 2020. The annual rainfall average observed at the Soure station, represented by the orange line, was approximately 3,033 mm.

Graph 10: Annual accumulated precipitation (1968–2020)

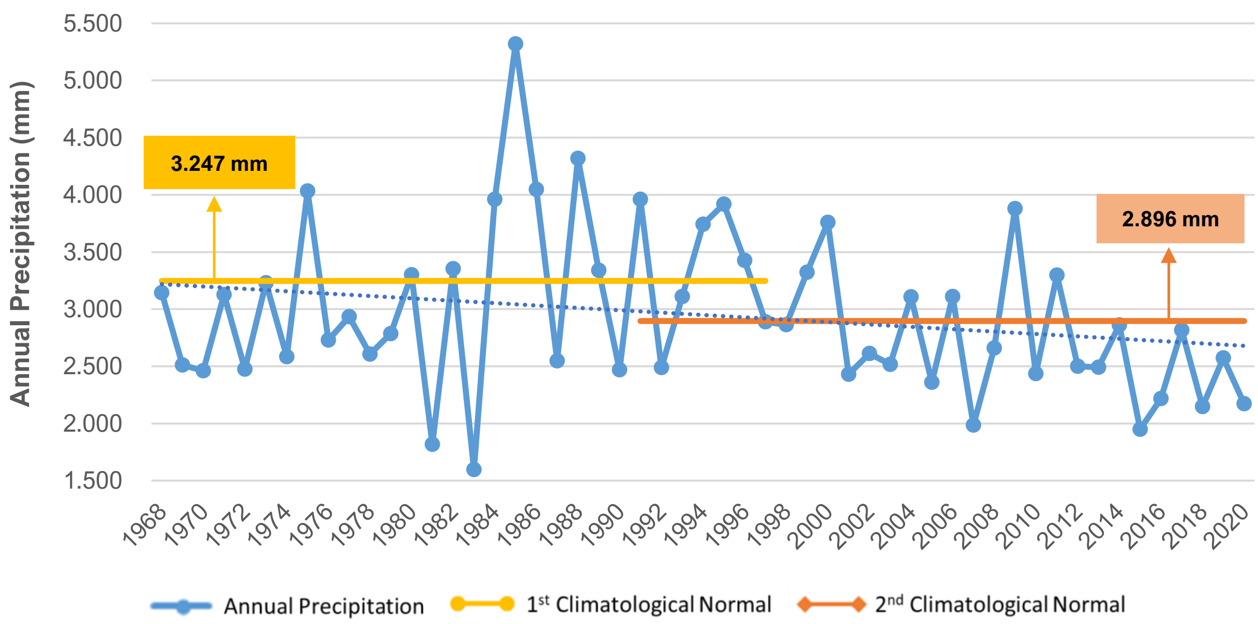


It can be observed that over the 53 years analyzed, the highest index of precipitation occurred in 1985, with a total of 5,319 mm registered in a positive variation of 2,286 mm in relation to the historical average (3,033 mm), followed by 4,361 mm in 1975 and 4,351 mm in 1988. On the other hand, the lowest index was observed in 1983, when a precipitation of 1,596 mm was recorded, with a negative deviation of -1,437 mm in relation to the average, establishing an amplitude of 3,723 mm in relation to the precipitation in 1985.

It is notable that in the last 20 years of the series, there were only five years (2004, 2006, 2009, 2011 and 2017) in which the annual precipitation was greater than the climatological average. For the other 15 years in the period, the precipitation was lower than the historical average.

Graph 11 presents the accumulated annual precipitation together with the decreasing trend line, representing a reduction in the precipitation values. Also presented are the two climatological normals (1968–1997 and 1991–2020), which present average values for the first and last 30 years of the series.

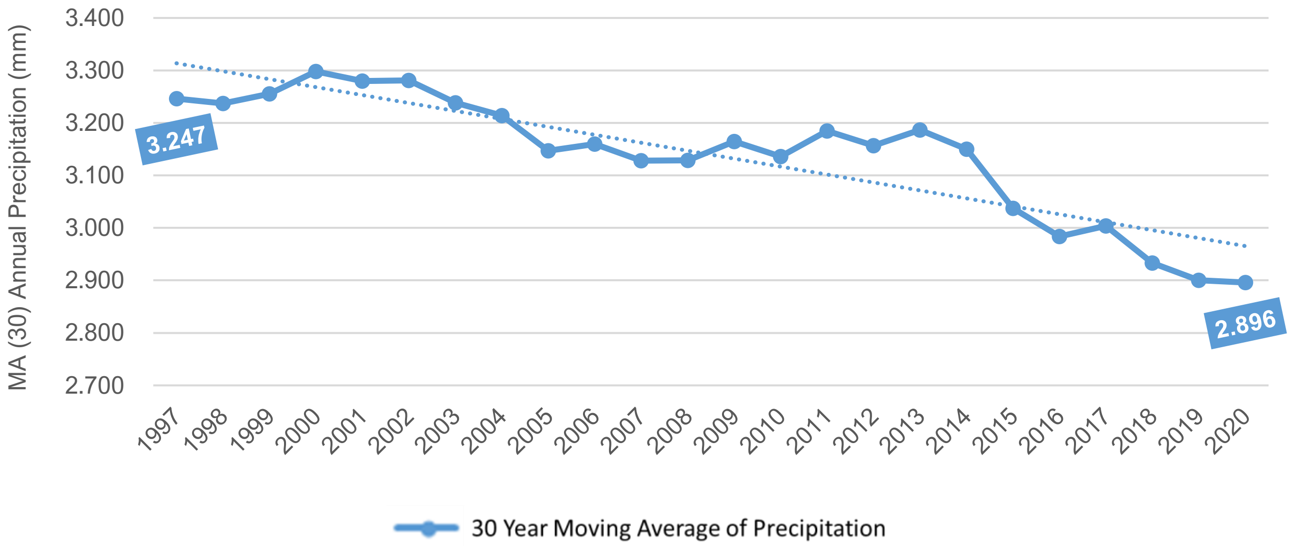
Graph 11: Trend line of the annual accumulated precipitation series (1968–2020)



The average annual precipitation for the first 30 years of the historical series evaluated is 3,247 mm, and for the last 30 years of the series, it is 2,896 mm. The difference is 351 mm, which represents a reduction of approximately 11% in the value of the average annual precipitation. This information corroborates the trend identified in graph 1, where the annual precipitation for the most recent period is below the historical average of the series.

To better evaluate the trend of reduction in the climatological normal for the annual precipitation variable, a moving average of 30 years was calculated, presented in graph 12.

Graph 12: Thirty-year moving average of annual precipitation (1968–2020)



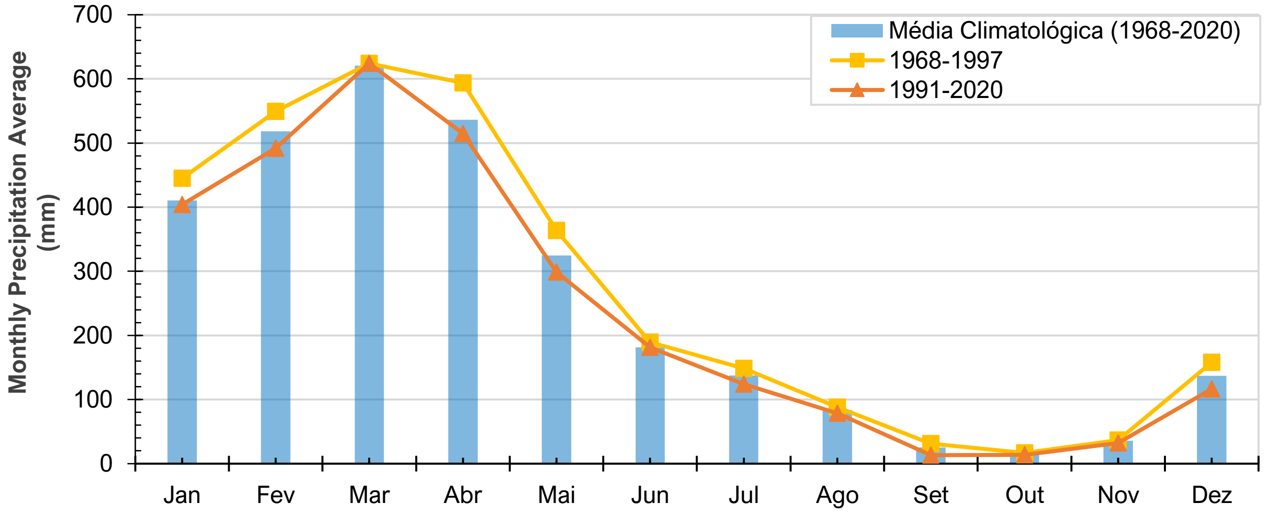
The 30-year moving average represents how the value for the climatological normal of annual precipitation evolved over the evaluated period, moving from 3,247 mm to 2,896 mm. The value presented for the year 1997 represents the average annual precipitation value presented in the 1st climatological normal in graph 2, and the value presented for the year 2020 represents the value of the 2nd climatological normal.

The 30-year moving average shows a decreasing trend in the value of the climatological normal for annual accumulated precipitation during the period evaluated.

MONTHLY PRECIPITATION

Graph 13 presents the monthly histogram of average precipitation for the period of 1968 to 2020, as well as the values for the two climatological normals.

Graph 13: Monthly precipitation average (1968–2020) and monthly precipitation average in each climatological normal



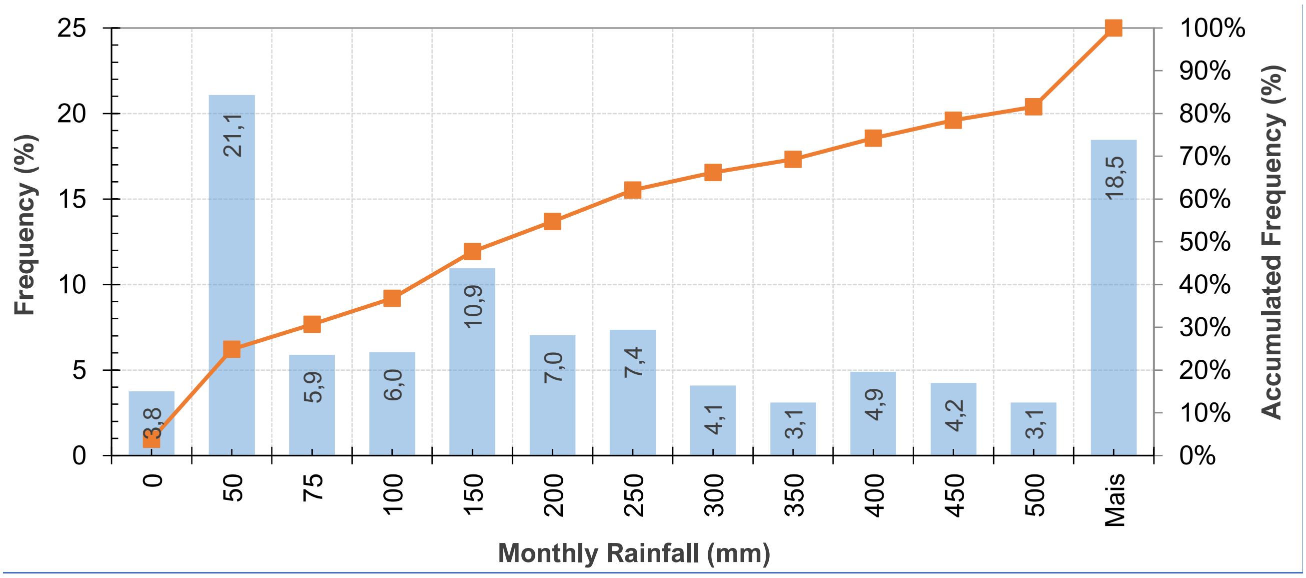
It can be observed that the rainy season occurs between the months of January and June, with March being the month of the highest precipitation in the historical average, with 621 mm, and the month of June that of the lowest precipitation, with 181 mm. The dry season occurs from July to December, with a monthly precipitation varying in the range between 15 mm (October) and 138 mm (December).

Through the two climatological normals, it is perceived that the behavior of the precipitation variable has been altered in such a way that the 2nd climatological normal presents monthly average precipitation values that are lower than those presented in the 1st normal. The greatest difference between the normals occurs in the months of April, May and February, with reductions of 79, 65 and 57 mm, respectively. In relation to the dry season, the 2nd normal also presents lower precipitation values, the greatest difference being for the month of December, with 41 mm.

The reduction in annual precipitation identified between the two climatological normals (351 mm) translates into a greater reduction in monthly precipitation during the rainy season (January to June), with a difference of 250 mm, than in the dry season (July to December), with a difference of 101 mm.

Graph 14 presents the monthly rain distribution (mm) for the Soure station associated with its frequency within the entire historical series, as well as the accumulated frequency.

Graph 14: Frequency of monthly rainfall (1968–2020)



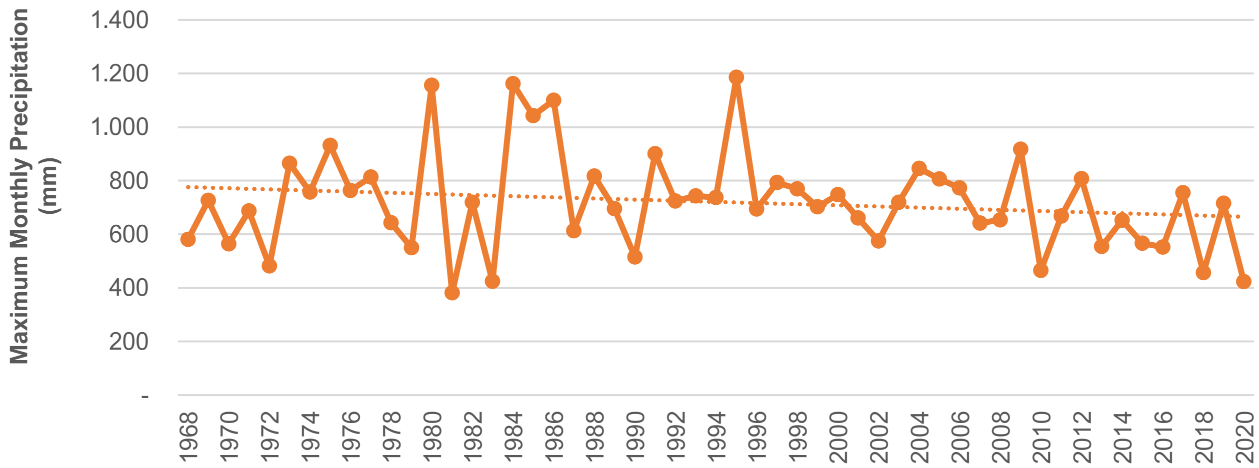
It can be observed that the months of zero precipitation represent around 3.8% of the months in the entire series. Monthly precipitation under 50 mm represents 21.1% of the months in the series, these monthly rains being the most frequent. Of note are the months with less than 150 mm of rain, which occur with a frequency of 10.9%, and monthly precipitation of over 500 mm, which represents 18.5% of all the months in the historical series.

MAXIMUM AND MINIMUM MONTHLY ACCUMULATED PRECIPITATION

The highest monthly precipitation occurs in the period between January and June, and the lowest precipitation, in the period from July to December. Aside from evaluating the monthly precipitation average, it is also relevant to evaluate the maximums and minimums of the monthly precipitation throughout the series.

Graph 15 presents the monthly maximum precipitation, in the first semester of each year in the series.

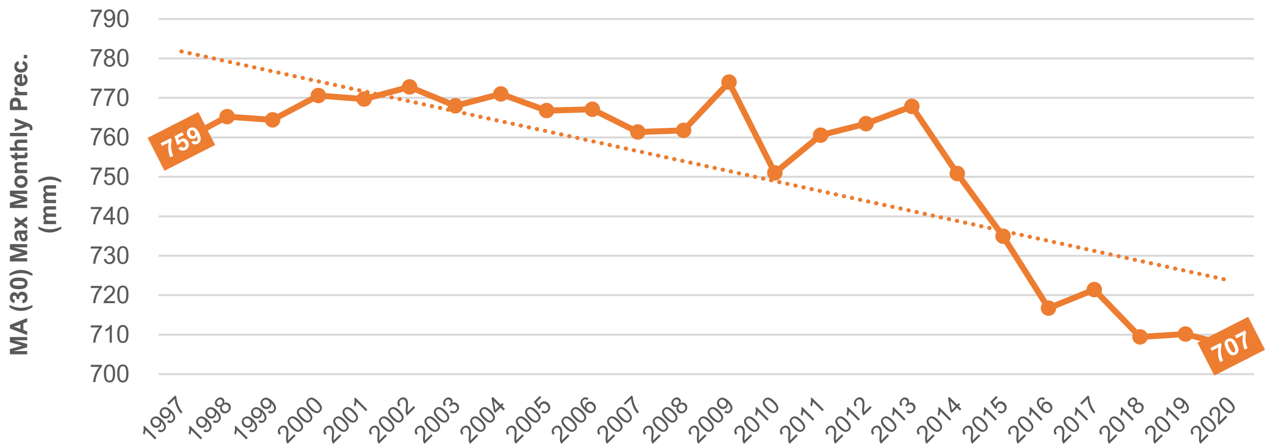
Graph 15: Maximum monthly precipitation from January to June (1968–2020)



From 1968 to 1995, there were five events in which the maximum monthly precipitation passed 1,000 mm. From 1996 to 2020, there was no monthly precipitation above 1,000 mm. The highest monthly precipitation in the historical series occurred in February 1980 (1,155 mm), April 1984 (1,162 mm) and April 1995 (1,185 mm). A reduction in values of maximum monthly precipitation throughout the series is noted.

To better identify the variable trend, the moving average of 30 years was evaluated. Graph 16 presents the 30-year moving average of maximum monthly precipitation from January to June.

Graph 16: Thirty-year moving average of maximum monthly precipitation from January to June (1968–2020)

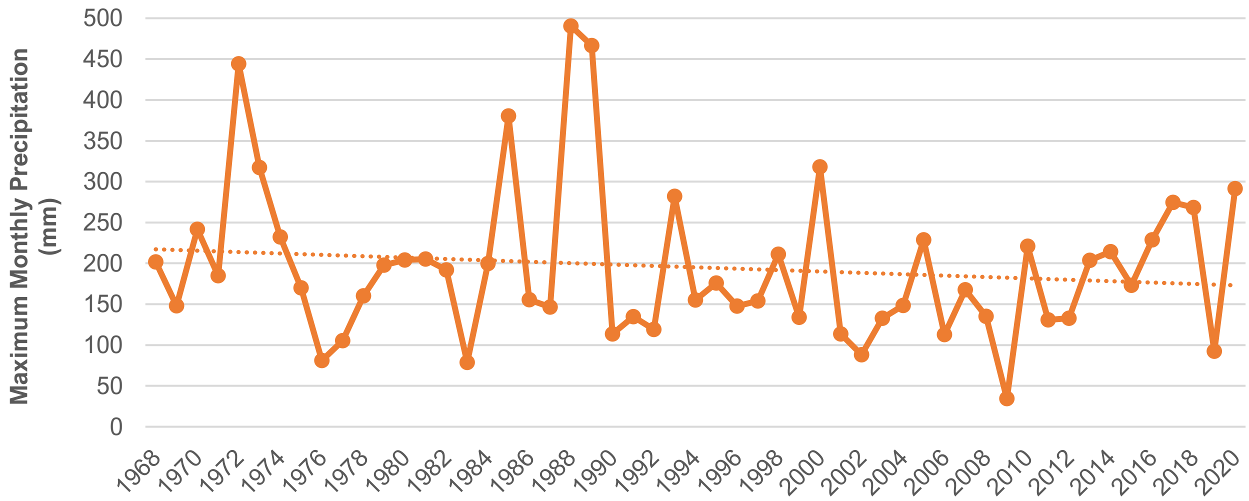


The maximum monthly precipitation average value between January and June for the first 20 years of the series is 759 mm, and for the last 30 years it is 707 mm — a reduction of 52 mm, or approximately 7%.

The moving average remains practically constant in the period between 1997 and 2008, presenting a steeper drop from then on.

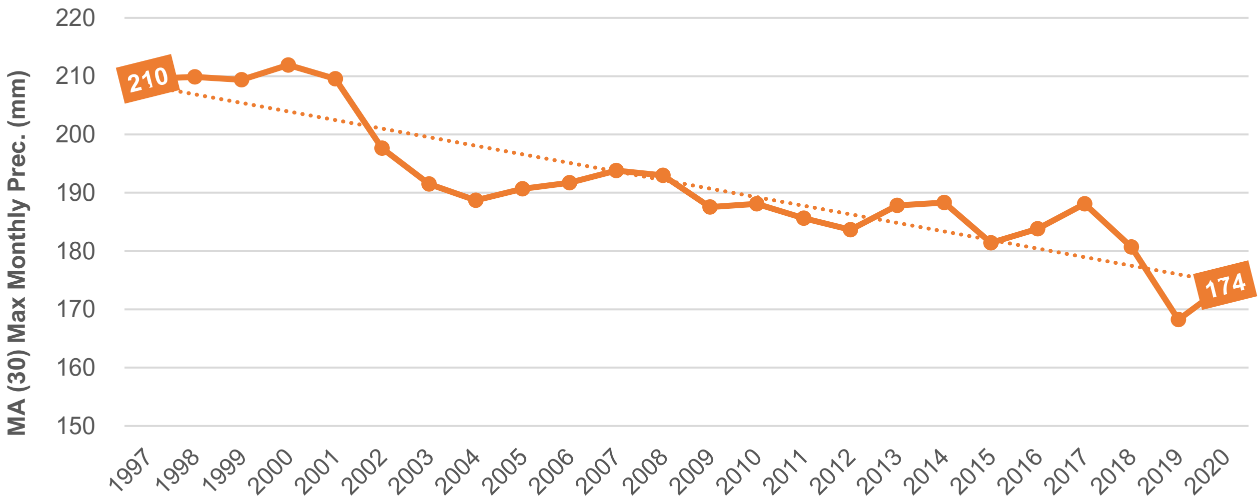
Graph 17 presents the maximum monthly precipitation for the period of July to December.

Graph 17: Maximum monthly precipitation average from July to December (1968–2020)



From 1968 to 1989, there were two events in which the maximum monthly precipitation passed 400 mm (December 1972 and December 1985) and two events in which it passed 450 mm (December 1988 and December 1989). From 1990 to 2020, there was only one event of precipitation above 300 mm, in July 2000. To better identify the variable trend, a moving average of 30 years was evaluated. Graph 18 presents the 30-year moving average of maximum monthly precipitation from July to December.

Graph 18: Thirty-year moving average of maximum monthly precipitation from July to December (1968–2020)



The monthly maximum precipitation average in the dry season for the first 30 years of the series is 210 mm, and for the last 30 years, it is 174 mm, a reduction of 36 mm, or approximately 17%. The moving average presents a significant drop between 2000 and 2003, remains practically constant in the period between 2003 and 2017, and presents a new drop near the end of the series.

RAINFALL ANOMALY INDEX

The Rainfall Anomaly Index (RAI) evaluates the degree of severity and duration of dry and rainy years and the intensity by means of the frequency of occurrence. It is a method to study rainfall, evaluating the driest years and the years of excessive rainfall, which facilitates the climatological understanding of the region.

The Rainfall Anomaly Index (RAI) is calculated with the following formulas:

$$IAC = 3 \,.\, \frac{(N_i - N)}{(M - N)} \,, for\ positive\ anomalies$$

$$IAC = -3 \,.\, \frac{(N_i - N)}{(X - N)} \,, for\ negative\ anomalies$$

$N_i = Annual\ rainfall\ for\ the\ year\ i\ (mm)$

$N = Annual\ rainfall\ average\ for\ the\ historical\ series\ (mm)$

$M = Average\ of\ the\ 10\ highest\ annual\ rainfalls\ for\ the\ historial\ series\ (mm)$

$X = Average\ of\ the\ 10\ lowest\ annual\ rainfalls\ for\ the\ historical\ series\ (mm)$

The difference between the annual precipitation and the historical average precipitation (1968–2020) was used as a comparison base for the framework of the negative and positive anomalies.

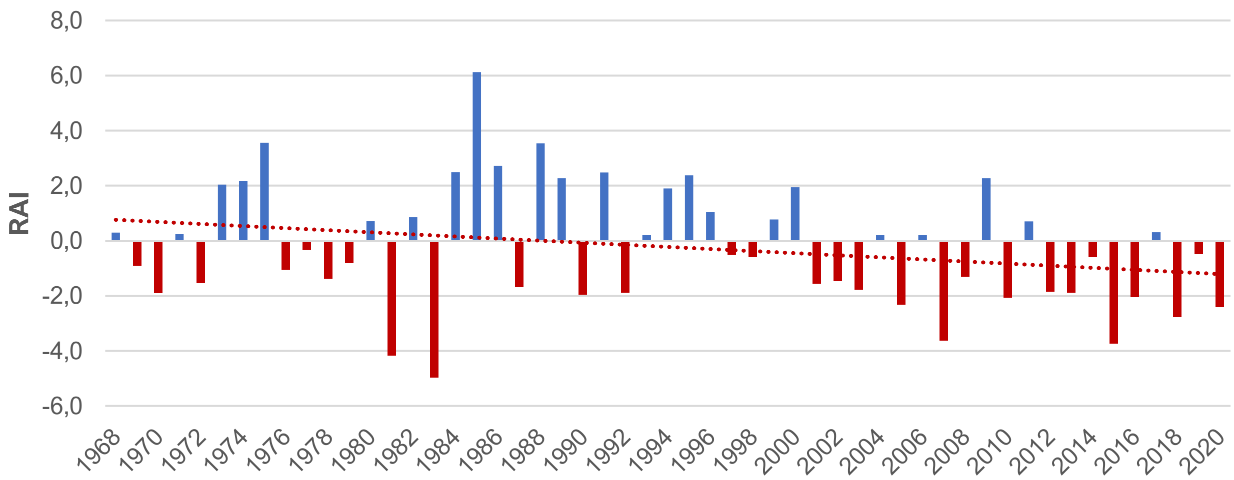
From the values found, the rainfall regime was classified according to the RAI methodology presented in table 6.

Table 30: Rainfall Anomaly Index (RAI) classes

RAI Range	Classification
> 4	Extremely humid
2 to 4	Very humid
0 to 2	Humid
0 to -2	Dry
-2 to -4	Very dry
< -4	Extremely dry

Graph 19 presents the RAI value for the entire historical series of data.

Graph 19: Rainfall Anomaly Index (1968–2020)

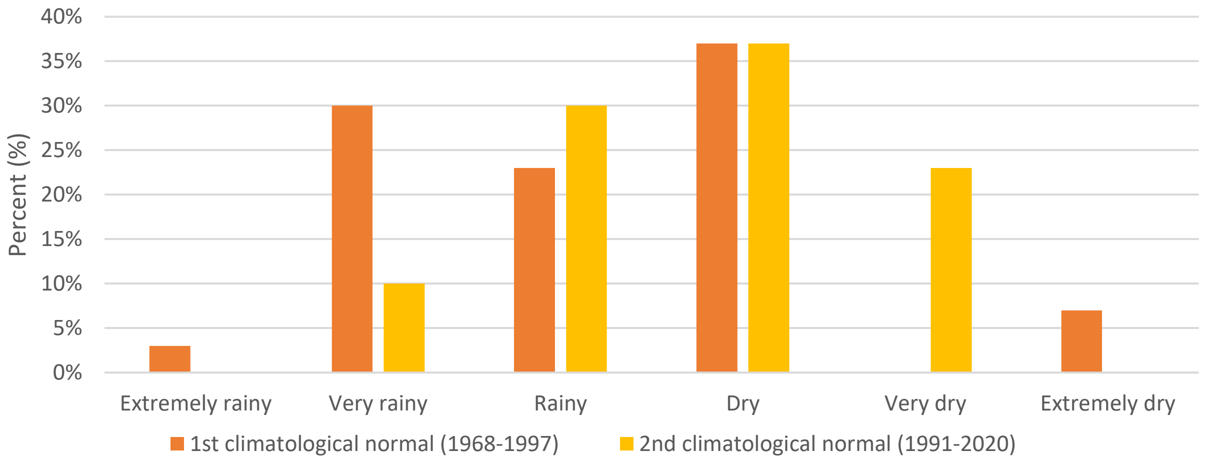


In the RAI values, it is verified that there were 29 negative deviations and 24 years of positive events. Of the negative RAI values, 20 years were dry, seven were very dry and two were extremely dry. The 27 positive years were divided into: 13 rainy years, 10 very rainy years and one extremely rainy year.

Although the numbers of dry and rainy years are similar, the distribution in the period of 1968 to 2020 is irregular. For the period of the 1st climatological normal (1968–1997), 17 positive events are counted while in the period of the 2nd climatological normal (1991–2020), 12 positive events occurred, a decrease of 29%. Meanwhile, the negative events occurred in 13 years in the first period and in 18 years of the second period, an increase of 38%.

Graph 10 presents the percent of years in each RAI classification for the two climatological normals, in order to present the decrease in the years with very rainy events and the increase of very dry events.

Graph 20: Rainfall Anomaly Index classification by percent (1968–1997 and 1991–2020)



The result of the RAI calculation for the entire period considered is presented in table 31.

Table 31: Rainfall Anomaly Index (1968–2020) — Soure station

Year	Annual precipitation (mm)	RAI	Classification
1968	3,144.00	0.3	Rainy
1969	2,512.40	-0.9	Dry
1970	2,459.40	-1.9	Dry
1971	3,127.50	0.3	Rainy
1972	2,474.40	-1.5	Dry
1973	3,230.50	2.0	Very Rainy
1974	2,584.50	2.2	Very Rainy
1975	4,032.90	3.6	Very Rainy
1976	2,729.50	-1.0	Dry
1977	2,933.00	-0.3	Dry
1978	2,607.50	-1.4	Dry
1979	2,785.30	-0.8	Dry
1980	3,301.20	0.7	Rainy
1981	1,818.40	-4.2	Extremely Dry
1982	3,351.90	0.9	Rainy
1983	1,595.70	-5.0	Extremely Dry
1984	3,961.00	2.5	Very Rainy

1985	5,318.80	6.1	Extremely Rainy
1986	4,046.80	2.7	Very Rainy
1987	2,546.50	-1.7	Dry
1988	4,318.20	3.5	Very Rainy
1989	3,339.80	2.3	Very Rainy
1990	2,469.90	-1.9	Dry
1991	3,958.90	2.5	Very Rainy
1992	2,488.30	-1.9	Dry
1993	3,111.00	0.2	Rainy
1994	3,741.10	1.9	Rainy
1995	3,919.40	2.4	Very Rainy
1996	3,426.80	1.1	Rainy
1997	2,889.00	-0.5	Dry
1998	2,863.20	-0.6	Dry
1999	3,322.70	0.8	Rainy
2000	3,758.50	1.9	Rainy
2001	2,430.90	-1.5	Dry
2002	2,611.10	-1.5	Dry
2003	2,518.00	-1.8	Dry
2004	3,107.80	0.2	Rainy
2005	2,360.70	-2.3	Very Dry
2006	3,109.60	0.2	Rainy
2007	1,986.10	-3.6	Very Dry
2008	2,658.80	-1.3	Dry
2009	3,878.90	2.3	Very Rainy
2010	2,436.10	-2.1	Very Dry
2011	3,296.30	0.7	Rainy
2012	2,500.30	-1.8	Dry
2013	2,490.30	-1.9	Dry
2014	2,860.80	-0.6	Dry
2015	1,949.90	-3.7	Very Dry
2016	2,217.40	-2.0	Very Dry
2017	2,816.40	0.3	Rainy
2018	2,146.50	-2.8	Very Dry
2019	2,573.80	-0.5	Dry
2020	2,172.50	-2.4	Very Dry

DAILY INDICATORS

To complement the analysis of the precipitation variable behavior, different rainfall indicators elaborated from the Soure station's daily data were analyzed. The following data do not consider the filling in of the gaps from the Soure station since such a correction can only be made at the monthly precipitation level.

It can be noted that, despite the gaps present in the daily precipitation data, they correspond to only 3.7% of the entire daily series of precipitation, exercising little influence on the observed trends.

AVERAGE RAINFALL INDEX

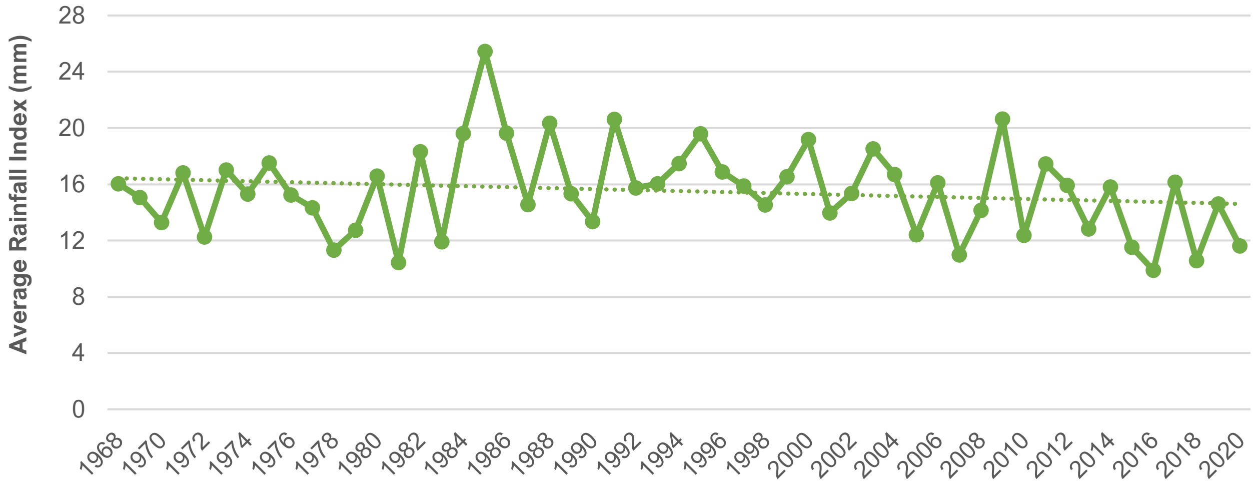
The average rainfall index represents the value of rainfall that, if replaced by all the rain that occurred during the year in question, would result in the same accumulated annual precipitation. This index is calculated by dividing the total annual precipitation by the number of rainy days for the same period.

The average rainfall index is calculated through the following formula:

$$Average\ Rainfall\ Index = \frac{Total\ accumulated\ precipitation\ for\ the\ year\ (mm)}{Number\ of\ rainy\ days\ for\ the\ year}$$

Graph 21 presents the values for the average annual rainfall index for each year in the historical series.

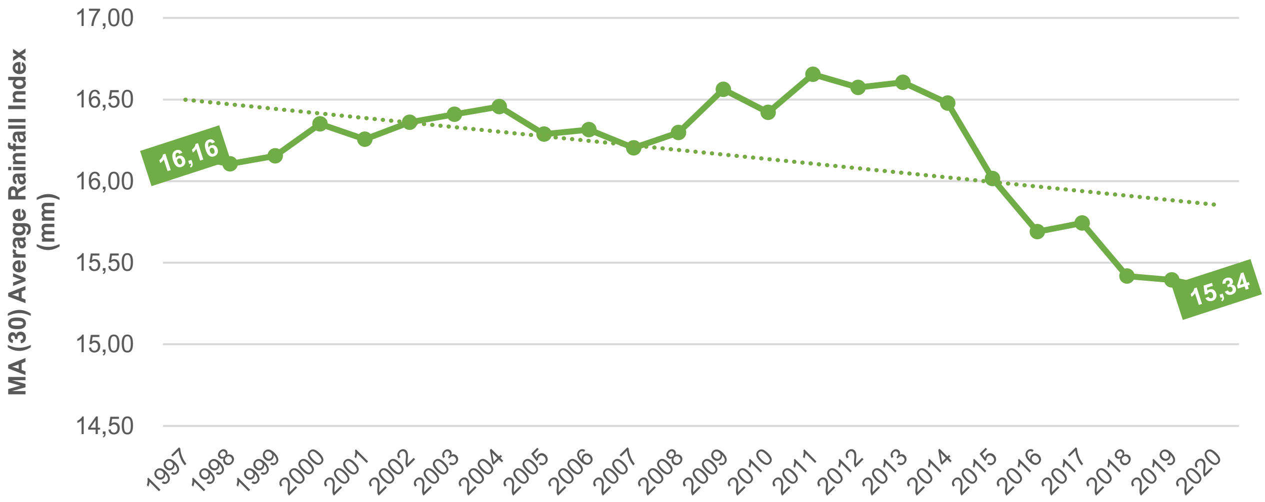
Graph 21: Average rainfall index (1968–2020)



From 1968 to 2006 (39 years), there were three years (1978, 1981 and 1983) in which the average rainfall index was below 12 mm whereas over the last 14 years (2006 to 2020), there were five years (2007, 2015, 2016, 2018 and 2020) in which the value was below 12 mm, with the lowest value of the entire historical series occurring in the year 2016.

To identify the trend of this variable, its 30-year moving average was evaluated. Graph 22 presents the 30-year moving average of the Average Rainfall Index for the entire period considered.

Graph 22: Thirty-year moving average of the Average Rainfall Index



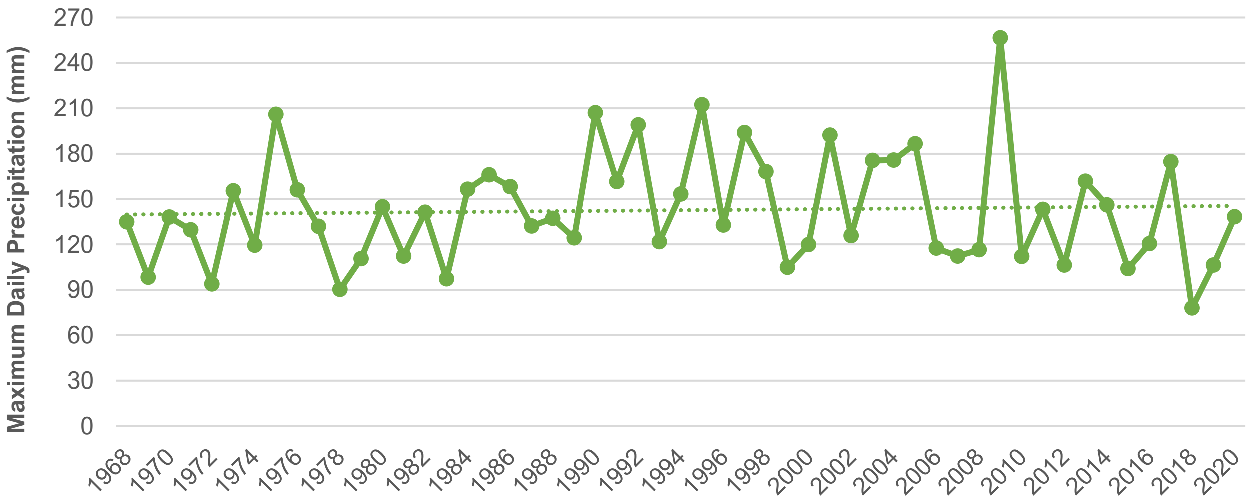
The average value for the average rainfall index in the first 30 years of the series is 16.16 mm, and for the last 30 years of the series, it is 15.34 mm, a reduction of 5%.

MAXIMUM DAILY PRECIPITATION

The maximum daily precipitation indicates the values of the most intense rainfall in a single day for each year of the historical series.

Graph 23 presents the maximum precipitation values in a single day for each year of the series.

Graph 23: Maximum daily precipitation by year (1968–2020)

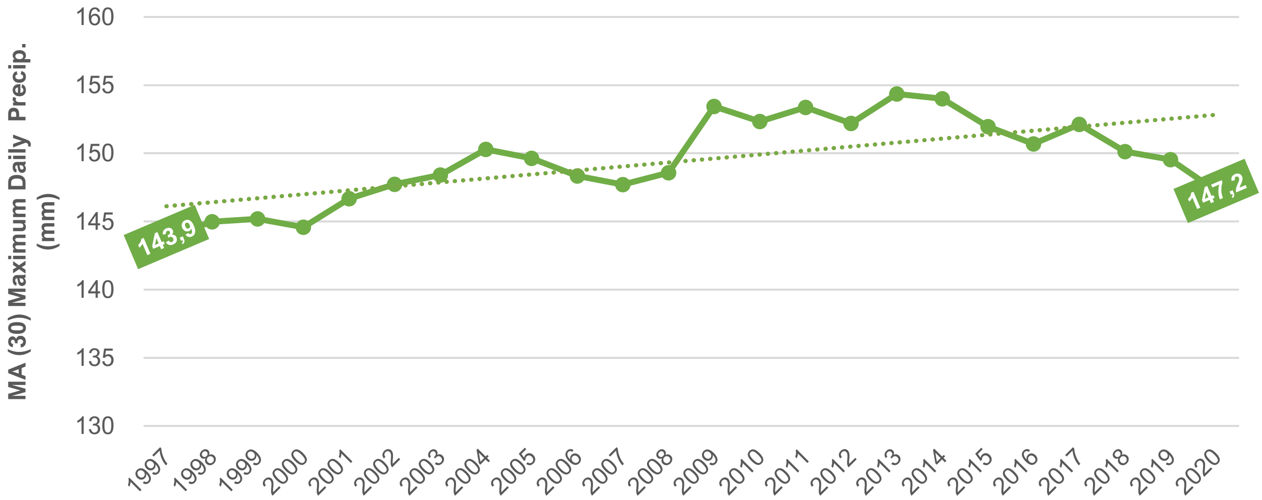


It can be determined that during the period of the 1st climatological normal (1968–1997), there were five years in which the most intense daily rainfall passed 180 mm. In the period of the 2nd climatological normal

(1991–2020), there were six years with rains above 180 mm, 2009 being the only year in the series in which daily rainfall was registered above 250 mm.

To help identify the trend for this variable, graph 24 presents the 30-year moving average of maximum daily precipitation.

Graph 24: Thirty-year moving average of maximum daily precipitation

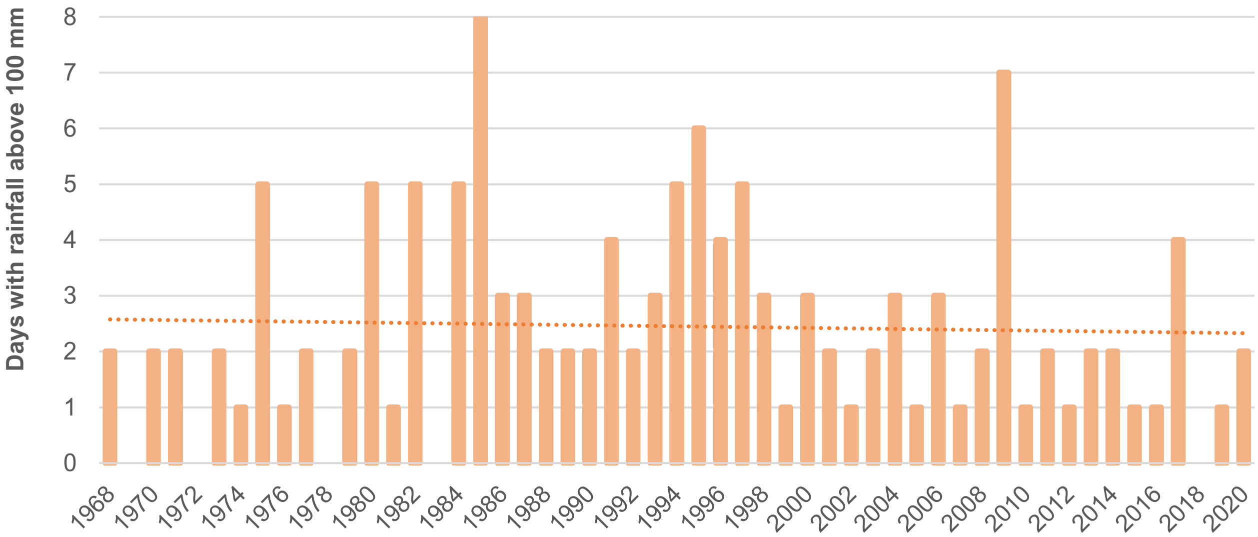


There is an increasing trend in the value of maximum daily precipitation, albeit moderately. The value of the moving average of the maximum daily precipitation for the first 30 years of the series is 143.9 mm, and for the last 30 years, it is 147.2 mm, an increase of 2.3%.

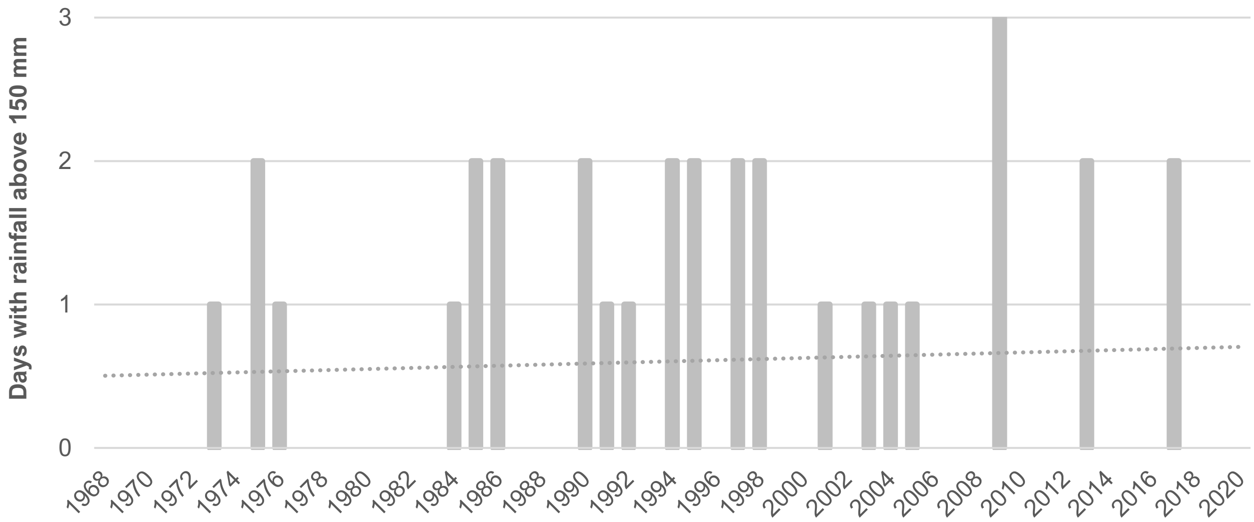
NUMBER OF DAYS WITH HEAVY RAINFALL

Graphs 25 and 26 present the number of days per year in which heavy rainfall occurred, with rainfall above 100 mm and 150 mm, respectively.

Graph 25: Number of days with rainfall above 100 mm (1968–2020)



Graph 26: Number of days with rainfall above 150 mm (1968–2020)



In the period defined by the 1st climatological normal (1961–1997), there were a total of 84 days with rainfall above 100 mm and, in the same period, there was no rainfall of this intensity for four years. In the period of the 2nd climatological normal (1991–2020), there are 75 days in which rainfall exceeded 100 mm, a reduction of nine days, or 10.7%. However, within the last 30 years of the series, there was only one year in which there was no rain of this intensity.

Regarding rainfall above 150 mm, the period of the 1st climatological normal (1961–1997) presents 19 days with rainfall of this intensity. In the period of the 2nd climatological normal (1991–2020), 21 days with rainfall above 150 mm were registered, an increase of 2 days, or 10.5%. It is also noticeable that the interval of time between years that present rainfall of this intensity is smaller for the last years of the series when compared to the initial years.

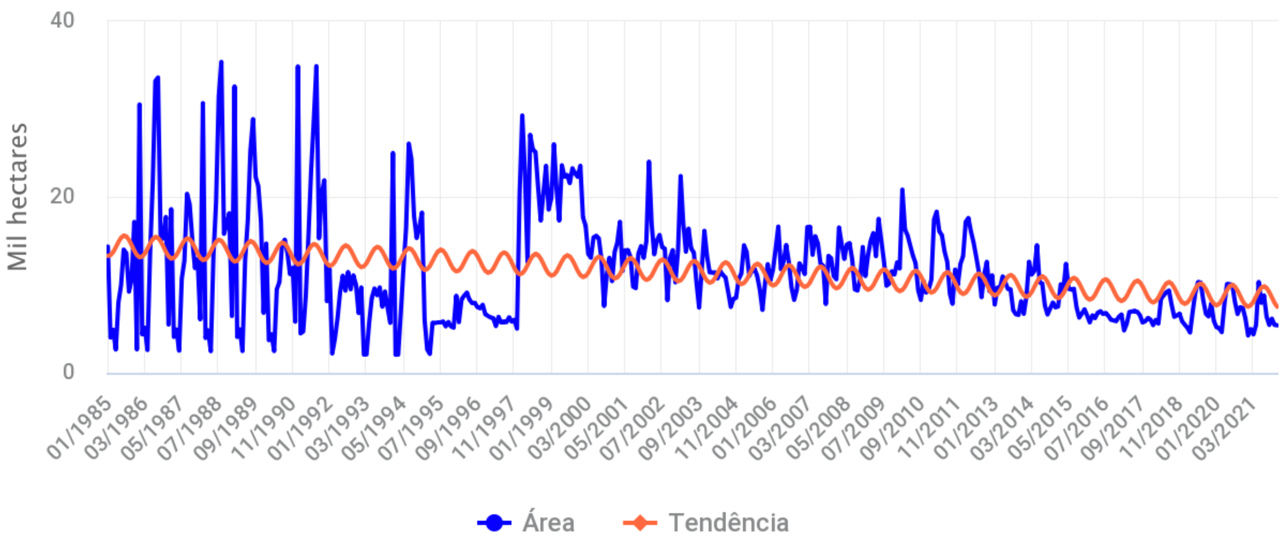
WATER SURFACE AREAS

Once the trend of reduction in annual precipitation volumes in the study area was identified, the evolution of water surface areas (streams, rivers, lakes, ponds and wetlands) within the three studied municipalities was also evaluated. For this analysis, the MapBiomas Água platform was used as an information base, which presents data for the period from 1985 to 2021.

Surface water areas, in part, represent important locations for local populations due to their way of life, as they obtain diverse resources from these areas.

Graph 27 represents the monthly historical series, in area, of the water surface in the municipality of Soure. In blue, the area calculated from the monthly data produced by the MapBiomas Água work team. In orange, the trend, based on a harmonic model.

Graph 27: Monthly series of water surface area in Soure (1985 - 2021)



It can be seen that the area of water surfaces in the municipality of Soure follows the same trend of reduction, as was identified for the climatic variable of precipitation.

The reduction of water surface areas is correlated with the reduction of precipitation volumes, and is also influenced by temperature, due to higher evaporation values.

Graph 28 presents the annual historical series, and table 32 presents the maximum, average and minimum values of the series, as well as the value for the most recent year (2021).

Graph 28: Annual series of water surface area in Soure (1985 - 2021)

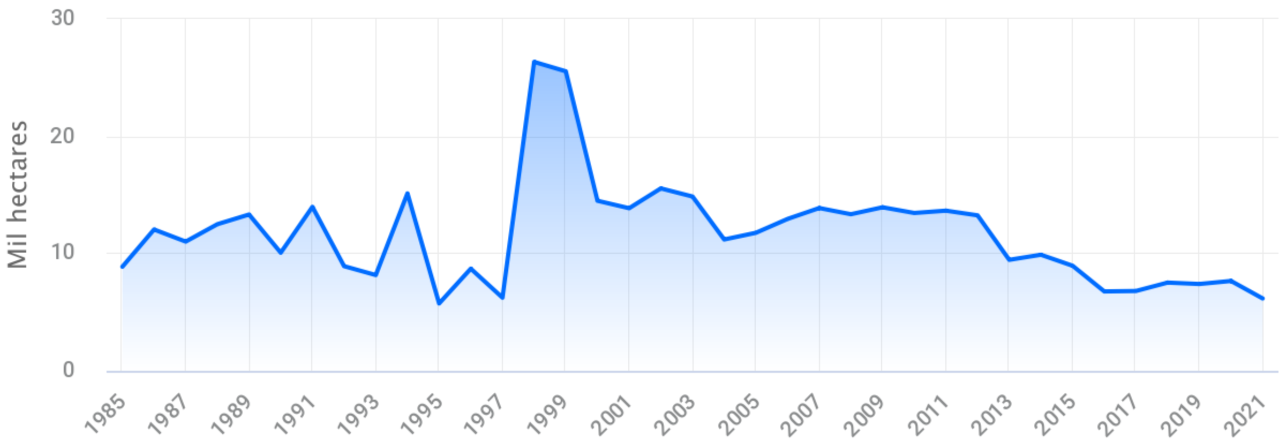


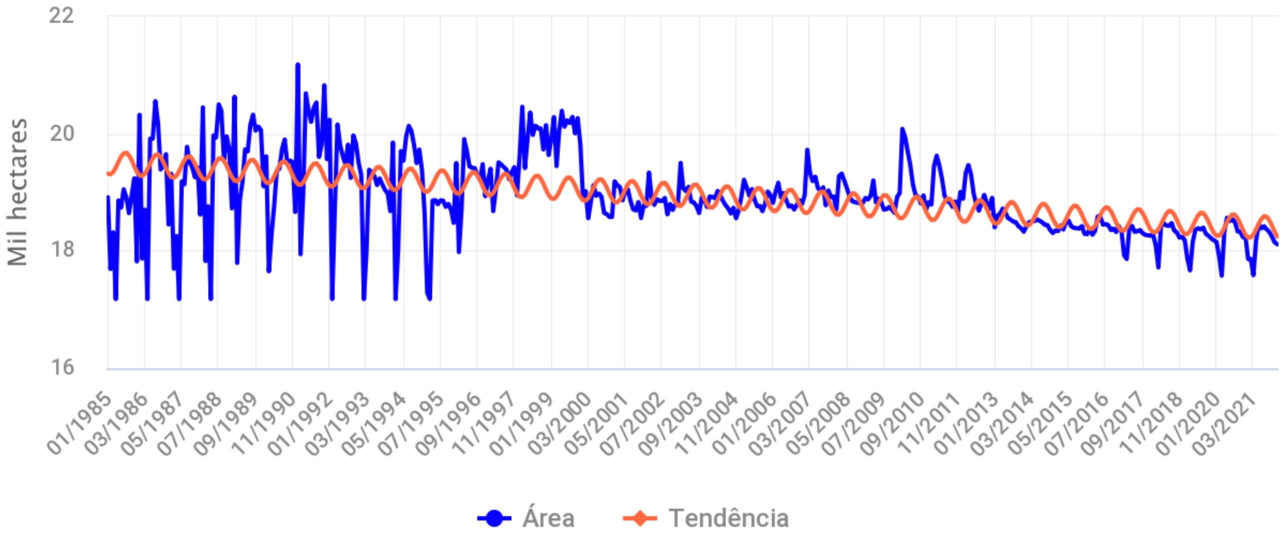
Table 32: Statistics from the annual series of water surface area in Soure

Maximum extent of water surface (1998)	26.328 ha
Average extent of water surface (1985-2021)	11.707 ha
Minimum extent of water surface (1995)	5.737 ha
Extent of water surface in 2021	6.612 ha

In relation to the beginning of the historical series (1985), there is a loss of 2,730 ha of surface water in the municipality of Soure, which represents a reduction of approximately 30% of these areas. The reduction in area from 2000 onwards is correlated with the Rainfall Anomalies Index (Graph 19), with the predominance of drier years from this year onwards.

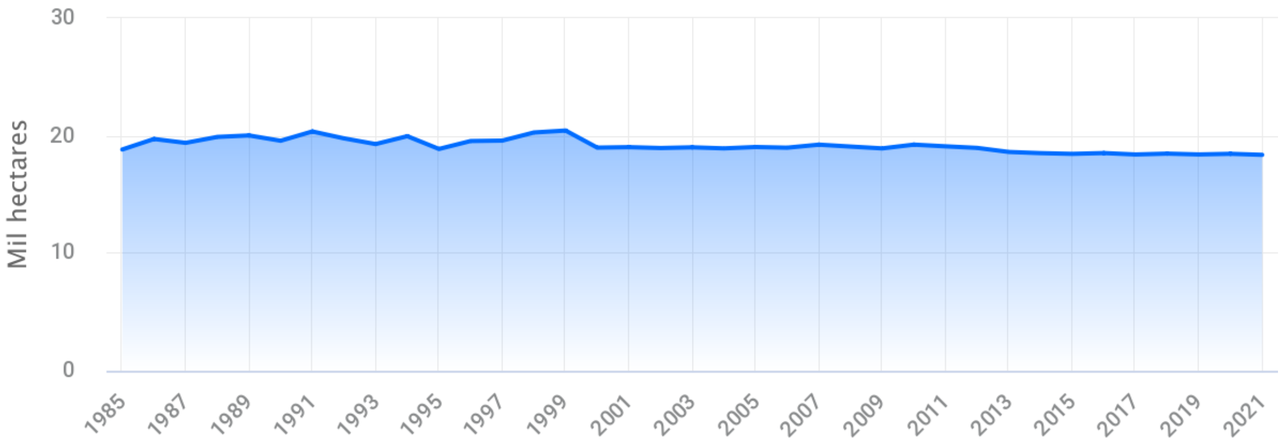
Graph 29 presents the monthly historical series, in area, of the water surface in the municipality of Salvaterra.

Graph 29: Monthly series of water surface area in Salvaterra (1985 - 2021)



Graph 30 presents the annual historical series, and table 33 presents the maximum, average and minimum values of the series.

Graph 30: Annual series of water surface area in Salvaterra (1985 - 2021)



The trend of reduction of water surfaces in the municipality of Salvaterra is also much less pronounced, compared to that presented in Soure. The downward trend also becomes clearer from the year 2000 onwards.

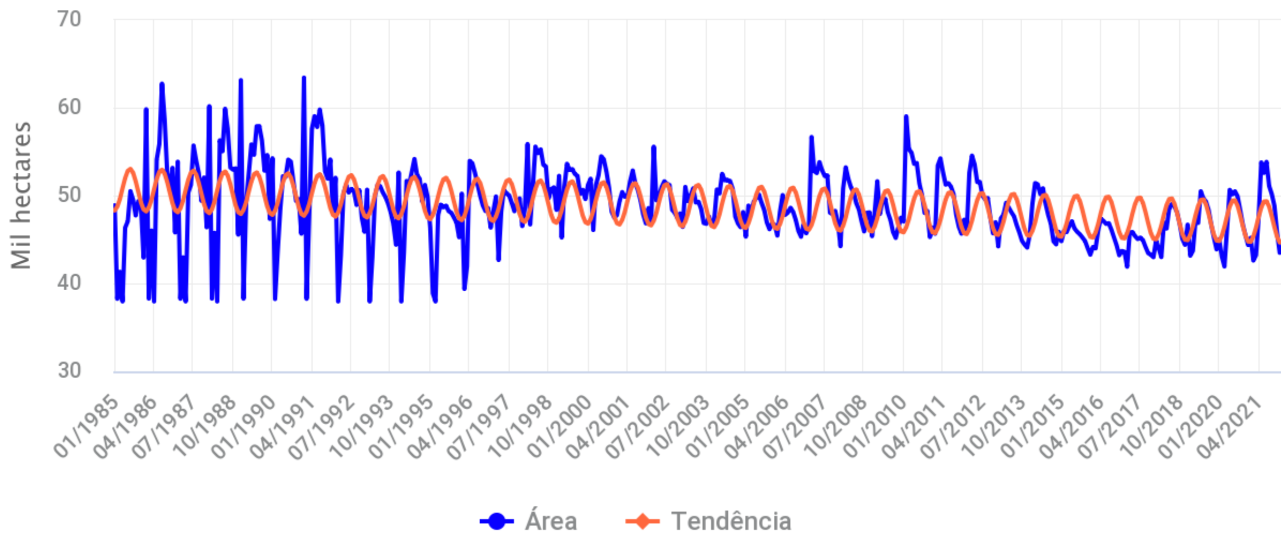
Table 33: Statistics from the annual series of water surface area in Salvaterra

Maximum extent of water surface (1999)	20.246 ha
Average extent of water surface (1985-2021)	19.155 ha
Minimum water surface extent (2021)	18.360 ha

Salvaterra has an average length of water surface of 19,155 ha, a value higher than that found in the municipality of Soure (11,707 ha). It is noteworthy that the smallest extension of water surface in Salvaterra occurred in the year 2021. In relation to the beginning of the historical series, there is a loss of 455 ha of water surface in the municipality of Salvaterra, which represents a reduction of approximately 2.5% of these areas.

Graph 31 presents the monthly historical series, in area, of the water surface, in the municipality of Cachoeira do Arari.

Graph 31: Monthly series of water surface area in Cachoeira do Arari (1985 - 2021)



Graph 32 presents the annual historical series, and table 34, some statistics of the series.

Graph 32: Annual series of water surface area in Cachoeira do Arari (1985 - 2021)

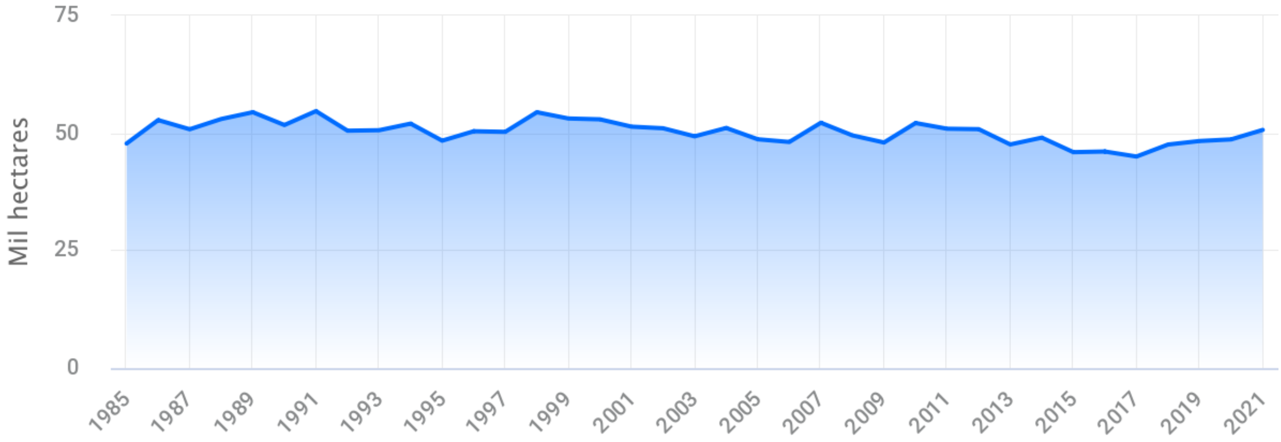


Table 34: Statistics from the annual series of water surface area in Cachoeira do Arari

Maximum extent of water surface (1999)	54.659 ha
Average extent of water surface (1985-2021)	50.251 ha
Minimum water surface extent (2017)	44.996 ha
Extent of water surface in 2021	50.656 ha

The municipality of Cachoeira do Arari has an average length of water surface of 50,251 ha, being the municipality with the largest surface area of water. Much of this area is due to Lake Arari, located to the west of the municipality, on the border with Santa Cruz do Arari.

The year in which the minimum extension of water surface in the municipality occurred was in 2017, and after this period, there was an increase in water surfaces in consecutive years.

In relation to the beginning of the historical series, there is an increase of 2,888 ha of water surface in Cachoeira do Arari, which represents an increase of approximately 6% of these areas.

TEMPERATURE VARIABLE

The statistical application of temperature data was based on measures of central tendency (average, maximum and minimum) and behavior of the climatological normal of temperature variables for the entire historical series (1968–2020). Such elements were obtained from data processing in Excel spreadsheets, through the application of descriptive statistics, identifying the main measurements related to the data, as well as their graphical representations.

The historical series of temperature of the Soure station presents a greater number of gaps than the series of precipitation, being that for the values of maximum, average and minimum temperature, there are different gaps, presented below.

- Maximum Temperature: Presents 12.5% of gaps in the entire historical series. The years with the greatest gaps in daily measurements, and their respective percentage of gaps, are: 1974 (33%), 1975 (18%), 1978 (22%), 1984 (47%), 1985 (40%), 1989 (51%), 1990 (100%), 1991 (34%), 1993 (18%), 2004 (16%), 2015 (49%), 2016 (27%), 2017 (38%), 2018 (41%), 2019 (40%) and 2020 (27%).
- Average Temperature: The most incomplete variable within the temperature series, it presents 17.1% of the gaps in the entire historical series. The years with the greatest gaps in daily measurements, and their respective percentage of gaps, are: 1970 (59%), 1971 (100%), 1972 (42%), 1974 (33%), 1975 (19%), 1978 (22%), 1984 (47%), 1985 (40%), 1989 (51%), 1990 (100%), 1991 (34%), 1993 (18%), 2004 (16%), 2015 (50%), 2016 (28%), 2017 (56%), 2018 (62%), 2019 (39%) and 2020 (28%).
- Minimum Temperature: Presents 9.9% of the gaps in the entire historical series. The years with the greatest gaps in daily measurements, and their respective percentage of gaps, are: 1970 (59%), 1971 (100%), 1972 (42%), 1974 (33%), 1975 (19%), 2016 (30%), 2017 (58%), 2018 (64%), 2019 (42%) and 2020 (25%).

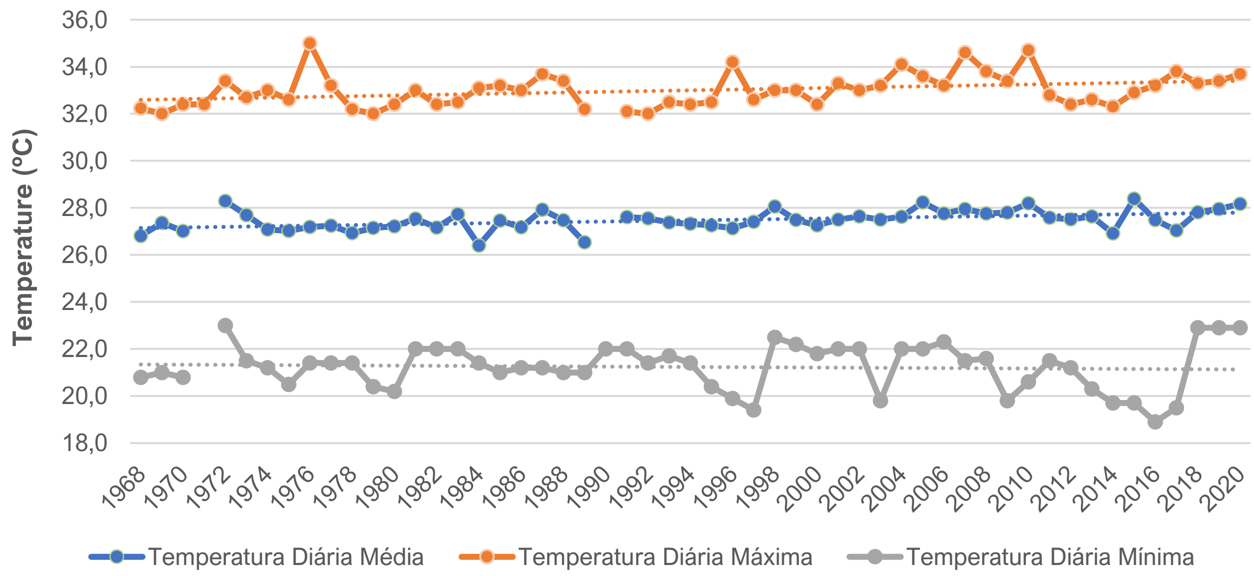
The series worked on has a total of 53 years (1968–2020). Therefore, even though there are gaps of up to 20% in the series, there are more than 42 years of data available for analysis. To make the use of this historical series unfeasible, the gaps would have to reach at least 30% in order for the available data to represent a period of less than 30 years.

The climatic temperature variable presents much smaller variations between the daily measurements, compared to the precipitation variable, which justifies the use of the historical temperature series, although it has greater gaps than the precipitation series.

ANNUAL TEMPERATURE

Graph 33 presents the historical series of daily data observed for the variables of maximum, average and minimum temperature from the Soure station. The missing points in the graph represent those years in which the gaps reach 100% of the data, i.e., there is no data available for these periods.

Graph 33: Maximum, average and minimum temperatures (1968–2020)



The highest maximum temperature value of the series occurred in 1975, with a registered temperature of 35 ºC. In the period of the first 30 years of the series, there were only two years (1975 and 1996) in which the maximum temperature passed 34 ºC. In the last 30 years of the historical series, there were four years in which the temperature exceeded 34 ºC.

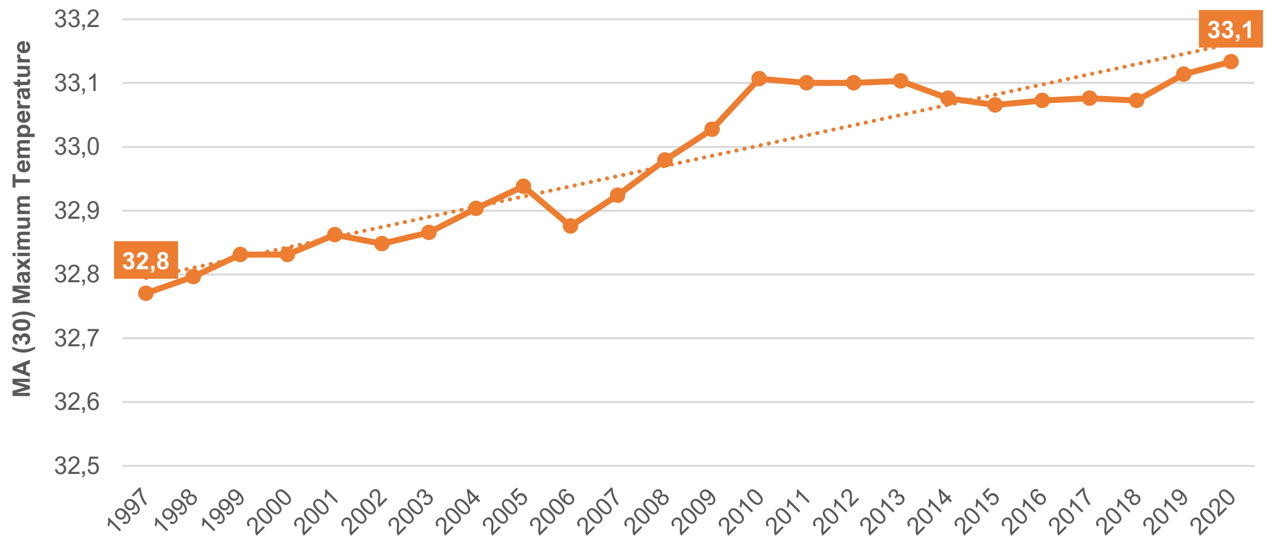
The average temperature values present a variation similar to that of the maximum temperature, showing trend lines with a positive slope.

The minimum temperature has a slightly different behavior, with the trend line showing a slightly negative slope. The lowest minimum temperature value occurred in 2016, when a temperature of 18.9 °C was recorded. In the first 30 years of the series, the minimum temperature only fell below 20 ºC in two events

(1996 and 1997), whereas in the last 30 years of the series, the minimum temperature reached values below 20 ºC in eight events.

To better comprehend the trend presented for the maximum, average and minimum temperature variables, 30-year moving averages were elaborated and are presented in graphs 34, 35 and 36, respectively.

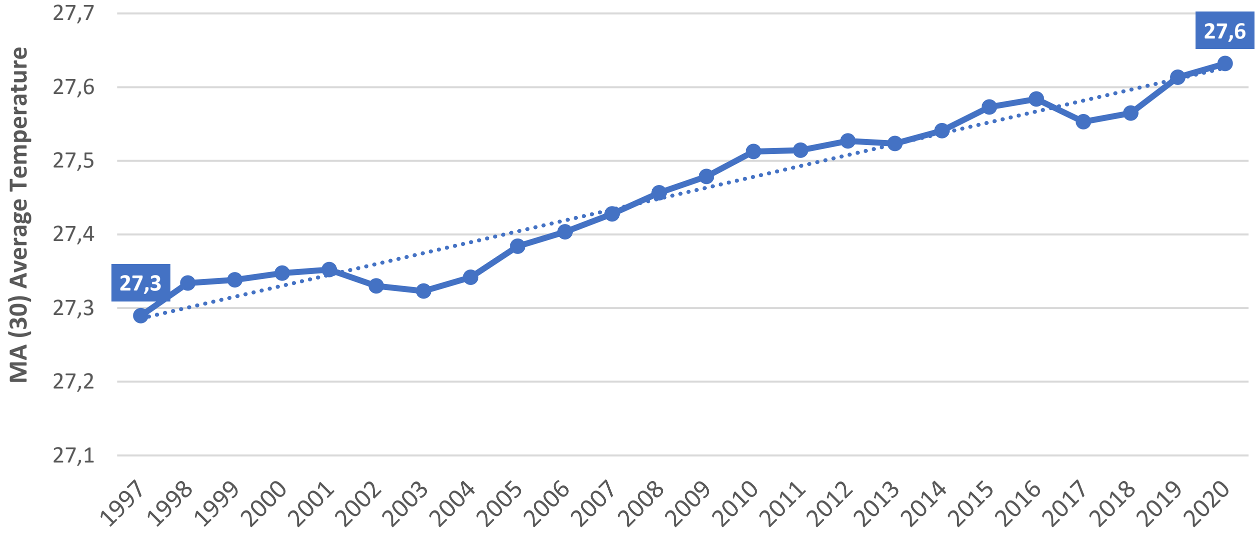
Graph 34: Thirty-year moving average of maximum temperature



The moving average of the maximum daily temperature for the first 30 years of the series is 32.8 °C, and for the last 30 years of the series, the value is 33.1 °C, an increase of 0.3 °C in the average of the values of maximum temperature, or approximately 1%.

Graph 35 presents the 30-year moving average for the average temperature.

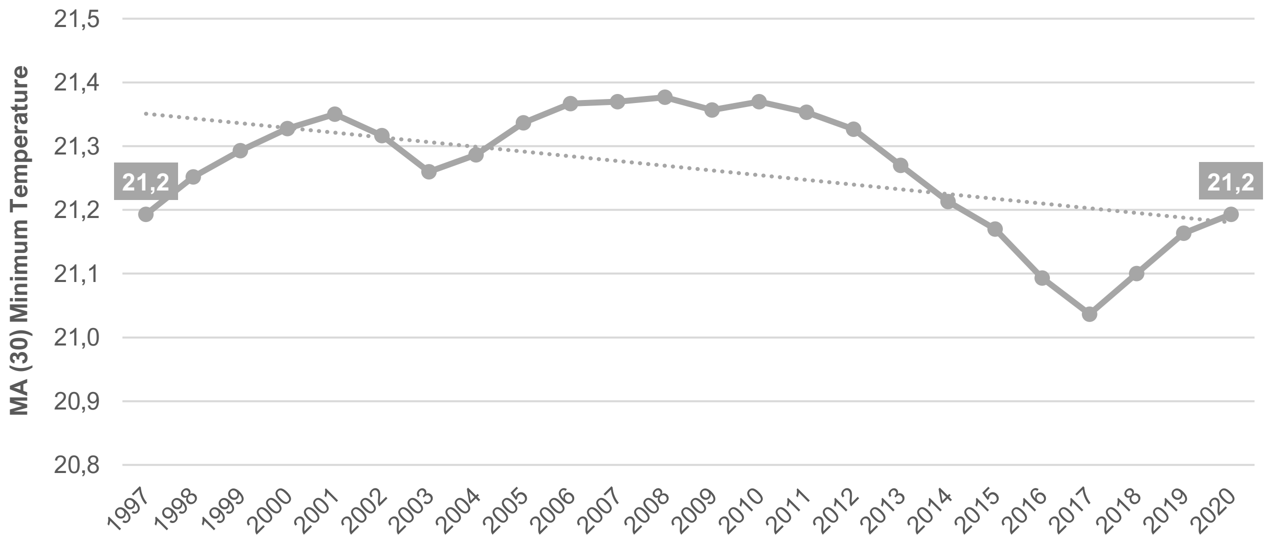
Graph 35: Thirty-year moving average of average temperature



The moving average of the average temperature for the first 30 years of the series is 27.3 °C, and for the last 30 years of the series, the value is 27.6 °C, an increment of 0.3 °C, or an increase of 1.1%. The behavior of the average temperature is similar to that of the maximum temperature.

Graph 36 presents the 30-year moving average of the minimum temperature.

Graph 36: Thirty-year moving average of minimum temperature

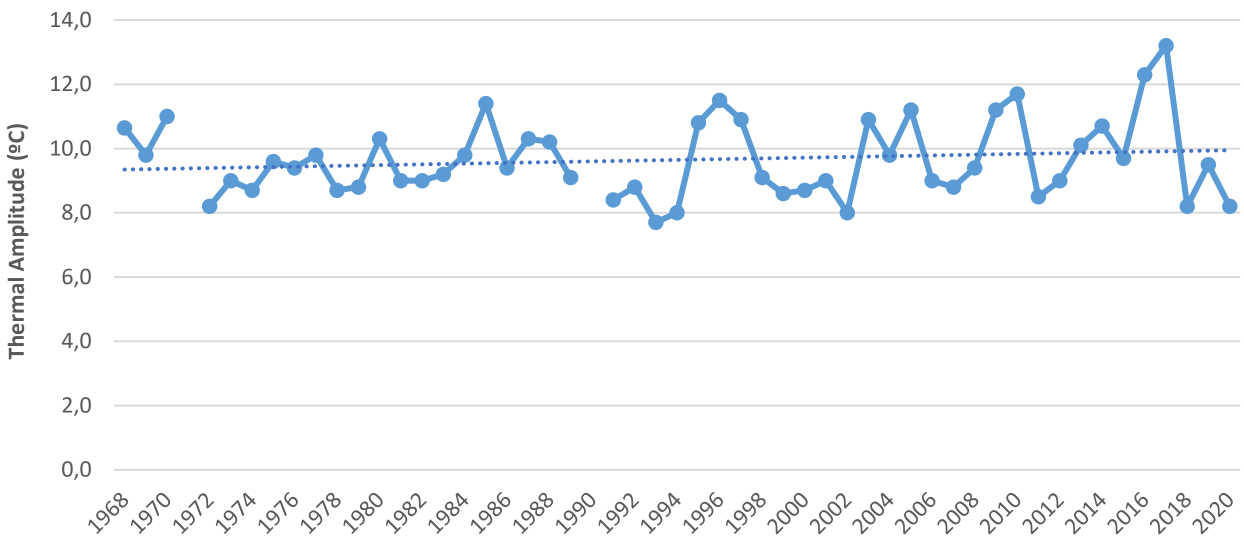


The moving average of the minimum temperature for the first 30 years of the series is 21.2 ºC, the same value presented for the last 30 years of the series. Although these values are the same, the behavioral trend of this variable is one of decrease, as indicated by the moving average.

In accordance with the evaluation, the 30-year moving averages indicate a trend of increasing maximum temperatures and decreasing minimum temperatures. The maximum annual thermal amplitude was calculated for the entire series, seeking to confirm these identified trends.

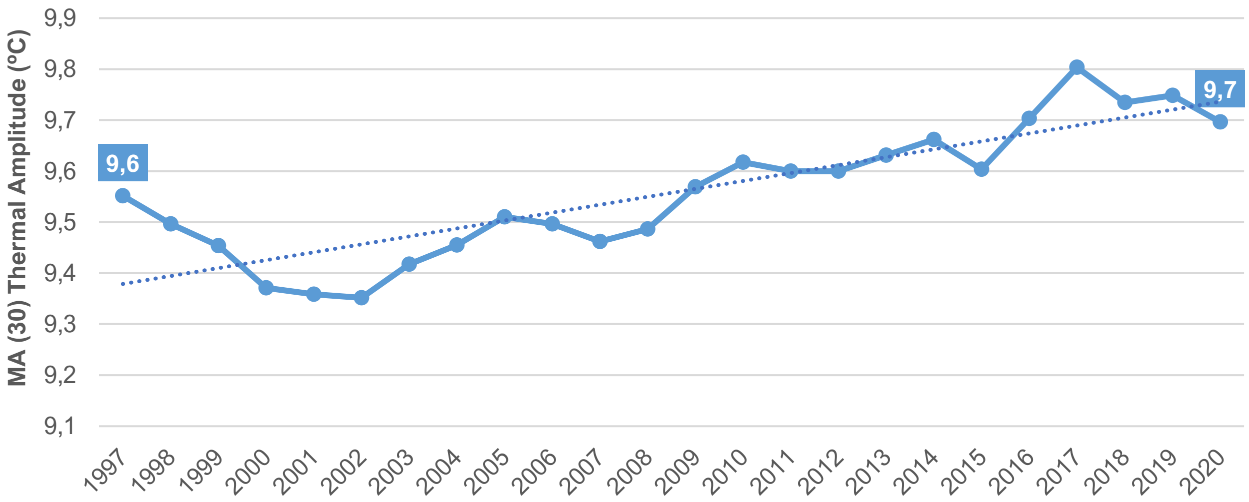
Graph 37 presents the maximum daily thermal amplitude for each year of the historical series.

Graph 37: Maximum thermal amplitude by year (1968–2020)



It can be seen that in the first 30 years of the series, the maximum daily amplitude reaches values above 11 ºC in three years (1970, 1985 and 1996). In the last 30 years of the series, this value is exceeded in six years, being that for the first time, the amplitude reached values of over 12 ºC in 2016 and above 13 ºC in 2017.

Graph 38: Thirty-year moving average of maximum daily thermal amplitude

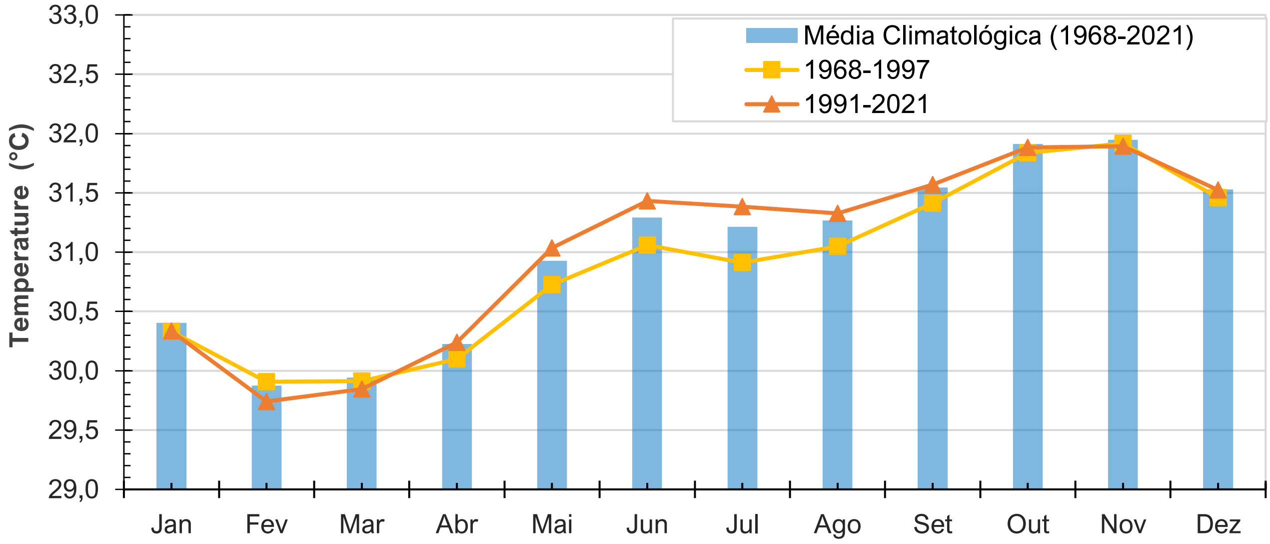


The moving average of the maximum thermal amplitude for the first 30 years of the series is 9.6 °C, and for the last 30 years of the series, the value is 9.7 °C, an increment of 0.1 °C. Even though the trend for the value of this variable is incremental throughout the series, the difference in insignificant.

MONTHLY TEMPERATURE

Graph 39 presents the monthly histogram of temperature for the period of 1968 to 2020, as well as the values for the two climatological normals.

Graph 39: Average monthly temperature (1968–2020) and average monthly precipitation in each climatological normal



It is observed that the highest monthly temperature values occur in the months of October (31.9 ºC) and November (32.0 ºC), followed by September (31.5 ºC) and December (31.5 ºC). The months with the lowest temperatures are February (29.9 ºC) and March (30.0 ºC).

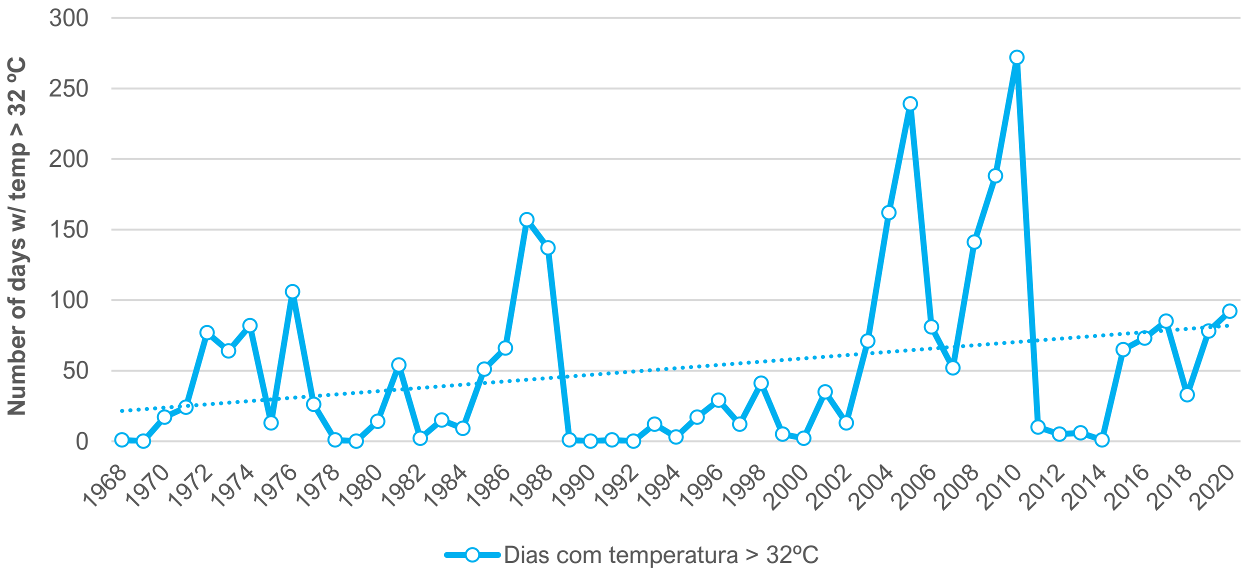
It can be seen that the behavior of the monthly average temperature variable has changed, with an increase in temperature in the values of the 2nd climatological normal for most of the year, with the exception of February and March. The biggest difference between the climatological normals occurs in June and July, with an elevation of 0.4 ºC and 0.5 ºC, respectively while in the months of February and March, the average temperature values of the second climatological normal are 0.2 °C and 0.1 °C lower.

The increase in annual average temperature identified between the two climatological normals (+0.3 °C) translates into a greater increase in monthly temperature in the months from April to September.

DAILY INDICATORS

Graph 40 presents the count of the number of days, per year, in which the maximum temperature exceeded the value of 32 ºC.

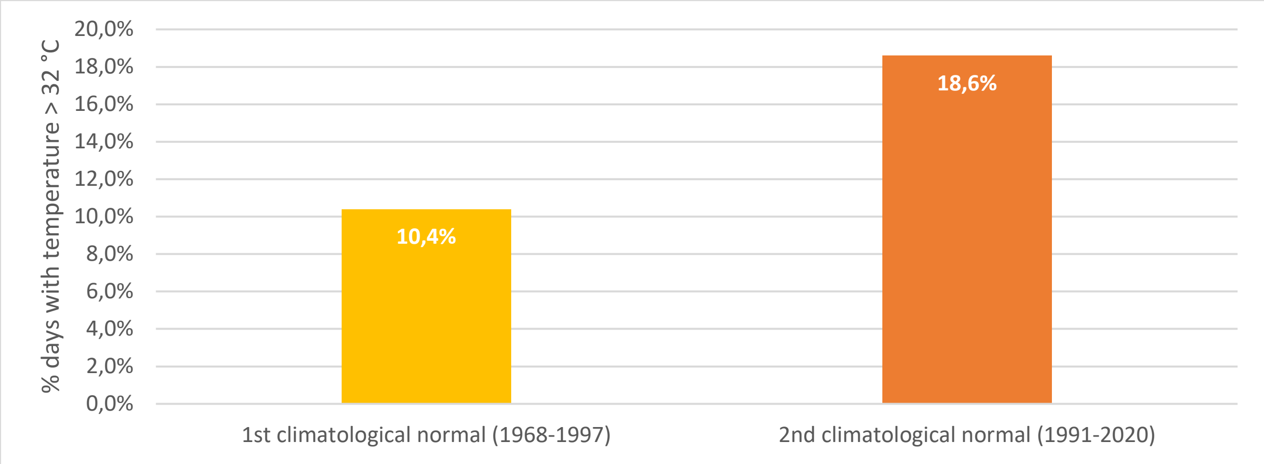
Graph 40: Nº of days in which the maximum temperature exceeded 32 ºC (1968–2020)



In the period defined by the 1st climatological normal, there was only one year (1987) in which the temperature passed the 32 °C mark for more than 150 days, and two years (1976 and 1988) with more than 100 days in which the temperature exceeded this value. In the period of the 2nd climatological normal, there was one year (2010) in which the temperature exceeded 32 °C for more than 250 days, one year (2005) with more than 200 days, and two years (2004 and 2009) with more than 150 days of temperatures above 32 ºC.

With the aim of disregarding the effect of gaps in the historical series of maximum temperature, the percentage of days that exceed 32 ºC in each climatological normal was evaluated, in relation to the monitored days (excluding days in which there are measurement gaps). Graph 41 shows this result.

Graph 41: Percent of days in which the maximum temperature exceeded 32 ºC in each climatological normal



From 1968 to 1997, only 10.4% of the days with temperature measurements passed the 32 °C mark while from 1991 to 2020, the temperature passed 32 °C on about 18.6% of the days with measurements.

EVAPOTRANSPIRATION

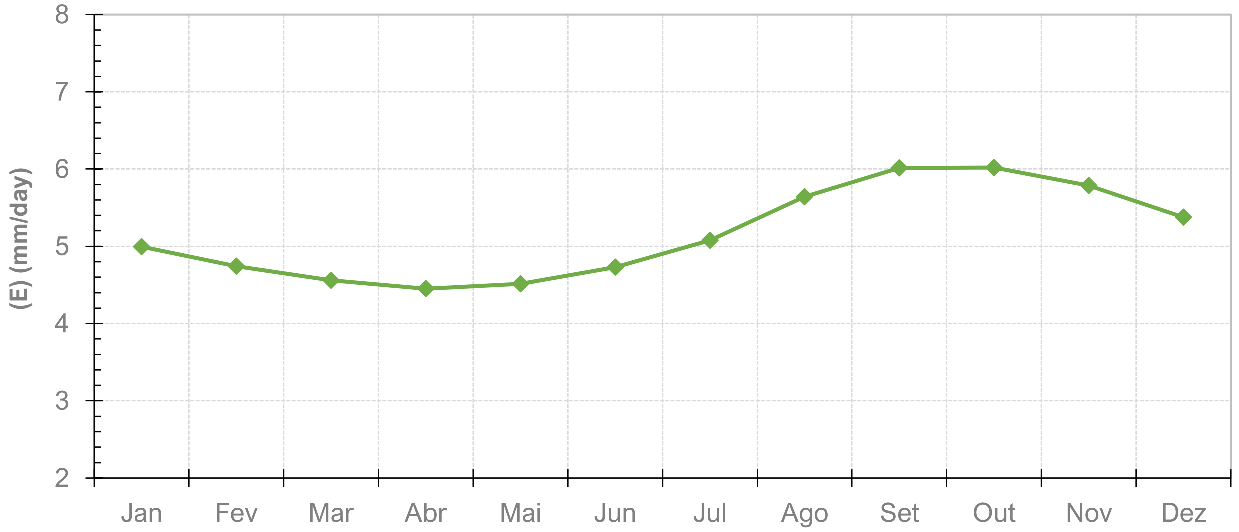
The evapotranspiration (E) data were obtained using the Operational Simplified Surface Energy Balance (SSEBop) model (ANA, 2020) which replicates the reference evapotranspiration associated with alfalfa. According to Allen et al. (1998), grass and alfalfa are well-studied crops in relation to their aerodynamic and surface characteristics, being globally accepted as reference surfaces for evapotranspiration.

Parameterized for operational applications in Brazil, this model provides estimates applying remote sensing techniques to the Brazilian territory (SENAY et al., 2013; ANA, 2020). Although it was developed to subsidize the use of water in the irrigation sector, the estimates are calculated for any target, with applicability in other sectors, as in the assessment of the water balance.

In the SSEBop model, the reference evapotranspiration (alfalfa) is calculated according to the Penman–Monteith equation, standardized by the American Society of Civil Engineers (ASCE) (WALTER et al., 2000), and represents an almost maximum evapotranspiration rate. The SSEBop BR version depicts the spatio-temporal variability of evapotranspiration and presents values consistent with data measured in the field and indirect estimates (ANA, 2020).

Graph 42 presents the average monthly evapotranspiration for the period of 2000 to 2020.

Graph 42: Monthly seasonality of evapotranspiration (2000–2020)



It is observed that the estimated average monthly evapotranspiration oscillates between 4.5 mm/day in the wet season and 6 mm/day in the driest season, as shown in graph 26. Allen et al. (1998) mention that in a humid tropical climate with an average temperature close to 30 °C, the average reference evapotranspiration remains between 5 and 7 mm/day.

WATER BALANCE

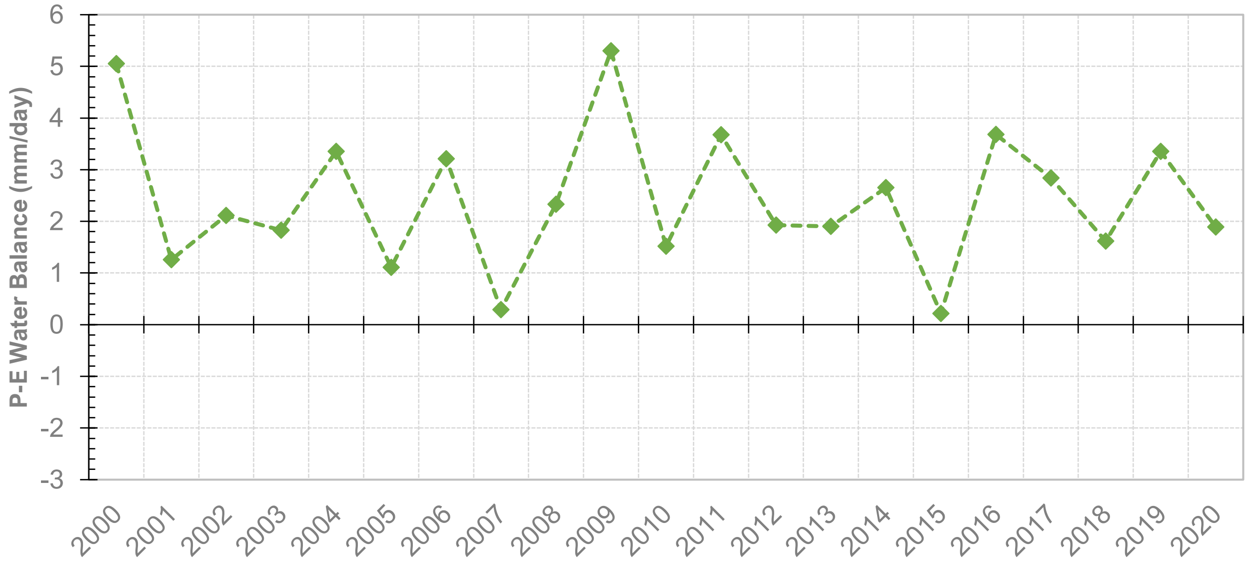
To analyze hydrological changes, the aim is to reproduce the balance between precipitation and evapotranspiration, called the P-E balance, which can signal important characteristics for changes in the patterns of hydrological response.

The P-E balance can be considered an indicator of the surface runoff component in the hydrological process. Negative values indicate a reduction in water surplus. Therefore, studies feeding hydrological models with precipitation projections (P) can indicate changes in the hydrological regime of the basin (CHOU et al., 2017).

ANNUAL BALANCE

Initially, the dashed segment is analyzed in graph 43, in reference to the P-E balance estimated based on data observed in the basin. In the periods 2006–2008 and 2014–2016, this situation triggers an intense reduction of the water surplus in the system (Ilha do Marajó). From the hydrological point of view, this behavior suggests a scenario of greater water reduction preceded by an intense process of reduction of the water surplus in the basin.

Graph 43: Annual P–E water balance (2000–2020).

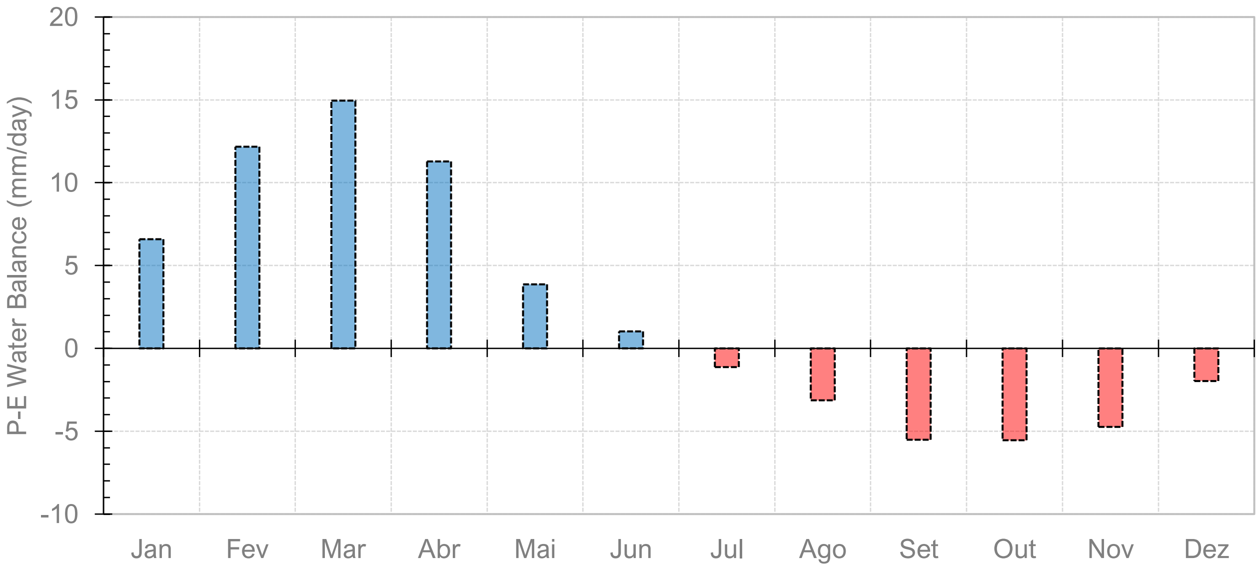


It is verified that, for the entire period analyzed, the P-E balance values were positive, with their values closer to zero in the years 2007 and 2015. These same years had the lowest RAI values since 1984, representing anomalies for dry years.

MONTHLY BALANCE

Although the annual balance remains positive, there may be months in which it is negative, and therefore, the monthly balance was also evaluated. Graph 28 presents the seasonal variability of the P-E balance.

Graph 44: Monthly P–E water balance (2000–2020).



OCCURRENCE OF EXTREME WEATHER EVENTS

The year 2009 can be seen as a typical example of extreme events that are already taking place in the territory. In March 2009, the municipality of Cachoeira do Arari declared a situation of emergency due to the floods caused by the heavy rains that hit the region (PARÁ, 2009). At the end of the same year, there were more than 2 months without records of heavy rains, which resulted in a reduction in the flow of rivers and difficult access to drinking water, especially for riverside populations (GLOBO AMAZÔNIA, 2009).

In Cachoeira do Arari, the drought lasted until the beginning of 2010, registering the worst drought in the last 30 years. The drought caused the loss of herds of cattle, the vegetation withered, and the relocation of families to other municipalities, as they no longer had access to drinking water and the rivers in which they fished had already dried up (JORNAL DA RECORD, 2010).

Graphs 17 and 40 help to reinforce the occurrence of these events. It is possible to notice that in the last 30 years, 2010 was the year with the lowest average monthly precipitation value, and in terms of temperature, 2009 and 2010 are among the years with the longest periods of days with temperatures above 32°C.

In 2017, the municipality of Salvaterra also declared a situation of emergency due to the high risk of river erosion with the influence of waves and tides in the Centro neighborhood and risk of river erosion in the regions of Bairro do Caju, Caldeirão, Porto do Camará and Condeixa community (SALVATERRA , 2017). As seen in graph 11, the annual accumulated precipitation in 2017 was higher than the average calculated for the period of 1968 to 2020.

The municipalities of Soure and Salvaterra were affected in May 2022 by strong winds that roofed houses and felled trees (STAMM, 2022).

OBSERVED CLIMATE CHANGE AND IMPACTS

According to the analysis of historical data from the selected meteorological stations, two central trends in the behavior of the climatic variables of precipitation and temperature for the three municipalities are clear. Regarding precipitation, there is a tendency of a reduction in the volume of annual precipitation, mainly in the rainy season (January to June), and the occurrence of off-season rains, in the dry period (July to December). In relation to temperature, the tendency is for the average and maximum values of this variable to rise in the region.

The reduction of precipitation in the region corroborates with the reduction of the flow of the rivers that flow in the interior of the archipelago and dump their waters in the bay of Marajó. This effect, added to the rise in sea level in future scenarios, may contribute to the advance of sea waters towards the interior of the island, triggering a greater risk of salinization of soils and waters close to the coastal region. This effect is more pronounced for the municipalities of Soure and Salvaterra, which have greater influence from the Atlantic Ocean. Soil salinization can lead to productive losses for agricultural crops in the region, such as açaí. This type of impact is already felt by communities living in the region of the Bailique archipelago, in Amapá, at the mouth of the Amazon River, about 250 km away from the municipalities studied.

According to reports by residents of the Quilombola community of Caldeirão, during the second semester, the dry period, the inflow of the tide is perceived in the daily life of the community, as residents need to go further in to get better quality water. That effect could be amplified due to the strong reduction of precipitation in the Araguaia-Tocantins river basin (Chou et al., 2014), one of the most important contributors for the estuary.

According to the reports collected in the field during the visit, the analysis regarding the behavior of precipitation and temperature are confirmed. According to some residents of the communities visited, the reduction in the amount of precipitation in recent years is noticeable. Mr Fabiano, resident in the community of Pau Furado in Salvaterra, with diversified plantations on his property, reported that in recent years he has felt the need to irrigate crops, due to the reduction in annual rainfall.

Since the year 2000, annual precipitation has been characterized by the predominance of drier years, as shown by the rainfall anomaly index, in graph 9. According to the data, the years 2007, 2015, 2018 and 2020 were much drier than would be reasonable, according to the historical series data. The year 2020 was cited by some interviewees in the field visit as a drier year, with less precipitation.

Despite the reduction in the annual amount of precipitation, it can be seen that extreme precipitation events have not been reduced in the same proportion. In fact, according to the analysis of graphs 13 and 14, the most intense daily rainfall has been markedly intense in the most recent period. For example, the most intense rainfall recorded in a single day at the Soure station was in 2009, with a rainfall of 256 mm. By comparison, this intensity of precipitation in a single day is similar to what happened recently in Petrópolis, Rio de Janeiro, causing irreparable damage. In the same year of 2009, there are records of the occurrence of two other events with precipitation above 150 mm. In the years 2013 and 2017 there were also two days each year with rainfall above 150 mm.

Some potential impacts on agricultural production in the target communities are highlighted. During the sowing period, for example, excessive rainfall can delay the entire production and even make certain crops unfeasible. Also, the harvest can be compromised during this period, directly affecting the quality of the products. Indirect factors also include the agricultural production chain. Excessive rain and prolonged periods with overcast sun reduce the light reaching the plants, which impacts crops that need more sun. Heavy and excessive rains can cause flooding and make access impossible, which impairs the transport of food and increases expenses. In addition, damage to storage locations can also compromise products. Rural infrastructure can be severely compromised after storms, delaying or making cultural treatment activities unfeasible. In rural areas, intense rainfall is of great importance, since its intensity is an expressive factor in the process of soil erosion.

Regarding temperature variations, several reports were heard about communities witnessing higher temperatures. For example, in the community of Caldeirão, in Salvaterra, community residents reported that in the past it was common for work in the fields to take place from 7:00 am or 8:00 am to 12:00 pm or 1:00 pm. However, due to the sensation of higher temperature in recent years, work on the farm is not taking place after 11:00 am due to the difficulty of withstanding the heat at this time. Representatives of CAFAS (Salvaterra Family Farmers Cooperative) also reported the occurrence of heavy rainfall out of season (October, November and December) and increased thermal sensation throughout the year.

Although not the focus of the study, another example seen in the field, which confirms the trend of rising temperatures, is from a dairy farmer in the municipality of Soure, who reported that a greater number of buffalo abortions in the months of November and December would be indicative of higher values of thermal sensation, and that a regular increase in temperature can affect production as a whole.

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ANNEX — Interviewed actors

Municipality	Category	Entity/Location	Interview format
Belém	Civil Society Organization	Peabirú Institute	Remote
Belém	Civil Society Organization	Institute of Forest Development and Biodiversity (IDEFLOR-BIO)	In person
Belém	Civil Society Organization	Institute of Forest Development and Biodiversity (IDEFLOR-BIO)	In person
Belém	Research	Federal University of Pará	In person
Belém	Research	Federal University of Pará	In person
Soure	Civil Society	Association of Artisanal Fishers	In person
Soure	Public Authority	Chico Mendes Institute for Biodiversity Conservation (ICMBio)	In person
Soure	Civil Society	Mata Fome Community	In person
Soure	Public Authority	Municipal Secretariat for the Environment (SEMMA)	In person
Soure	Civil Society	Barra Velha Community	In person

Soure	Civil Society	Association of users of the Marine Extractive Reserve of Soure (ASSUREMAS)	In person

Municipality	Category	Entity/Location	Interview format
Soure	Civil Society	Cheese Factory	In person
Soure	Public Authority	EMATER-PARÁ Soure Regional Office	Remote and in person
Soure	Civil Society	Pedral Residents' Association	In person
Soure	Civil Society	-	In person
Soure	Civil Society	Mironga Farm	In person
Salvaterra	Public Authority	EMATER-PARÁ Salvaterra Regional Office	Remote
Salvaterra	Public Authority	Municipal Secretariat for the Environment	In person
Salvaterra	Public Authority	Municipal Secretariat for the Environment	In person
Salvaterra	Civil Society	Farmers and Family Farmers of Salvaterra Cooperative	In person
Salvaterra	Civil Society	Pau Furado Community	In person

Salvaterra	Civil Society	Bacabal Community	In person
Cachoeira do Arari	Public Authority	EMATER – PARÁ Cachoeira do Arari Regional Office	In person
Salvaterra	Civil Society Organization	State Coordination of Associations of Remaining Quilombo Communities of Pará (MALUNGU)	Remote and in person

ANNEX — Interview script

The interview script followed a semi-structured format, which uses a list of previously prepared questions that can be complemented by follow-up questions that arise during the dialogue. This type of interview can make information emerge more freely, and the answers are not conditioned to a standardization of alternatives. The full script can be found below.

General questions for all interviewees
Specific questions for the public authority

1	From your observation, do the municipalities (Soure, Salvaterra and Cachoeira do Arari) already suffer any impact from climate change? If so, what would these impacts be? *
2	* *alternatively, if the interviewee doesn't know what climate change is*: Do you perceive any change in floods, low water, the tides or the rains (a change in the time they occur, a higher or lower volume, bigger flood, etc.)?
3	Are there specific regions in these municipalities in which the climatic impacts are more representative or recurring?
4	Would you point out any specific year in which these impacts due to climatic alterations were more noticeable? *(E.g., occurrence of disasters, production loss, etc.)*
5	Which communities and/or locations have suffered or benefited more as a result of these impacts?

6	What are the principle agricultural activities developed in the region of Soure, Salvaterra and Cachoeira do Arari?
7	Which of these activities are predominant in family farming? Where are these producers located?
8	How are the productive activities divided between men and women in the family? *(E.g., Preparation of cultivation, harvest, storage, commercialization, etc.)*
9	How do these producers work with the market? *(Does commercialization of products only occur in the archipelago? Can they access outside markets?)*
10	Have there been changes to the agricultural production process in recent years because of climate change?
11	Was there migration to new economic activities (e.g., tourism) or even to other municipalities because they were no longer able to produce?
12	In your opinion, what strategies could be adopted in the production process that could minimize these impacts?
13	How do you evaluate, at this moment, the municipality's position on these issues? What actions are being taken to mitigate and adapt the territory to the effects of climate change?
14	Are there investments that you relate to climate change adaptation planned for the 2022–2025 Municipal multi-year plan?
15	Are there actions, projects and guidelines in the current Master Plan that you relate to climate change adaptation?
16	Is there a Risk Map or Contingency Plan in the Municipality?
17	Are there any recommendations, suggestions or aspects you would like to report in this interview that we have not addressed?
18	Would you like to indicate someone who has knowledge about the topics in question and can contribute with new information?

ANNEX — Remote Interviews

The selection of actors was made in order to explore the various representations of the object of study in order to expand the comprehension of the theme. From an internet search, public authorities, civil society, academia and civil society organizations were listed by municipality. Of these, those who were closest to the topic of the present study and who could provide us with a broad view of the territories were selected for a first round of conversation.

The first round of interviews took place remotely between the 23rd and 25th of February, 2022, through Google Meet, and the following actors were invited: Orlando Sauma Lameira, Local Head of the EMATER-PARÁ Salvaterra Regional Office; Fernando da Conceição de Moura, Local Head of the EMATER-PARÁ Soure Regional Office; Thiara Fernandes, Coordinator of Technical Assistance and Rural Communication of the Peabirú Institute; and Raimundo Hilário, Regional Coordinator of the State Coordination of Associations of Remaining Quilombo Communities in Pará — MALUNGU.

At the end of the interview, each participant was asked to refer other individuals that they considered to be relevant to the subject. Such referrals contributed to the elaboration of the technical visit script, at which time a second round of conversations was held, this time in person.

When asked about the effects of climate change on the municipalities, respondents reported a change in the rainfall cycle, which became more intense and irregular, accompanied by an increase in temperature. In addition, some regions already suffer from the process of surface and groundwater salinization.

Changes in the productive activities of farmers, extractivists and fishers are also perceptible. It has been difficult for family farmers to plan their planting and harvesting activities, which interferes with the agricultural calendar that had been adopted. The emergence of pests in pineapple crops, changes in the taste of açaí, reduction of fish and native fruits such as bacaba and bacuri were also mentioned. However, it is still not possible to say that these changes have a direct and exclusive relationship with the effects of climate change. The adoption of inadequate management techniques for the species planted as well as overfishing may also have contributed to this scenario.

Regarding the existence of agroforestry systems in the municipalities, all interviewees stated that there were few initiatives. Cultural aspects were mentioned as reasons for this beginning, as is the case, for example, of communities with more of a fishing profile in the municipality of Soure, as well as physical and geographical aspects. Another cause mentioned is related to the way the population raises livestock, which is extensive and does not use fences. This modality demands the use of large areas, which makes it difficult to manage the species for agriculture and agroforestry systems (AFS). Despite these limitations, it was reported that the quilombolo communities in Salvaterra have some familiarity with the AFSs, as they already practice intercropping.

ANNEX — Field Report

The Marajó Project, object of cooperation between H_2O Company and ITA, comprises the analysis of vulnerability of municipalities in the south-eastern portion of the Marajó Archipelago (Soure, Salvaterra and Cachoeira do Arari) in the face of climate change. This analysis, although it is based on data and secondary information from historical series and climate projections, involves a field research, to know the local reality and the modus vivendi of traditional communities and population, in the light of their susceptibility to changes in patterns and increased frequency of extreme events.

The field visit was carried out between March 6th and 17th, 2022 and had prior preparation, through online interviews with key actors, meetings with institutions related to the topic, visits to communities with potential for climate vulnerability and inspections in localities. with markings and records associated with climate change.

The report is presented in chronological order of the field research, which started in Belém. On 03/08/2022 the team docked in Soure, with later passages through Salvaterra (03/11 to 03/14) and Cachoeira do Arari (03/15 to 03/16), returning to Belém on 03/17/2022.

<u>Technical Team:</u>

Dener Ghenov – H_2O Company

Meiriane Lopes – ITA

Osvaldo Stella – H_2O Company

Shaji Maliekal – Fundação Avina

Wilson Cabral - ITA

Institute for Forestry Development and Biodiversity of the State of Pará (IDEFLOR), 07/03/2022, Belém/PA

Vicente Neto (Director) and Daniel Frances (Technician)

https://ideflorbio.pa.gov.br/

- The Institute works with Agroforestry Systems (AFS) and sustainable production and has, among its target audience, traditional communities and family farming, acting on demand and also with goals related to restoration with the possibility of economic use.

- They focus on the production and distribution of seedlings, but without a team to support the development and implementation of AFS.

- They identify the importance of fishing and marine extractivism in the municipalities of Soure and Cachoeira do Arari.

- About the Marajó Environmental Protection Area: https://ideflorbio.pa.gov.br/unidades-conservacao/area-de-protecao-ambiental-do-marajo#topo

- Açaí varieties: research has adapted açaí to the terra firme ("pai d'égua" variety), which can be exploited in SAF. Emater de Breves/PA has an initiative in Cachoeira do Arari (Indication: Paulo Lobato and Márcio Nagaishi). Contact with the Agricultural School of Salvaterra was also indicated.

- Project "*Manejaí*" and implementation conditions for analysis of climate adaptation strategies. https://www.br.undp.org/content/brazil/pt/home/presscenter/articles/2020/manejai--ha-um-ano-fazendo-a-diferenca-na-vida-dos-produtores-de.html

- The Reference Center for Management of Native Açaizais of Marajó, MANEJAÍ, began to support the Project "*Bem Diverso*" (https://bemdiverso.org.br/), in Pará, with the objective of stimulating sustainability and biodiversity in fruit production processes, ensuring the ways of life of traditional communities and family farmers, in addition to generating income and improving the quality of life of forest peoples.

- The Project "*Bem Diverso*" is the result of the partnership between the Brazilian Agricultural Research Company (EMBRAPA), the United Nations Development Program (UNDP) and the World Fund for the Environment (WFE). The contact for the "Bem Diverso" in Marajó is at EMBRAPA Oriental: Raimundo Nonato Teixeira:raimundo.teixeira@embrapa.br

- They reported the possibility of requesting the territorial base of the study municipalities with the Land Institute of Pará (ITERPA) and the base of fishing communities with the State Secretariat for Agricultural and Fisheries Development (SEDAP).

Federal University of Pará - UFPA, 07/03/2022
Henrique Cattanio
Julia Cohen

- Indication of work developed by UFPA research groups, focusing on climate change and vulnerability, including parts of the Marajó archipelago:

    - Productive and socio-environmental characteristics of Family agriculture in Salvaterra/PA (2021)
    http://bdta.ufra.edu.br/jspui/handle/123456789/2022

    - Geoenvironmental Zoning from the Conservation Units: subsidies for the Integrated Management of the Coastal Zone of Pará - Brazil (2019)
    https://periodicos.ufpe.br/revistas/rbgfe/article/viewFile/245075/37231

    - The quality of groundwater in the city of Salvaterra, Marajó - Pará (2017)
    http://repositorio.ufpa.br/handle/2011/10756

    - Vulnerability and climate change: socio-environmental analysis in an Amazon mesoregion (2017)
    https://www.scielo.br/j/ambiagua/a/9sY7KbQMthVXCNZt5jVqrGR/abstract/?lang=pt

    - Relative sea-level and climatic changes in the Amazon littoral during the last 500 years (2015)
    https://www.sciencedirect.com/science/article/abs/pii/S0341816215300485

    - Socioenvironmental Vulnerability to Climate Change: Conditions of Coastal Municipalities in the State of Pará.
    https://www.scielo.br/j/asoc/a/WySQfWfSBLLnFjxwZcbCZXh/?format=pdf&lang=pt

    - Environmental Vulnerability of the Coastal Edge of the Municipality of Salvaterra, Ilha de Marajó-PA, in the Stretch Between the Foz do Rio Paracauari and Ponta do Tapariuaçu.
    https://periodicos.ufpe.br/revistas/rbgfe/article/view/232663/26676

Vila do Pesqueiro and Vila do Céu communities – Soure, 08/03/2022
Lisângela (ICMBio) and Community.

Visit to Vila do Pesqueiro and surroundings, places where susceptibility to tidal variations and influences of solid discharge levels and coastal hydrodynamics on the morphology of beaches and mangroves can be seen (Figure 1).


Figure 1. Changes in the beach environment in Vila do Pesqueiro – Soure/PA – 03/08/2022. Image: Wilson Cabral.

The community has been instructed to carry out the replanting of sand dunes, from the seeds brought by the river itself, so that they serve as a barrier to the advance of the waters. (Figure 2)

Figure 2. Vegetated sand dunes to serve as a barrier to the advance of river waters – 03/08/2022. Image: Dener Ghenov.

Visit, by boat, to the community of Céu, with access via the creek in mangrove and teso environments (firm land) and return via the beach. Register of sites prone to investment in climate mitigation and adaptation (Figure 3).

Figure 3. Changes in the beach environment in the Céu Community – Soure/PA – 03/08/2022. Image: Wilson Cabral.

In a meeting with the community (President of the Fishermen's Association and other community members), the following aspects that may be related to climate change were mentioned:

- Disappearance of species such as Xaréu and Mullet in fisheries, while others currently predominate, such as Pratiqueira, Tambaqui and Tucunaré;
- Changes in the dynamics of beaches have led to the need to relocate houses (Figure 4).

Figure 4. House with demand for shoring or relocation in Vila do Pesqueiro, Soure/PA – 03/08/2022. Image: Wilson Cabral.

The main activities in the community were mentioned, in which all families are related to fishing. There are also a few shrimp harvesters, and this activity is an alternative during the fishing season. There is also crab catching activity, although limited to a few families.

In the community of Pesqueiro there are about 120 families, with approximately 367 people. The dynamics alternate between the city, during the closed season, and the RESEX, when fishing is allowed. RESEX is a source of food resilience, as well as extra income at certain times of the year (andiroba seed oil, coconut, açaí, etc.).

The community participates in community savings and income projects for women, led by the NGO Rare (Bruna Martins, Monique and Henrique) and in participatory monitoring of species such as manatees, dolphins and turtles, coordinated by the Bixo D'água initiative.

Inside the RESEX are located three communities: Pesqueiro, Céu and Caju Una. RESEX has a Management Plan.
(https://www.icmbio.gov.br/portal/images/stories/plano-de-manejo/plano_de_manejo_resex_marinha_de_soure_v19.pdf).

According to the community members, it is difficult to isolate which impacts are directly linked to climate change and which result from other vectors of environmental degradation such as industrial fishing and fishing during the closed season.

The composition of community income is dependent on social programs and other public incentives such as closed-season insurance.

Interesting point: The Pesqueiro community organized a closure of access to the area in the first 6 months of COVID-19 (March to September/2019), in addition to controlling access after this period. As a result, the community has only had 5 confirmed cases (one family) and has not recorded any serious cases of the disease. The communities of Céu and Caju Una, further away, also remained closed during most of the pandemic period, ensuring that there were no cases.

Small property with AFS, Soure/PA

Lisângela and Iashi

The property visited is an example of environmental transformation. Flanked by the city dump, the property has a slate extraction ditch, in addition to soils impacted by traditional activities in the past. The couple has been carrying out a process of recovering the area with Agroforestry Systems (AFS) for three years (Figure 5), in addition to applying permaculture techniques (Figure 6). The transformation of the area is already clearly perceptible.

Figure 5. SAF in a small property, Soure/PA – 03/08/2022. Image: Wilson Cabral.

During the visit, it was possible to observe in the field a successful experience of the implementation of SAF's and their potential to increase the climate resilience of the environment and communities as well. On the other hand, it is also possible to observe that the implementation of complex systems requires a lot of training and also a vocation for the implementation and conduction of these systems. Once these barriers have been overcome, it is necessary to define a market strategy to connect production systems to the market. Diverse systems imply a greater diversity of products to be commercialized and, consequently, a more complex chain to be implemented and managed.

Figure 6. Chicken coop built with natural materials, Soure/PA – 03/08/2022. Image: Dener Ghenov.

Mata Fome beach, Soure/PA, 09/03/2022

Mr Edevaldo

As reported by Mr. Edevaldo, the place is called that because it was a beach with corrals (fishing) and tents. 25 years ago, the beach was covered and the stream changed its course, forming a mangrove, which protected banks and ravines (Figure 7).

Figure 7. Altered area in Mata Fome, Soure/PA – 03/09/2022. Image: Wilson Cabral.

Inhabited by fishermen who fish all year round (in Defeso, they go out to fish). In addition to fishing, they extract turu, shrimp and crab. Mr. Edevaldo notes a change in the amount of fish (reduction) which he associates with pollution (plastic bags). Also note the reduction in rainfall, especially in recent years.

Here again, one notes the complexity of isolating the impacts resulting from climate change from those arising from pollution, overfishing, etc.

Next to Mata Fome beach is located the Soure Lighthouse, where the Paracauari River flows into Marajó Bay. It was reported that this is a region that suffers from the advance of the waters on the mainland. The erosion of the banks in this region is noticeable, and it almost reaches the Lighthouse (Figure 8).


Figure 8. Altered area near the Lighthouse of Soure and Mata Fome beach, Soure/PA – 03/09/2022. Image: Dener Ghenov.

SEMMA – Soure/PA, 09/03/2022

Municipal Secretary of the Environment

SEMMA has maps of risk areas for landslides and floods prepared by CPRM in 2018. The studies were prepared in conjunction with the State Civil Defense. In the municipality, the official João Henrique (Secretary of Administration) would have accompanied the studies.

There are records of ancient occupation in Araruna, which suffered from erosion and sea advance, reported over 50 years ago. There was an eviction of the area about 20 years ago, as it was considered a risk area, with migrations to what are now the neighborhoods of Mirizal/Pacoval and Barra Velha. The latter also underwent changes in the morphology of the beach, causing traders to move their tents to more sheltered locations.

The municipality is the focus of public policies regarding coastal management, as is the case with the Orla project and the state policy on Coastal Management, although there do not seem to be enough elements to contain more recent occupations on the coast, in areas of potential vulnerability, as in the case of the Alegria communities. and Sossego (around 150 families installed in the last 10 years). The occupied region suffers from landslides and is under the influence of the flow and tide regime. The Administration Department has information about communities in the municipality.

Some specific studies are being carried out in the municipality, on the initiative of research institutions and other non-governmental institutions. This is the case of studies by the NAEA/UFPA on the variation in shrimp size with increasing water temperature. A work by Emater (Sandro) accompanied by shrimp farmer Nilson Cardoso led to improvements in the gear for artisanal shrimp (matapi) fishing. And the NGO Bixo D'água monitors mammals and turtles in the region.

Barra Velha Community – Soure/PA – 09/03/2022

Mr. Jorge

Fisherman and stallholder born in the old community of Araruna, Mr. Jorge tells the story of the changes on the beaches, with the consequent migration of communities and commerce to other points (Barra Velha, Figure 6). And also the most recent move to the new location of the tents. He currently maintains sporadic fishing and operates the tent full time. It was also reported that the waters advance every year.

Figure 6. Mangrove areas in Barra Velha beach, in transformation. Soure/PA - 03/09/2022. Image: Wilson Cabral.

Figure 7. Mangrove areas at Barra Velha beach, in transformation. Soure/PA - 03/09/2022. Image: Dener Ghenov.

Users' Association of the De Soure Marine Extractive Reserve (ASSUREMAS), Soure/PA – 09/03/2022

Sr. Paulo – President

Mr Paulo commented on a study by UERJ, carried out in 2017, which collected data on tidal levels and mangrove heights, for the purposes of climate change analysis, in which he participated. In later research, the Costa Norte project was identified, whose main objective is to determine the vulnerability, sensitivity and susceptibility to oil contamination of mangroves located in the Foz do Amazonas and Pará-Maranhão Basins, in the Brazilian Equatorial Margin, from the development of a computer simulation environment. From the point of view of biological resources, information was collected from the environments in situ and remotely. (http://projetocostanorte.eco.br/#apresentacao)

In addition, he was also part of the support team of the project Network for Monitoring Reproductive Walks of Crabs (REMAR), through participatory monitoring. REMAR is a network of researchers who study the occurrence of the reproductive gaits of crabs, object of local extractivism. Through this project, the reproduction period of crabs in the region was updated.

An initiative sent by the NGO RARE, with support from the “Fundo Casa”, was reported for studies on the perception of the local population about climate change.

Currently, the association has 1,500 registered residents and has been approached by companies seeking to establish carbon credit commercialization projects (see CarbonNext), although there are land conflicts in the RESEX. This event deserves to be noted since the maintenance of forests and mangroves in the RESEX is a fundamental element of the system's resilience and it was possible to observe the need for support to the communities and also to ICMBIO to deal more adequately with this issue.

Cheese factory “PÉUA”, Soure/PA – 09/03/2022

Haroldo “Péua”

The family has been producing cheese for 4 generations, the last one for the artisanal production of Búfala do Marajó Cheese (Figure 8). Although it has reached higher production in the past, it currently works with a small amount of cheese (10 to 12 kg/day). Its cheese has already received national and international awards.

Figure 8. Tricycle used to transport buffalo cheese from the Péua cheese factory. Soure/PA - 03/09/2022. Image: Dener Ghenov.

Mr Haroldo associates with the IG seal - Geographical Identity (a milestone reached in 2017) some problems with bureaucracy and certification that are incompatible with small artisanal production. He reported that the implementation of the GI for Marajó cheese mainly favored large producers, and made it difficult for medium and small producers to adapt. The activity has 4 months of high productivity (winter) and 8 months of low productivity (summer), with a strong seasonal outline. According to the producer, there are about 20 artisanal Marajó cheese producers in the municipality, including small, medium and large.

The producer notes a reduction in rainfall in the winter and an increase in temperature in the summer in recent years (the abortion of buffaloes in the months of Nov-Dec would be an indication of this change in temperature). Overall, he sees a reduction in extremes in the last 10 years (less rain in winter), which he sees as favorable to his business. He believes that a regular rise in temperature can affect production as a whole.

From the story of Mr. Haroldo, it is possible to observe that there is a process of transformation in the production chain of milk and dairy products in the municipality. There is potential for the implementation of AFS, mainly in the model of integrated livestock-forestry (ILF), linked to dairy production, for this it would be interesting to have a clearer view of how this chain works in the region.

Technical Assistance and Rural Extension Company (EMATER), Soure – 10/03/2022

Fernando (technician)

The municipality has large landowners, with areas varying on average between 400 and 800 hectares, with a few properties reaching more than 2,000 hectares, dedicated to extensive buffalo cattle ranching, predominantly focused on meat production. A small portion is dedicated to dairy production, which supplies the small cheese industry in Marajó.

According to the technician, pressure from the Ministry of Labor in 2008/09 on slave labor in the region would have resulted in an increase in unemployment, with a consequent increase in the irregular occupation of land in the municipality. He mentions the emergence of the communities of Sossego and Alegria as a result of this process. Such communities are found in areas susceptible to landslides (river bank) and flooding. Most of its residents are registered as fishermen and work for subsistence.

Pedral Community – Soure, 10/03/2022

Mr. Jorge and leaders of the Pedral Residents Association (men and women)

The community of Pedral, which occupies a strip of land in the northern portion of the municipality, between the highway and the edges of the RESEX, brings together residents with a profile for the implementation of AFS, as a resilience and food security strategy.

About 82 families live in the community, all registered with the Federal Government's social programs, in addition to having been the object of projects such as the Pedagogical Social Gardens (Projects for Socio-Productive Inclusion of the Banco do Brasil Foundation, Figure 9), and Saving’s Club (“Pesca para Sempre” Project, carried out by the organizations RARE and Fish Forever) – these projects, although not fully operational, seem to have generated some learning and are mentioned by the community as initiatives with the potential for continuity after adaptation to the local reality. The association was recently sworn in after election by the community.

Figure 9. Community vegetable garden at the Pedral Residents Association, Soure/PA - 03/10/2022. Image: Wilson Cabral.

The properties have around 1 hectare on average and there are some unoccupied areas that could be used for some type of system for collective use. The area experiences sporadic flooding in winter.

Families live predominantly from the capture and sale of crabs, an activity that involves the whole family: men and some women collect, and women process, when sold processed. The sale is made to middlemen. They also capture shrimp, in addition to extracting forest products for their own consumption and sale of surpluses, such as açaí, bacuri and tucumã oil (beetle larvae that infect tucumã coconuts when they fall on the ground).

The implementation of the community garden is a good example of a good idea implemented in the wrong way, without planning with the community.

It was the community themselves who implemented the project and, according to the report, they themselves worked for many days without pay. The project location was also not a consensus among the group members, not even the structure that was implemented. That is, there was no preparatory work prior to the execution of the project, which caused several frictions between the project beneficiaries themselves.

Another issue that is evident is the need for a plan and management of the system, that is, how the system should be managed on a daily basis by the community. Finally, there is no production and marketing plan that could define what should be grown and how these products could be marketed, thus, an individual production model can be more successful, leaving the community organization more focused on the commercialization of products.

Small producer (20 ha), Soure – 10/03/2022

Mr. Álvaro Carrara

There is a range of small producers in the municipality, which seeks to diversify activities for their maintenance. These are small properties, generally smaller than the local fiscal module (65 ha). This is the case of Forestry Engineer Álvaro Carrara. On his farm, he already practices production in an Agroforestry System, with intercropping of fruit and non-timber species (açaí, cupuaçu, taperebá, bacuri). This producer has explored the production with greater added value, through pulps, jellies and other forms. The processing has in energy a factor of concern, since it requires storage of perishable products, and according to the report, there is some instability in the energy supply in the region.

As well as this small producer, there are a series of others, with properties characteristic of family farming, which are not properly recognized in the economic activity of the municipality. An example is the small properties around the RESEX, associated with the extraction of coconut and açaí.

It is necessary to differentiate the adaptability of these different profiles of producers and owners in relation to climate change.

Here we had another example where a greater plan for adding value and commercialization of extractive products and family farming would be necessary. Even having technical knowledge, land and inputs, there is great difficulty in defining a business model and access to markets. This development is quite complex if done individually, but it can be a great vector of development if implemented regionally, connecting the various communities and their products to the consumer market in a structured way.

Mironga Farm, Soure/PA – 10/03/2022

Carlos Augusto, “Tonga”

Mironga Farm is an 80-hectare property dedicated to buffalo breeding, Marajó Cheese production and rural tourism associated with the theme. The farm can be considered a reference in terms of use and occupation. With a relatively small area, the property has about 240 heads (3 animals/hectare), in a pasture management system (napier and elephant grasses, exotic). The property has areas in mangroves, sandbanks and firm áreas for planting (tesos) and has a clonal garden with fruit species. Currently, rural tourism, based around the buffalo culture, represents 50% of the property's income.

This farm can be considered a good example of integration of livestock with other agricultural activities, even though no organization was planned in the ICLFS (Integrated Crop-Livestock-Forestry Systems). Farms of this size can serve as a basis for implementing ILPF's (Lavoura, Livestock and Forest Integration), this type of system is the agroforestry system that has the largest area implemented in Brazil, but still does not have a model adapted to the region. The development of systems adapted to climatic conditions and local diversity can be important in increasing climate resilience in the region.

SEMMA, Salvaterra/PA – 11/03/2022

Municipal Secretary of the Environment

Maria Lucineide Correa – Secretary

Gabriela – Environmental technique

The municipality was charged by the Public Ministry about initiatives to adapt to climate change, but it does not have the technical capacity to respond. The main problem identified, which can be associated with the theme, is the burning of organic material on the properties, in addition to the use of fire in gardens (This activity also occurs in the pineapple crop, predominant in the municipality, and whose licensing is waived, making control difficult). There are records of large fires started from the occasional burning of waste.

Another problem raised is associated with the extraction of sand and gravel on beaches and coastal regions, carried out irregularly and with low control capacity by the municipality. Such activity even involves the removal of sand on the banks of the rivers, causing small landslides and silting.

Recently, rice production activity was started in the municipality, in an area of approximately 2,000 hectares. Such activity is a matter of concern, as it has no regulation and uses a large amount of water and use of pesticides with potential environmental impact.

There are communities that suffer from periodic flooding. This is the case of the Passagem Grande community. Such situations can worsen due to extreme events.

The municipality's "Plano Diretor" needs to be updated and there is no mention of climate change. Neither does SEMMA have an updated mapping of the municipality.

Considering the 3 municipalities visited, Salvaterra would be the one with the most suitable profile for the implementation of small AFS's, due to the abundance of small rural producers and also the availability of land on the properties.

Perhaps, in terms of adapting to climate change, the most urgent project would be to adapt the issue of solid waste management. The practice of burning waste added to the increase in droughts exposes a high risk environment to fires, which already puts some production systems at risk.

Salvaterra Family Agriculture Cooperative - CAFAS, Salvaterra/PA – 11/03/2022

Cooperative leaders

The cooperative started from the initiative of the Federal Rural University of the Amazon (UFRA), in 2011/12, when training courses were given in community hours and the registration process of the National Register of Legal Entities (CNPJ) was formalized. Initially, the program involved 50 families. The activity lasted a few years and was paralyzed for a period, having been resumed 5 years ago, by 21 families, from an order made to one of the former cooperative members (800 kg of fruit pulp). The joining of these cooperative members to meet the request made them come together again and start the process of regularization of the entity and collective production.

Since then, the women at the head of the initiative (they are predominant in the cooperative) started to organize themselves to raise funds in projects and participate in bids for the National School Feeding Program (PNAE). With resources from projects from the Pará Development Agency – ADEPARÁ, they equipped the fruit processing environment and today have the capacity for extraction and storage (Figure 10).

Figure 10. Conversation circle in front of the CAFAS structure for fruit processing, Salvaterra/PA - 03/11/2022. Image: Dener Ghenov.

The cooperative acquired areas (having started with a plot of 0.3 hectares, today it has 1.3 hectares for collective plantations) and plans to diversify production (Figures 11 and 12). Currently, they purchase products from their own cooperatives and third parties, for processing and commercialization: cupuaçu, bacuri, taperebá, açaí, pineapple, among others.

Figure 11. Diversified planting in a cooperative in Salvaterra/PA - 03/11/2022. Image: Wilson Cabral.

Figure 12. Diversified planting in a cooperative in Salvaterra/PA - 03/11/2022. Image: Dener Ghenov.

They reported that there is a noticeable variation in the availability of fruits as a function of climatic conditions. As an example, they note that the production of cupuaçu decreased in the last summer, which was rainier in the months of October, November and December, in addition to reporting an increase in the thermal sensation (temperature).

Pulp prices reach an average of R$15/kg, but they collect tax as a large processing company. There is a need to adjust the CNAE (National Classification of Economic Activities) and accounting to reduce the impact of taxes on the cooperative's activity.

What does the forest represent?
"For me, the forest represents support because we are extractivists and the forest gives us piquiá, peach palm, cupuaçu, soursop, native açaí...".

This is an example of the need to include the implementation of SAF's in a broader project that involves managing the business and defining market strategies based on viable business plans. Even though it is a highly developed nucleus and with a positive history of associative work, there is still no plan for the cooperative to reach its objective, which according to the report of one of the interviewees would be *"each member to receive 1,000 reais per month for work in the cooperative"*.

Quilombola Community Caldeirão, Salvaterra, 12/03/2022

Raimundo Hilário and community leaders of the quilombola association (Figure 13)

Figure 13. Meeting with leaders of the Quilombola community Caldeirão, Salvaterra/PA - 03/12/2022. Image: Dener Ghenov.

The Caldeirão community is located in an area of 1,680 hectares, however, the community suffers today from the fragmentation of its territory. It has been reported that there are several invasions, and it is estimated that about 60% of the area is currently owned by owners outside the quilombola community. There is a process at INCRA (National Institute of Colonization and Agrarian Reform) for reintegration.

Families in the community own properties with an average of 1 hectare, with the largest reaching up to 3 hectares.

"There are 210 quilombola families, recognized by the Palmares Foundation, out of a total of 315 families residing in the community" - Raimundo Hilário Seabra de Morais (Regional Coordinator of Malungu, organization of quilombola communities in the state of Pará).

They reported that they perceive an increase in temperature in more recent periods. One of the participants mentioned that *"The sun is stronger"*. They note the influence of possible climate changes on works on the riverside, which have been affected and need repairs or even new interventions. At some points along the river bank, there is a landslide (Figures 14 and 15).

Figure 14. Bank landslide in Caldeirão community, Salvaterra/PA – 03/12/2022. Image: Dener Ghenov

Figure 15. Bank landslide near the road in the Caldeirão community, Salvaterra/PA – 03/12/2022. Image: Wilson Cabral

Fishing is pointed out by most residents as the main economic activity. Most community members are registered as “fishermen”, but only a small part actually practice fishing on a daily basis (about 10 families). The rest fish for subsistence. There is also the extraction of tucupi, cultivation of own gardens and collection of açaí.

They reported that there is a reduction in fish - attributed to industrial fishing, especially commercial, but also related to climate change. There is no inspection of the fishing closed period. They mentioned that one problem is that the closed season insurance started to be paid in a single installment, which influences family financial planning.

The influence of the incoming tide and the "saltpeter" is perceived on a daily basis, for example, in certain places, in the summer, it is necessary to go further to get better quality water. With the rise in mean sea level, this influence may increase, generating greater demands for adaptation. They notice reduced rainfall in winter. They call it "creative winter", due to the extension of agricultural activities.

They commented on the harassment of private companies on the communities, about carbon credits. Projects are presented at times of extreme vulnerability (covid pandemic, high unemployment rates, etc.), sometimes even promising "green grants", from R$300-600, similar to a social program.

This represents yet another account of a community harassed by carbon projects, but unable to assess the real potential, or not, of these projects. The project already causes discord among community members even before it brings concrete results. Advising these communities to deal with this issue can be an important item to reduce the socio-environmental vulnerabilities of the community.

They also mentioned the pressure of rice monoculture, which uses pesticide spraying and pumping large amounts of water over large tracts of land and pasture areas.

Pau Furado and Bacabal Communities, Salvaterra/PA – 13/03/2022

Haroldo (Bacabau Community)
Fabiano (30 hectare property).

The communities of Bacabau (approximately 100 families) and Pau Furado (approximately 50 families) are formed by fishermen who also practice agriculture and extractivism.

The visit was carried out in a differentiated property, due to the size of 30 hectares (Figures 16 and 17). The family works on family farming and is not interested in community projects. They produce cassava, watermelon, tomato. They still produce pineapple, but for this crop it is difficult to transport and store. They are gradually replacing pineapple with cassava, as they already had prior knowledge. They commented that if there was knowledge, they would also plant other cultures. They have a partnership with a flour factory belonging to a large producer in the region, which also encouraged the transition to planting cassava. "*Things are getting difficult, you have to plant a little bit of everything*".

Figure 16. Property of 30 hectares with different crops, Salvaterra/PA – 03/13/2022. Image: Wilson Cabral.

Figure 17. Property of 30 hectares with different crops. Highlight for the large pineapple planting area at the bottom of the image, Salvaterra/PA – 03/13/2022. Image: Dener Ghenov.

It was reported that recently it has felt the need to irrigate the crops, due to the reduction of rainfall. The extraction of Açaí and Bacuri has been reduced because of over-exploitation: "*people have been harvesting green*". There have already been material losses with fire from a neighboring farm, spread in the summer.

Fabiano is a farmer who already works with different systems and can serve as an example for the expansion of this model in the region. Credit mechanisms, technical assistance and marketing support can further catalyze this model.

Flour Factory, Salvaterra/PA – 14/03/2022

Mr. Eduardo

The owner of the cassava factory migrated from Mato Grosso (MT) to the region 5 years ago and has been expanding cassava cultivation in the region. His initial strategy was to work in partnership with small rural producers, but he reported that it did not work due to the varieties planted and the quality of the final product for flour production. Now, he has focused on land acquisition and own cultivation of cassava (Figure 18) coupled with the processing (Figure 19) of the product.

Figure 18. Extensive cassava production area, Salvaterra/PA – 03/14/2022. Image: Dener Ghenov.


Figure 19. Cassava flour factory, Salvaterra/PA – 03/14/2022. Image: Osvaldo Stella.

During the visit, it was possible to see that the region has a very large agricultural potential and also that cassava can be a key element of the systems to be implemented. In addition to agricultural aptitude and the consolidated market, cassava can be intercropped with several other species such as açaí, for example. Furthermore, they reported the advantage that once the flour is produced, it can be stored for longer periods than fruits, such as pineapple.

Embrapa Farm, Salvaterra/PA – 14/03/2022
Paulo Leles (Assistant at EMBRAPA Eastern Amazon)

The Embrapa farm, in Salvaterra, is far from the urban area and on the banks of the Paracauari River. The farm is visibly abandoned, with only two employees. Research was interrupted due to the covid-19 pandemic period. Currently, they only work with the preservation of herds of various buffalo genetics. With little investment, it can serve as a basis for the development and projects of ICLFS (Integrated Crop-Livestock-Forestry Systems) based on the creation of buffaloes for both beef and milk.

Figure 20. Embrapa Farm, Salvaterra/PA – 03/14/2022. Image: Dener Ghenov.

SEMMA, Cachoeira do Arari, PA – 15/03/2022

Municipal Secretary of the Environment
Daniel – Environmental analyst

The municipal environment secretary, who was going to receive us, had an unforeseen event and could not be present on the day of our visit. Analyst Daniel received us even though he was not informed about our visit.

It was informed that the environmental secretariat of Cachoeira do Arari is about two years old, being very recent. Currently, they do not have any work or research related to the topic of climate change. They mainly work on the topic of solid waste in the municipality.

Technical Assistance and Rural Extension Company (EMATER), Cachoeira do Arari, PA – 15/03/2022

Herlon Pereira – Coordinator

Reported that the main activity in the municipality is livestock. When crossing from Salvaterra to Cachoeira do Arari, one travels about 60 km in a landscape of flooded natural fields where the expressive presence of buffalo livestock on the properties can be seen (Figure 21), and more recently the introduction of cattle. He informed that about 80% of the territory is associated with large farms with livestock activity, with the landscape of natural fields predominating.

Figure 21. Extensive flooded fields with the presence of buffalo cattle, Cachoeira do Arari/PA – 03/15/2022. Image: Dener Ghenov.

Artisanal fishing is very strong among the population of the municipality, serving basically for subsistence. EMATER develops fish farming work with 15 families in the municipality.

The rice culture entered the municipality about ten years ago, producing throughout the year. It is reported that the introduction of rice is associated with the population that migrated from Roraima, from the Raposa Serra do Sol Indigenous Land region. It is estimated that there are already more than 10,000 ha of rice plantations. They associate rice cultivation with environmental impacts due to the excessive use of pesticides. This same population also raises white cattle that were brought from Roraima.

The main native crops in the municipality are açaí, cassava, corn, bacuri, taperebá and cupuaçu. EMATER develops açaí plantation management work in a floodplain area.

The municipality has two PAE (Extractive Settlement Project): Xipaia (1,200 ha) and Urubuquara (3,600 ha), and a quilombola community: Gurupá (10,184 ha). It was reported that most of the municipality is in lowland areas, with little availability of dry land available for planting.

Aranaí community, Cachoeira do Arari, PA – 15/03/2022

Mr. Pedro Caroncho (Fishermen's Pastoral)

Mr Pedro lives in a community of fishermen and extractivists, with around 270 families. The community lives in a lowland area with little land area. He commented that the population of fishermen has been reducing, as there is an evasion of young people who seek new opportunities, mainly through education.

He reported that the winter of 2021 had lower rainfall.

He associates rice cultivation with impacts on the availability of freshwater fish, which has been decreasing. The rice crop caused some fishermen to start fishing in secondary drainage channels within the plantation areas. He commented that the reduction in fishing may also be associated with industrial fishing, with large vessels causing greater turbulence in river waters. He also reported reduced availability of shrimp, saying that for about 5 years they no longer have a crop..

Visit to points of interest for spatial analysis purposes

Soure, Salvaterra e Cachoeira do Arari

Although they are contiguous municipalities, in the eastern portion of the Marajó Archipelago, the environments differ significantly in terms of relief and phytophysiognomy.

In Soure, mangroves predominate, interspersed with tesos (firm land domains for planting) in the coastal and estuarine region, with a large part of these environments within the limits of the Soure Marine Extractive Reserve (Figure 22). The rest of the municipality is made up of extensive fields with floodable stretches.

Figure 22. Mangrove area in the Marine RESEX of Soure/PA – 03/09/2022. Image: Wilson Cabral

The municipality of Salvaterra has slightly higher land (the highest point in the region is in Joanes, a village in Salvaterra). In large part, there is a predominance of vegetation similar to the Cerrado (Figure 23), interspersed with riparian forest vegetation around the streams (Figure 24).

Figure 23. Phytophysiognomy of cerrado in Salvaterra/PA – 03/12/2022. Image: Wilson Cabral.


Figure 24. Igarapé surrounded by riparian forest in Salvaterra/PA – 03/12/2022. Image: Wilson Cabral.

In Salvaterra, coastal areas intersperse extensive beaches with stretches of small vegetated dunes (Figures 25 and 26) and riverside areas form ravines subject to river movements.

Figure 25. Beach in the coastal region of Salvaterra/PA – 03/12/2022. Image: Wilson Cabral.

Figure 26. Beach in the coastal region of Salvaterra/PA – 03/12/2022. Image: Dener Ghenov.

This profile is found even in the urban area, where the edge has been reworked by the river, in a constant process of erosion of the banks (Figure 27).

Figure 27. Margin in an urban area, subject to erosion, in Salvaterra/PA – 03/12/2022. Image: Wilson Cabral.

The municipality of Cachoeira do Arari, on the other hand, is largely covered by a landscape of flooded fields (Figure 28), in which recent rice production has been installed, which already occupies a large part of the central region of the municipality.

Figure 28. Flooded fields in Cachoeira do Arari/PA – 03/13/2022. Image: Wilson Cabral.

The fields come close to the banks of the streams and the Arari River, at the western limit (Figure 29). The riparian vegetation intersperses forests and open areas (Figure 30).

Figure 29. Water catchment structure for rice irrigation, Cachoeira do Arari/PA – 03/13/2022. Image: Google (2022).

Figure 30. Riparian vegetation on the left bank of the Arari River, Cachoeira do Arari/PA – 03/13/2022. Image: Wilson Cabral.

Fundación Avina

CLIMATE VULNERABILITY ANALYSIS IN ILHA DO MARAJÓ / PA

PRODUCT A.2

Climate-Resilient Agroforestry Activities

Developed by:

H2O Company

2022

CLIMATE VULNERABILITY ANALYSIS IN ILHA DO MARAJÓ / PA

2022

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CLIMATE CHANGE AND IMPACTS

According to Product B.2, lower rainfall distribution, higher frequency of extreme events, increase in temperature and sea level rise are already being verified in the region and an increase in the intensity of these events is expected for the next decades.

Based on these projected climate change, Table 1 illustrates the main expected impacts that may affect the development of agricultural and forestry species and consequently reduce their production. The details of each impact will be presented in the following topics.

Table 1: Potential impacts according to climate change

Impacts	Temperature rise	Precipitation reduction	Increase in extreme events		Sea level rise
			Increase in consecutive days without rain	Heavy rains	
Change in the development of plant species					
Reduction of water in the soil					
Increase in the frequency and duration of floods					
Increase in fire spots					
Increase in erosion					
Increase in evapotranspiration					
Soil salinization/groundwater/surface water					
Water table rise					
Habitat loss					
Reduction of the water surface					

In a conventional agricultural system, these impacts would lead to large losses of resources, making the system more vulnerable and less productive. However, as we will see later, it is possible to adopt strategies to reduce this loss and obtain greater productivity, as is the case with the use of agroforestry systems.

TEMPERATURE RISE

The increase in temperature on the earth's surface will cause **greater evapotranspiration of water.** For agriculture, this can result in **variation in soil water storage**, which in turn will condition crop growth, development and yield (NOBRE, 2007; SENTELHAS, ANGELOCCI, 2012).

There is also an **increase in fire spots** due to high temperatures. A study carried out for the state of Pará found that there is an increase in fire spots from the month of July, which belongs to the so-called "Amazonian summer", continuing until the month of November, when the rainiest season begins. In December, there was a decrease in the incidence of fire spots (COSTA et al, 2022). In 2020, 59 fire spots were recorded in Cachoeira do Arari, 52 in Salvaterra and 28 in Soure (FAPESPA, 2021).

The development and productivity of species are determined by the combination of edaphoclimatic factors (soil and climate). The authors Lobell and Field (2007) identified in their study that the **average temperature and the spatial distribution of precipitation during the planting season explain about 30% of the variation in productivity** of the principal crops around the world.

PRECIPITATION REDUCTION

The reduction in precipitation tends to exacerbate the impacts described above. With less rain, even **less water infiltrates the soil** and less availability of this resource for plants, impacting agricultural and forestry development.

The **fire spots**, when associated with the precipitation reduction and dry season, makes vegetation more flammable due to low availability of water in the soil and drying of vegetation. Allied to the predominant agricultural practice in the region, which uses fire to prepare the cultivation areas, this situation can worsen considerably (NOBRE, 2007) and lead to the loss of cultivated areas.

INCREASE IN EXTREME EVENTS

It was identified that in the last 30 years, the 3 municipalities were facing an increase in the frequency of episodes of intense rain (above 150 mm), and for the future, it is expected an increase in consecutive days without rain.

The combination of the effects of the reduction of annual precipitation, the increase of the average temperature in the region and longer periods without rain should contribute to accentuate the already observed trend of **reduction of the water surface** areas in the studied municipalities, as evaluated in Product A.1.

Water deficits caused by long periods of drought can **compromise the physiology of plants** and induce stomatal closure, reduced photosynthetic rate and leaf transpiration, consequently, negatively interfering with the productivity of roots, stems and leaves of the crop (EL-SHARKAWY, 2007).

When heavy rains occur, the amount of water in the soil rises beyond what can be drained naturally. This condition **intensifies soil erosion**, gradually removing organic matter and nutrients, resulting in soil degradation and a drop in productivity over the years (SANTOS et al, 2010). It also intensifies the surface runoff, and a **greater risk of flash floods**.

This condition is also often harmful to seeds, which may die without germinating or fail to survive after germination. The effect is a reduction in production and, in some cases, a drop in productivity, as the surviving plants are weaker.

SEA LEVEL RISE

The rise in sea level will negatively impact the **sedimentary balance** of the coasts of the municipalities through erosion and will flood the nearest low-lying areas. The result will be the **loss of habitat** and consequently of areas with potential use for agroforestry activities in communities located near the affected areas.

The phenomenon also tends to aggravate the natural process of **saline intrusion**, the advance of sea waters towards the interior of the island, which can become even more severe when associated with long periods of drought. The atypical advance of marine waters in the coastal zone will lead to **salinization of the soil and waters**, consequently impacting the development of the species.

Excess soil salinity can negatively affect growth, leaf surface expansion and primary carbon metabolism of many crops due to osmotic effect, water deficit, ion toxicity and nutritional imbalance (DIAS et al, 2016)

Although much progress has been made in classifying the various plant species based on salinity tolerance, this indicator is highly variable as it depends on the genotype, soil and climatic conditions and the agronomic techniques used (DIAS et al, 2016).

In the interior of the archipelago, as is the case of a considerable part of the municipalities of Soure and Cachoeira do Arari, where the plains and swamps predominate, an important part of this area has levels below the relative mean sea level and, therefore, will be subject to the **elevation of the water table level** given the increase in hydrostatic pressure from the higher marine environment.

AGROFORESTRY SYSTEM

To counterbalance the predicted impacts in the three municipalities of the Marajó region, it is necessary to increase the resilience and reduce the vulnerability of smallholders through Ecosystem-based Adaptation approach. In agricultural systems, adaptation implies adopting management practices that take advantage of the biodiversity, ecosystem services and ecological processes of natural or modified biomes, as a basis to help increase the ability of crops to adapt to climatic changes and variations (Assad et al., 2019).

In this sense, Agroforestry Systems (AFSs) can be considered an EbA measure. AFSs are defined as land use and occupation systems in which perennial woody plants are managed in association with herbaceous vegetation, shrubs, arboreal plants, agricultural and forage crops within the same management unit, according to spatial and temporal arrangement, with a high diversity of species and interactions between these components (MMA, 2009).

SPECIES SELECTION

The planning of an AFS starts with the identification of a “flagship” species, which in this case must be strategically selected to adapt to the predicted climate changes. In addition, the species must be relevant in the daily lives of communities and have potential commercial value. Four species were analyzed to compose the systems, they are: açaí, pineapple, cassava and cocoa.

PINEAPPLE

In 2019, Pará was a protagonist in the national production of pineapple, with 19.28% of the 1,617,684 ton harvested in Brazil (SEDAP/PARÁ, 2020b). Salvaterra is responsible for 12,584 tons, equivalent to 71% of the regional total, followed by Cachoeira do Arari (20%).

AÇAÍ

Pará is the largest national producer of açaí, reaching 1,320,150 tons of fruit in 2019 – the equivalent to 94% of all that was generated in Brazil. Marajó participates with 12% of Pará's performance, which demonstrates the importance of açaí management for the region. According to Vivian Zeidemann et al. (2015), in the study of perceptions of climate change by residents in the Amazon estuary on the production of açaí (*Euterpe oleracea mart*.), indicated that in extreme climatic years of drought, that is, when a year is warmer than normal years, the residents perceive the decay of fruit quality and with that, fruit production losses and social and economic losses are responses to climate risks in the current years. It is concluded that, given the future climate scenarios that point to a drier and warmer regime than current conditions, there are indications of positive and negative impacts on the productivity of açaí fruits. Thaiane Dias et al. (2019) evaluated açaí productivity in the state of Pará, and analyzed the effects of climate change considering the RCP 4.5 scenario. According to the study, the Lower Amazon and Southwest Pará region stands out as a climatic risk for the drying up of açaí production, where future projections indicate loss of productivity. Still, the Marajó mesoregion is identified as the one with the highest productivity in future scenarios, justifying its use in agroforestry systems that aim to adapt to the effects of climate change in the region.

CASSAVA

According to Gabriel et al. (2014), the temperature increase projected in future climate scenarios should not, in general, decrease the productivity of cassava tuberous roots. Assad and Pinto (2008) state that with the reduction of water surpluses, the Amazon can benefit from the growth of the cassava plantation area. Accordingly, cassava tends to be one of the crops that will best adapt to local climate changes.

COCOA

Cocoa is a native species of the Amazon biome and the state of Pará is the largest national producer. It is an extremely important crop for the economy of the local production chain and family farming.

AGROFORESTRY LAYOUTS

Based on the "flagship" species it is necessary to build consortia of species that are similar in structure and function to the forest ecosystem, with a high diversity of species belonging to different ecological groups, seeking to occupy the strata over time. Species are combined according to their life cycle, growth rate and stratification over time, fundamental characteristics of the ecological group to which they belong.

In a simplified way, to assist in agroforestry planning it is possible to consider the following groups of species: i) annual agricultural species, ii) semi-perennial agricultural species; iii) short/medium life cycle tree species, and iv) long life cycle tree species, also called primary forest species, or only primary.

Complex agricultural systems, such as agroforestry systems, create, by themselves, a protection of crops due to the ecological interactions and synergies between the biological components. Sustainable production in an agroecosystem derives from the balance between plants, soils, nutrients, sunlight, moisture and other coexisting organisms (ALTIERI, 2004).

The agroecosystem is productive and healthy when these rich and balanced growing conditions prevail, and when plants remain resilient enough to tolerate stress and adversity. Sometimes, disturbances can be overcome by vigorous agroecosystems that are adaptable and diverse enough to recover after the stress period (ALTIERI, 2004).

The species and layouts indicated in this study take into account the criteria of adaptability of systems to climate impacts. Still, it should be revised according to the economic and market analysis, aptitude of the families, and other criteria, which may result in variations from the suggested models.

We are suggesting models of diverse agroforestry systems that vary from 4 to 9 species, which can present high implementation costs and certain technical complexity for smallholders due to the number of species. If this type of situation is confirmed, it is possible that simpler models will be implemented, with a smaller number of species, initially enabling the implementation of the project. Over time, systems can gain complexity, following the maturity of the market and communities.

The species recommended in this study can be replaced by others that belong to the same group and stratification, without prejudice to the resilience of the system. Besides, it was also included species that demonstrated medium feasibility degree (Tables 3,4,7 and 8), since, as mentioned before, what protects the crops is the balance condition in the system components, and not just the species itself. Thus, compared to a conventional agricultural system, the species have a better performance in a balance agroforestry system.

The adaptation to climate change is the result of the implementation of a balance agroforestry system. The layout and species selected may vary according to the criteria applied (climate, economic or gender) and family affinity, without prejudice to the resilience of the system.

Three models of agroforestry systems are presented below: a simpler option – Agroforestry Home Gardens - a more complex one – Diverse Agroforestry Systems – and another aimed at restoring areas using species that are economically attractive to the population – Simplified Management Agroforestry System.

LAYOUT 1 — AGROFORESTRY HOME GARDEN

Considered species: Murici, açaí, guava, banana, papaya, cassava, coffee, gliricidia, vegetables.

Area: 0.1 hectare.

System design: In upland areas, adjacent to the residences, is possible to implant the Agroforestry Home Garden. The presence of different stratus vegetation helps to mitigate and regulate the effects of severe wind and rain storms, and also the effects of higher temperatures or hit waves. By doing this it is possible to reduce annual and seasonal production losses as well as provide cooler temperatures for smallholders to work.

Figure 1: Agroforestry Home Garden layout

The combination of species also helps form landscapes that are more resistant to erosion, maintain moisture during periods of prolonged drought, and increase water infiltration into the soil.

The design of the agroforestry home garden model is based on the combination of 2 windrows where the elements of the upper strata are inserted, 7 rows that will hold the agricultural species of medium and low strata, and 2 beds where the vegetables will be grown. These elements are distributed in the system in a “mirrored” way, as illustrated in figure 2.

Windrow 1 will be on the edge of the garden and will be composed of Murici, açaí, and guava. Row 1 is inserted next to this, occupied only by banana trees. Bed 1 is then inserted, which will be 1.0 meter wide and comprise short-cycle agricultural crops such as lettuce, arugula, chicory, green cabbage, coriander, parsley, and chives. The distance between the windrow, the row, and the bed should be 2 meters.

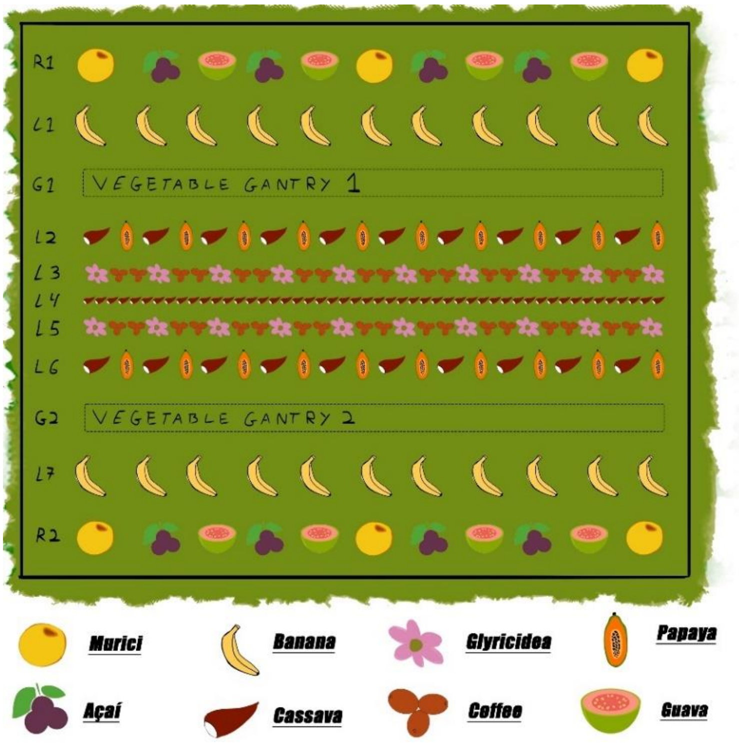
After bed 1, in the center of the system, 5 more rows will be created, numbered from 2 to 6 in the sketch. The first of them will be occupied by cassava and papaya, the second by coffee and gliricidia, and the third will have only casssava. From this point on, the system layout repeats in a “mirrored” way, with the coffee and gliricidia row being reproduced first, followed by the cassava row. The spacing between these 5 central rows should be 1.5 meters.

Next to them, bed 2 will be implanted, focused on the production of medium-cycle species, for example, sweet potato, broccoli, eggplant, and okra. Finally, the banana tree row and the windrow with Murici, açaí, and guava close the system module.

It is also necessary to respect the spacing between individuals within the same windrow/row, which varies according to the species:

- ✓ Murici: every 25.0 meters;
- ✓ Açaí: every 10.0 meters;
- ✓ Guava: every 10.0 meters;
- ✓ Papaya: every 10.0 meters;
- ✓ Banana: every 5.0 meters;
- ✓ Gliricidia: every 5.0 meters;
- ✓ Cassava intercropped with papaya: every 2.5 meters;
- ✓ Coffee: every 2.0 meters;
- ✓ Cassava: every 1.0 meter.

Figure 2: Sketch of the Agroforestry Home Garden layout



The table below lists the species considered for this layout with their respective groups, strata, spacing, and preferred environment, an important factor to be considered for the success of the project. The indicated spacing is a reference value and should be revised according to the final configuration of the system, determined based on the commercialization strategy for the products and the availability of farmland.

Table 8: Details of Agroforestry Home Garden layout

Species	Group	Stratification	Preferred Environment	Spacing (m)		Life cycle
				Between windrows/rows	Between individuals of the same species	
Murici (*Byrsonima crassifolia*	Long-lived tree	High stratum	Terra firme	2.0	25.0	+ 40 years
Açaí (*Euterpe oleracea*)	Long-lived tree	High stratum	Terra firme/lowlands	2.0	10.0	+ 40 years
Guava (*Psidium guajava*)	Medium-cycle tree	High stratum	Terra firme	2.0	10.0	20 years
Papaya (*Carica papaya*)	Semi-perennial crop	High stratum	Terra firme	1.5	10.0	2 years

Gliricidia *(Gliricidia sepium)*	Tree	Medium stratum	Terra firme	1.5	5.0	20 years
Banana (*Musa spp)*	Semi-perennial crop	Medium stratum	Terra firme (silver banana) Lowlands (plantain)	2.0	5.0	2 years
Coffee *(Coffea spp*)	Long-lived tree	Low stratum	Terra firme	1.5	2.0	20 years
Cassava (*Manihot esculenta)*	Annual crop	Low stratum	Terra firme	1.5	2.5 (intercropped with papaya) 1.0	18 months

Source: WWF, 2014; GUIMARÃES e MENDONÇA, 2019.

LAYOUT 2 — DIVERSE AGROFORESTRY SYSTEM WITH EMPHASIS ON AÇAÍ PRODUCTION

Figure 3: Diverse agroforestry system with emphasis on açaí production layout

Considered species: Açaí, guava, tucuman, bacuri, andiroba, banana, cassava, beans, pumpkin.

Area: 1.0 hectare.

System design: In upland areas is possible to implant the Diverse Agroforestry System. The presence of different stratus vegetation helps to mitigate and regulate the effects of severe wind and rain storms, and also the effects of higher temperatures or hit waves. By doing this it is possible to reduce annual and seasonal production losses as well as provide cooler temperatures for smallholders to work. The combination of species also helps form landscapes that are more resistant to erosion, maintain moisture during periods of prolonged drought, and increase water infiltration into the soil.

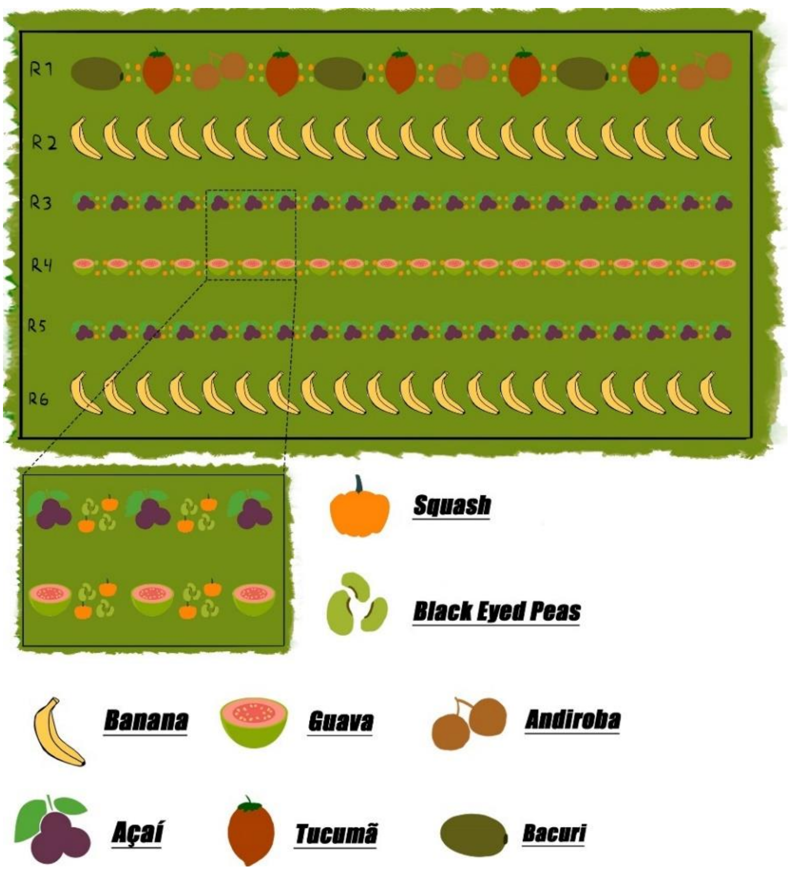
This system consists of 6 windrows, with 5.0 meters of space between them. Windrow 1 represents the emerging stratum, and tucuman, bacuri, and andiroba will be planted there. Windrow 2 will have banana trees, which will occupy the middle stratum. Rows 3, 4, and 5 represent the upper stratum and will hold açaí, a "flagship" species in the system, together with guava, increasing the diversity of individuals from the same group and stratum. Row number 6 will be the last one in the module, and banana trees will be planted. In the lower stratum, cassava will be planted between the rows. Between trees in the same row, except for those that contain bananas, beans and pumpkin will be planted.

Spacing between individuals in the same windrow varies according to species:

- Andiroba: every 40.0 meters;
- Bacuri: every 40.0 meters;
- Tucuman: every 20.0 meters;
- Açaí: every 5.0 meters;
- Banana: every 5.0 meters;
- Guava: every 5.0 meters;
- Cassava: every 1.0 meter.

This module can be repeated sequentially for the length of the available area so that 4 modules can be implemented in 1 hectare.

Figure 4: Sketch of the Diverse Agroforestry System with emphasis on açaí production layout



The table below presents the details of the system design.

Table 9: Details of Diverse Agroforestry System with emphasis on açaí production layout

Species	Group	Stratification	Preferred Environment	Spacing (m)		Life cycle
				Between windrows	Between individuals of the same species	
Tucuman *(Astrocaryum vulgare)*	Long-lived tree	Emergent stratum	Terra firme	5.0	20.0	+ 40 years
Bacuri *(P. insignis)*	Long-lived tree	Emergent stratum	Terra firme	5.0	40.0	+ 40 years
Andiroba *(C. guianensis)*	Long-lived tree	Emergent stratum	Terra firme	5.0	40.0	+ 40 years
Açaí (*Euterpe oleracea*)	Long-lived tree	High stratum	Terra firme/lowlands	5.0	5.0	+ 40 years
Guava (*Psidium guajava)*	Medium-cycle tree	High stratum	Terra firme	5.0	5.0	20 years
Banana (*Musa spp)*	Semi-perennial crop	Medium stratum	Terra firme (silver banana) Lowlands (plantain)	5.0	5.0	2 years
Cassava (*manihot esculenta)*	Annual crop	Low stratum	Terra firme	0.5	1.0	18 months
Black-eyed pea *(Vigna unguiculata)*	Annual crop	Ground level	Terra firme/floodplain	0.5	0.5	3 months
Pumpkin *(Corcubita sp.)*	Annual crop	Ground level	Lowlands	4.0	5.0	4 months

Source: WWF, 2014.

As previously mentioned, it is possible to create other combinations of species adopting the same layout without any loss of system resilience. In the annex there are 3 examples of AFS Diverse with emphasis on the production of cassava and pineapple, cocoa and a layout integrated with areas for raising small animals.

LAYOUT 3 — SIMPLIFIED MANAGEMENT AGROFORESTRY SYSTEM

Considered species: Açaí, inga, Murici, moriche palm, andiroba.

Area: 1.0 hectare.

Figure 5: Simplified Management Agroforestry System layout

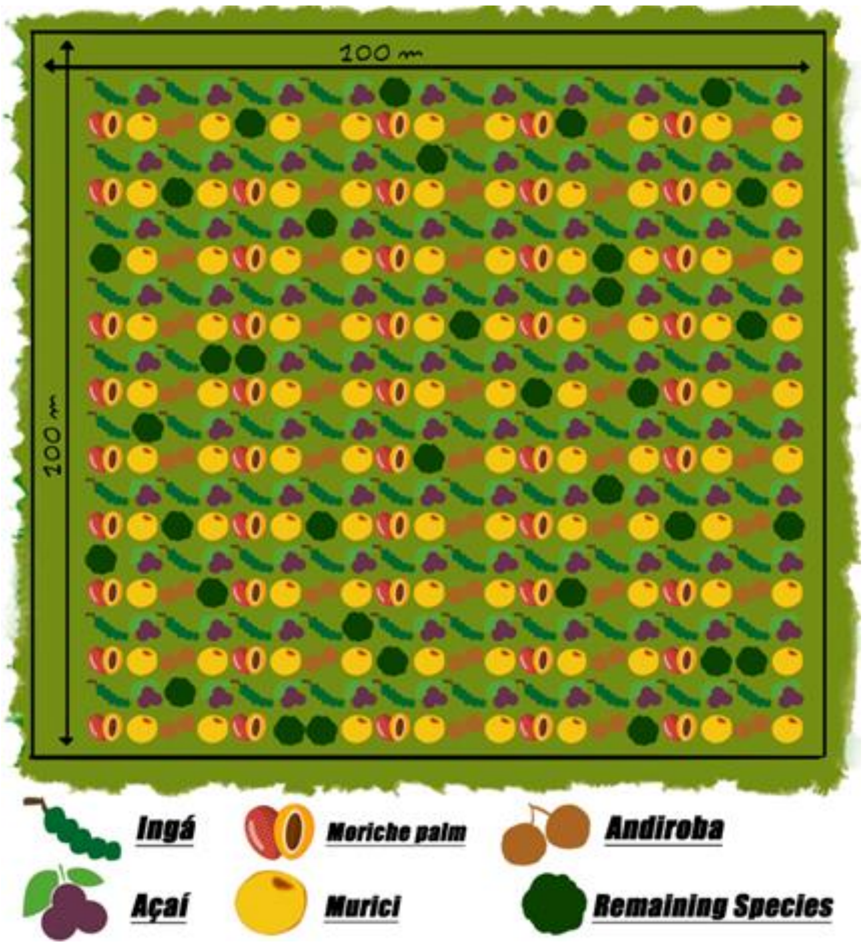
System design: In coastal regions and on the banks of water bodies, it is possible to implant agroforestry systems aimed at increasing the landscape's resilience to the effects of climate change. The combination of species already identified by VOGT et al. (2016) can help form landscapes that are more resistant to erosion, strong winds, and storms, maintain moisture during periods of prolonged drought, and increase water infiltration into the soil, etc. In addition to the direct contribution to the landscape's resilience, it is possible to select species that can provide timber and non-timber resources to communities. By doing this it is possible to build a system that, in addition to protecting the area, serves as farmland for communities, joining multiple environmental services. In the design of the system, all selected species contribute to combating lateral erosion, and feeding people and fauna. Inga, a plant well adapted to full sun, will occupy the lower stratum and create a good environment for the other species to develop in. Açaí, moriche palm and Murici will occupy the medium stratum, and, finally, andiroba will occupy the emergent stratum of the system.

Given the restoration perspective of this layout, it is unnecessary to define the windrows nor the constant management of the areas. Despite this, the spacing between individuals of the same species should be respected:

- ✓ Açaí: every 10.0 meters;
- ✓ Inga: every 10.0 meters;
- ✓ Murici: every 10.0 meters;

- ✓ Moriche palm: every 20.0 meters;
- ✓ Andiroba: every 20.0 meters.

Figure 6: Sketch of the layout for the Simplified Management Agroforestry System



The layout details are presented in the table below.

Table 10: Details of Simplified Management Agroforestry System layout

Species	Group	Stratification	Preferred Environment	Spacing (m)		Life cycle
				Between rows	Between individuals of the same species	
Andiroba (*C. guianensis*)	Long-lived tree	Emergent stratum	Terra firme	10.0	20.0	+ 40 years
Açaí (*Euterpe oleracea*)	Long-lived tree	Medium stratum	Terra firme/lowlands	10.0	10.0	+ 40 years

Moriche palm *(Mauritia flexuosa L.f)*	Long-cycle perennial	Medium stratum	Lowlands	10.0	20.0	+ 40 years
Murici (*Byrsonima crassifolia)*	Long-cycle perennial	Medium stratum	Terra firme	10.0	10.0	+ 40 years
Inga *(Inga sp.)*	Short-cycle tree	Medium stratum	Terra firme/lowlands	10.0	10.0	20 years

Source: WWF, 2014.

CORRELATION OF AGROFORESTRY SYSTEMS

From the systems RBAs, UBAs, SBAs and CBAs presented by Vogt et al. (2016), a correlation with the Agroforestry Home Garden, Diverse Agroforestry System and Simplified Management systems is identified in Table 11, considering the species that constitute each system and the benefits linked to them in order to mitigate the environmental impacts from climate change.

Table 11: Correlation between Agroforestry Systems (Vogt et al., 2016) and Agroforestry Systems of the proposed Layouts

Sistemas Agroflorestais (Vogt et, 2016)	Function	Benefits	Correlation	Species of the Agroforestry System	Justification
Umbrella based agroforest (UBAs)	Mitigate and regulate the effects of severe wind and rainstorms	Secure annual or seasonal production of fruits and other products, reduce risk of damages from felling trees	Diverse Agroforestry System	Açaí, guava, tucumã, bacuri, andiroba, banana, cassava, beans, pumpkin, corn, pineapple, cumaru, cocoa and cupuaçu	It is considered the presence of canopy tree species in the suggested agroforestry systems that contribute to the mitigation of strong winds and storms
			Simplified Management	Acai, ingá, Murici, moriche palm, andiroba	
Shade based agroforestry (SBAs)	Manages moisture and prevents the soil from drying out during droughts. Mitigate and regulate the effects of impact waves and periods of drought	Protect pollinators and pollination of açai and other market value fruits, reduce soil compaction	Diverse Agroforestry System	Açaí, guava, tucumã, bacuri, andiroba, banana, cassava, beans, pumpkin, corn, pineapple, cumaru, cocoa and cupuaçu	Palm species are considered in the suggested agroforestry systems that contribute to the mitigation of periods with great drought
			Agroforestry Home Garden	Murici, açaí, guava, banana, papaya, cassava, coffee, gliricidia, corn, vegetables	
Cluster based agroforest (CBAs)	Helps to filtrate, retain and store fresh water during droughts and sea-water-incursion	Maintain water pools to provide fresh water and refuge for fish and wildlife	Simplified Management	Acai, ingá, Murici, moriche palm, andiroba	It was considered that the species in its composition will provide the filtration and storage of water in the soil

BENEFITS

AFSs have multiple environmental, economic and social benefits, which vary in degree and importance according to the context, the type of system practiced and the management of the systems over time (MICCOLIS et al, 2016).

The following table presents the main environmental benefits that both Agroforestry Home Gardens, as well as Diverse Agroforestry System and Simplified Management Agroforestry Systems can provide.

Table 13: Benefits of agroforestry systems layouts and their effects on the microclimate

Environmental benefits	Microclimate effects			
	Reduce the effects of precipitation decrease	Reduce the effects of rising temperature	Reduce the effects of extreme events	Reduce the effects of sea level rise
Shade				
Erosion control				
Filtration and retention of water in the soil				
Reduction of surface runoff				
Wind Barrier				
Nutrient cycling				

Source: MICCOLIS et al, 2016.

In addition to the benefits of reducing the effects of climate change, AFSs have also the economic benefit. The first income, still in the first year, come from annual species (for example cassava and black-eyed pea), vegetables and semi-perennial species (for example pineapple and banana), and can be sold in the first 3 years, average. The productivity of annual and semi-perennial crops decreases as there is an increase in shading and competition with woody species (EMBRAPA, 2022).

From the fourth year onwards, fruit species begin their productive phase, reaching their productive stability at 10 years. Wood species can be harvested between 6 and 10 years. This phase presents a reduction in the demand for labor due to the lower intensity of maintenance activities for fruit and wood species (EMBRAPA, 2022).

Study carried out in the municipality of Tomé-Açu, in the state of Pará, one of the main centers for exploitation of agroforestry systems in the Amazon region, aimed at estimating the cost of production and profitability of an agroforestry system, having cupuaçu, Murici, banana, black pepper, rice and pigeon pea as components (SANTOS et al, 2020).

As a result, for every BRL 1,000.00 invested by the farmer in the system, a return of BRL 1,600.00 is expected. The estimated value for the period of return on investment, or economic payback, was 4 years and because this value is within the period of validity of the investment, it characterizes the recovery of the invested capital. This rapid return on investment had the considerable contribution of short-cycle crops, such as pepper and banana, which showed positive economic performance (SANTOS et al, 2020).

KEY RISKS IN CREATING RESILIENT LIVELIHOOD PRACTICES

Despite the multiple environmental, social, and economic benefits that agroforestry systems can generate, their implementation faces some risks. The first one is the non-acceptance of the proposed systems by the target group.

As it is a new experience in the region, the best arrangements and the best way to make the experience economically viable for smallholders in this location are still being studied. Such uncertainty can cause some resistance in communities. To minimize this risk, it is recommended to consult the smallholders about their interest in implement the AFS and their opinion about the suggested species and the layouts.

Also in this sense, as it is a new technology, it will be necessary the access to knowledge and technical assistance for the implementation techniques and good management practices to enable and balance the various functions of the AFSs. Despite the existence of institutions such as EMATER — Pará (the Company of Technical Assistance and Rural Extension of the State of Pará) and Ideflor BIO (the Institute of Forestry Development and Biodiversity of the State of Pará), which operate in the region and already have developed projects linked to the theme of this one, there is not enough technical staff to train and continuously serve all the public that could benefit from more resilient agroforestry practices.

To minimize this risk, it is recommended to dialogue with public sector and with technical assistance and rural extension institutions so that everyone can join forces and cooperate intensively for the implementation of the project.

The demand for labor can be another limiting factor in some regions for the administration of AFSs. In some communities within the project area, such as those included in the Soure Resexmar, families dedicate themselves exclusively to fishing, showing less affinity with agricultural practices and limited availability of time. These families tend to gradually abandon the AFSs, prioritizing the productive activities that they have more affinity for, that they know how to manage more easily, and on which they are financially dependent in the short term.

To minimize this risk, the community management model proposed in this report aims to distribute the demand for activities among a larger group of people, not overwhelming a single family and allowing families to dedicate themselves to different activities. Besides, it creates a space for interaction between the smallholders, stimulating the exchange of knowledge and allowing people with different vocations for agriculture to contribute.

It is important to note that this risk tends to be lower for species cultivated in an AFS compared to the development of species in conventional agricultural systems.

The production and distribution of seedlings can also be a risk factor for the project. It is necessary to include in the project planning the survey of nurseries that operate close to the study region and identify the cultivated species in order to verify if they will be able to meet the project's demand. To minimize this risk, as mentioned before, the list of species considered in this study is a suggestion, so it could be replaced according to the availability of seeds in the region, and respecting group and stratification of the layouts.

Another inherent risk is the difficulty in selling the production. The logistics to move food production are a challenge in Marajo given the distance and geography of the archipelago. This unfavorable scenario considerably influences the competitiveness of producers in markets, which may result in loss of income and, consequently, in the engagement of families throughout the project. This risk can be avoided by carrying out a market study of the species selected in the SAFs in order to identify their commercialization process.

Finally, to achieve a wide dissemination of agroecology, government engagement is needed. Despite the existence of scientific studies that indicate the impacts of climate change on the Marajó Archipelago, the municipal governments of the three locations under study do not have planning instruments that address the issue of climate change and adaptation strategies. Several reasons may have led municipalities to neglect the reality of climate change in their territories. In any case, this lack of position and action can be a complicating factor for project implementation

ESTIMATE OF GREENHOUSE GAS EMISSION REDUCTION

The implementation of Agroforestry Systems in the study areas collaborates with the development of phytophysiognomies that have greater potential for carbon sequestration in the atmosphere and reduction of emissions from land use and implementation of sustainable agricultural practices compared to the phytophysiognomy currently present in the respective areas of study. For this to be evidenced, this section aims to demonstrate the potential for mitigating climate impacts from the implementation of Agroforestry Systems - which contribute to forest restoration in the study regions and consequent increase in carbon stock, compared to a baseline composed of the local phytophysiognomy.

BASELINE

DEFINITION OF BASELINE IMPACT AREAS

For the baseline, the areas destined for the implementation of Agroforest Systems in each of the three municipalities were defined as part of the estimate (Table 14). The layout Emphasis on Açaí of Agroforestry Systems proposed in the section “Agroforestry System” was chosen for the calculations.

For the baseline, the possible reduction in greenhouse gas emissions caused by a possible reduction in agricultural management from the implementation of agroforestry systems was not considered.

Table 14: Impact areas defined for the baseline.

	Total Area (ha)			
Layout	Municipality			Total
	Soure	Salvaterra	Cachoeira do Arari	
Emphasis on Açaí	152	424	224	800

Source: Autors.

BASELINE AIR CARBON STOCK

In each area where agroforestry system was suggested, based on the socioeconomic diagnosis, land use is characterized by multiple uses, with a predominance of small agricultural crops with pastures. In order to estimate the total CO_2 stock of these areas, the carbon stock was calculated from the Savanna Park phytophysiognomy of the Amazon Forest biome based on the FOURTH NATIONAL INVENTORY OF GREENHOUSE GASES EMISSIONS AND REMOVALS from the Land Use Sector, Land Use and Forests. The bibliographic reference indicates that the stock of aerial carbon for the phytophysiognomy Savana Parque is 25.7 tC/ha.

The choice of this phytophysiognomy is due to an evaluation carried out in the field where it was found that in the region there is vegetation similar to that of the Savana Parque, pasture, agricultural cultivation and forests. As the areas covered by the project have characteristics closer to Savana Parque, this phytophysiognomy proved to be more suitable for the calculation. In addition, Savana Parque has a greater carbon stock, allowing a more conservative estimate and analysis in relation to the Baseline scenario and in relation to the difference between the two scenarios.

For the conversion of the aerial carbon stock calculated in each area of implementation of the layout of Agroforestry Systems in carbon dioxide stock, a conversion factor of 3.66 (CO_2/C ratio) was used. The results obtained for each of the municipalities and the total are shown in the tables below. A total of 25,700 tC of aerial carbon stock was obtained, equivalent to 75,333 tCO_2 in the areas where Agroforestry Systems should be implemented for the baseline.

Table 15: Aerial carbon stock for each municipality at baseline

Municipality	Total Area (ha)	Total Carbon Stock (tC)	Total CO2 (tCO_2)
Soure	152	3,906	14,313
Salvaterra	424	10,897	39,927
Cachoeira do Arari	224	5,757	21,093
Total	**800**	**20,560**	**75,333**

Source: Autors.

AGROFORESTRY SYSTEMS IN IMPACT AREAS

CARBON STOCK CALCULATION FOR INDIVIDUALS

For the layout proposed for the implementation of Agroforestry Systems, there are indications of types of individuals and the suggested quantity of these. For the estimation of the aerial carbon stock, it is necessary to obtain, first, the carbon stock for each of the individuals that compose the layout. This was accomplished through the use of an allometric equation for arboreal individuals proposed by Wanderlli (2008).

$$\mathbf{ln}\ ln\,(BA) = -1.869 + 2.231 * ln\,(DAP)$$

BA = aerial biomass (kg);

DAP = diameter at breast height (cm).

It was necessary to obtain the DAP (diameter at breast height) of each species and this was done through a bibliographic survey. The Table shows the results obtained from the aerial carbon stock using the allometric equation.

Table 16: Aerial carbon stock for individuals belonging to layout Emphasis on Açaí

Species	DAP (cm)	Source	Carbon Stock (tC/individuals)
Açaí (*Euterpe oleracea*)	7.94	MIRANDA, 2012	0.016
Guava (*Psidium guajava)*	22.40	VENDRUSCOLO, 2022	0.159
Tucuman *(Astrocaryum vulgare)*	2.00	SANTOS, 2010	0.001
Bacuri *(P. insignis)*	200.00	SOUZA et al., 2007	20.985
Andiroba *(C. guianensis)*	7.70	SOUZA et al., 2006	0.015

Source: Authors.

CARBON STOCK CALCULATION

To calculate the carbon stock, it was necessary to obtain an estimate of the number of individuals in the proposed layout. From the number of individuals estimated in the layouts (Table 17), the carbon stock for the respective layouts was obtained, represented by "Carbon Stock per Unit (tC/unit)". The calculation performed to demonstrate the estimated carbon stock in the AFS implementation areas was based on the product of the "Carbon Stock per Hectare (tC/ha)" and "Area (ha)" (Table 18). After obtaining the carbon stock, the conversion to carbon dioxide was performed.

Table 17: Estimation of individuals for layout Emphasis on Açaí and aerial carbon stock for individuals belonging to the layout

Layout	Species	Estimated Individuals	Carbon Stock (tC)
Emphasis on Açaí	Tucuman *(Astrocaryum vulgare)*	25	0.02
	Bacuri *(P. insignis)*	15	314.77
	Andiroba *(C. guianensis)*	15	0.22
	Açaí (*Euterpe oleracea*)	200	3.14
	Guava (*Psidium guajava)*	100	15.87

Source: Authors.

Table 18: Carbon stock per hectare for the layout

Layout	Carbon Stock per Unit (tC/unit)	Area (ha)	Carbon Stock per Hectare (tC/ha)
Emphasis on Açaí	334.02	1	334.02

Source: Authors.

Table 19: Carbon stock with the implementation of the agroforest system for the municipality

Municipality	Total Area (ha)	Total Carbon Stock (tC)	Total CO2 (tCO_2)
Soure	152	50,771	186,029
Salvaterra	424	141,625	518,923
Cachoeira do Arari	224	74,821	274,148
Total	**800**	**267,217**	**979,100**

Source: Authors.

COMPARISON WITH BASELINE

In this section, comparisons of the total stock of carbon dioxide between the baseline and the implementation of Agroforestry Systems in the impact areas are presented. The implementation of agroforestry systems in the impact areas has the potential to sequester approximately thirteen times more carbon dioxide compared to the phytophysiognomy established in the baseline. This demonstrates, based on the estimates made, that the implementation of the agroforestry system in the impact areas is crucial to promote natural forest restoration and consequently mitigate the impacts of climate change in the study region.

Table 20: Comparison of carbon dioxide stock for the baseline and for the implementation of the agroforestry system for the municipality

Municipality	Total Area (ha)	Baseline (tCO_2)	Agroforestry (tCO_2)
Soure	152	14,313	186,029
Salvaterra	424	39,927	518,923
Cachoeira do Arari	224	21,093	274,148
Total	**800**	**75,333**	**979,100**

Source: Autors.

Graph 3 and Table 21 shows the linear growth of CO_2 stock over the period of project implementation in the region (5 years). In the graph it is possible to observe the difference in annual values between the

Baseline scenario and the SAF scenario. The goal is that in the last year of the project the areas with SAF will have stored 0.3013 million tCO_2, while in the Baseline scenario the storage will be only 0.0873 million tCO_2. In the Baseline scenario, it was considered that annually there is a very low growth rate due to the natural regeneration of this phytophysionomy.

Graphic 3: Comparison of carbon dioxide stock for the baseline and for the implementation of the agroforestry system for all municipalities over 5 years.

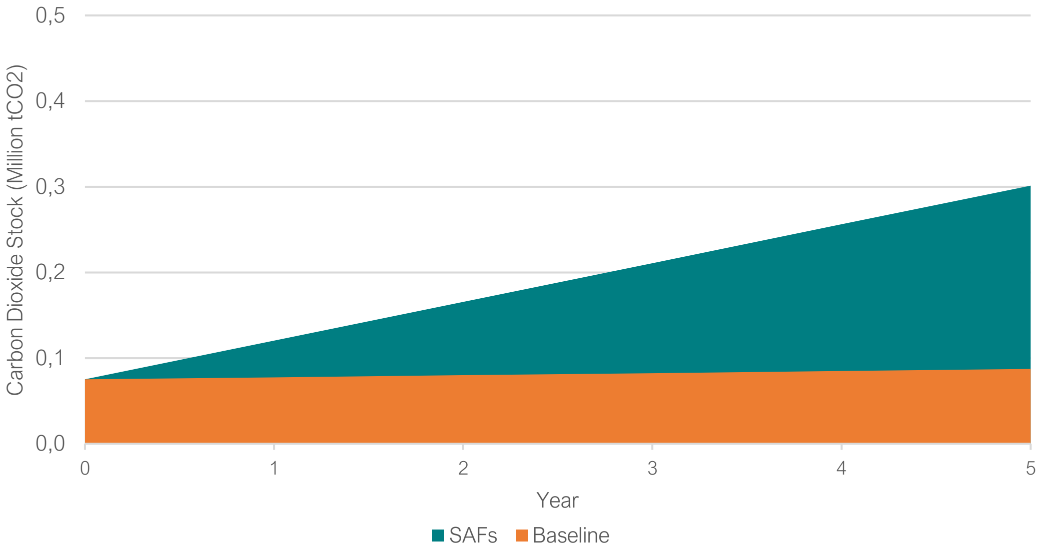


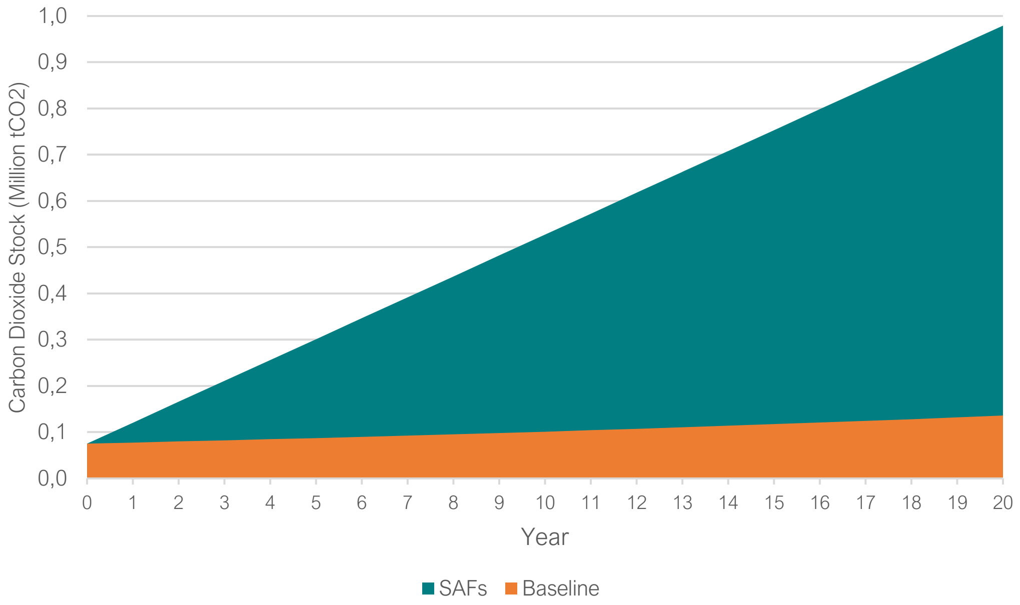
Table 21: Evolution of the carbon dioxide stock for the baseline and for the implementation of the agroforestry system for the municipality over 5 years.

Carbon Dioxide Stock (Million tCO_2)		
Year	**Baseline**	**Agroforestry**
0	0,0753	0,0753
1	0,0776	0,1205
2	0,0799	0,1657
3	0,0823	0,2109
4	0,0848	0,2561
5	0,0873	0,3013

Source: Authors.

Graph 4 shows the linear growth of the carbon dioxide stock over a 20-year period. In this case, the goal is that in 20 years of project the areas with SAF will have stored 0.9791 million tCO_2, while in the Baseline scenario the storage will be only 0.1361 million tCO_2.

Graphic 4: Comparison of carbon dioxide stock for the baseline and for the implementation of the agroforestry system for all municipalities over 20 years.



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Fundación Avina

CLIMATE VULNERABILITY ANALYSIS IN ILHA DO MARAJÓ / PA

PRODUCT B.1

IPCC Climate Scenarios

Developed by:

H2O Company

2022

CLIMATE VULNERABILITY ANALYSIS IN ILHA DO MARAJÓ / PA

2022

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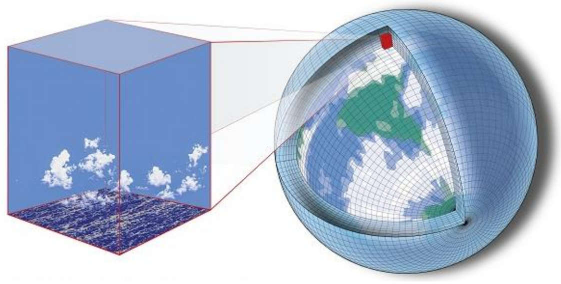
CLIMATE MODELS

Climate models are a numerical representation of the climate system based on the physical, chemical and biological properties of its components (atmosphere, ocean, ice, land surface) and their interactions. Climate models are applied as an analysis and research tool to study and simulate climate.

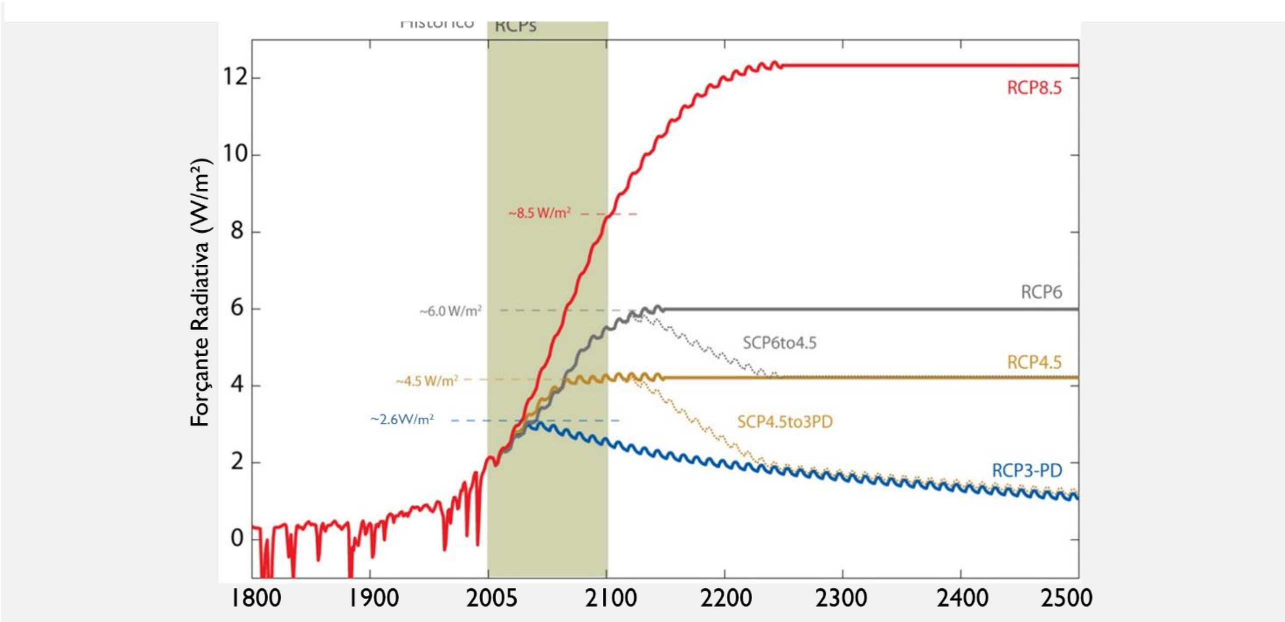


The results presented from the calculations of climate models are generally called climate projections (or climate scenarios). It is worth noting, however, that climate projections are not weather forecasts.

Unlike weather forecast models (forecast for days and weeks) or seasonal weather forecast models (forecast for a few months), climate projection models simulate future weather for a timescale of years to decades, based on assumptions. about this future, for example, the effects of a possible trajectory of increase or reduction in the concentrations of Greenhouse Gases (GHG) in the atmosphere.

In order to carry out future climate projections, climate models are forced by a set of boundary conditions and by certain GHG emission scenarios, called RCP's (Representative Concentration Pathways). The graph 1 presents the trajectories of atmospheric solar radiation (W/m²) based on the four different IPCC climate scenarios.

Graph 45 - Atmospheric solar radiation trajectories - RCP's Scenarios



Such emission scenarios are assumptions about future GHG emissions, based on estimates of world economic development, population growth, globalization, etc. The amount of greenhouse gases emitted depends on global developments. These scenarios are proposed by the IPCC (Intergovernmental Panel on Climate Change) through its Special Report on Emissions Scenarios (SRES).

The following is a brief description of what each RCP scenario represents.

- **RCP 8.5 (Scenario of Increase in GHG Emissions):** It is the high emissions scenario, consistent with a future without changes in public policies to reduce emissions and characterized by the increase in GHG emissions that lead to high atmospheric concentrations of GHG. It is largely aligned with the business-as-usual scenario.
- **RCP 6.0 (Stabilization Scenario of GHG Emissions):** It is a high-to-intermediate emissions scenario, where GHG emissions peak around 2080 and then decline throughout the century.
- **RCP 4.5 (Stabilization Scenario of GHG Emissions):** It is an intermediate emissions scenario, consistent with a future with relatively ambitious emission reductions, and GHG emissions increase slightly before starting to fall around 2040. Despite relatively ambitious emission reduction actions, RCP4.5 remains below the 2°C/1.5°C target set in the Paris Agreement.
- **RCP 2.6 (GHG Emissions Mitigation Scenario):** It is the only IPCC scenario that complies with the Paris Agreement's stated objective of limiting global warming to 2°C. It is consistent with the ambitious reduction of GHG emissions, which peak around 2020, then decrease linearly and become negative before 2100.

The following diagram illustrates and summarizes the information presented about each RCP scenario.

RCP 8.5	RCP 6.0	RCP 4.5	RCP 2.6
Business as Usual	Some Mitigation	Strong Mitigation	Aggressive Mitigation
Emissions continue to grow at current levels.	Emissions rise until 2080 and then fall.	Emissions stabilize at half of current levels by 2080.	Emissions fall by half by 2050.
It is likely to exceed 4°C	It is likely to exceed 2°C	Most likely not to exceed 2°C	Probably will not exceed 2°C

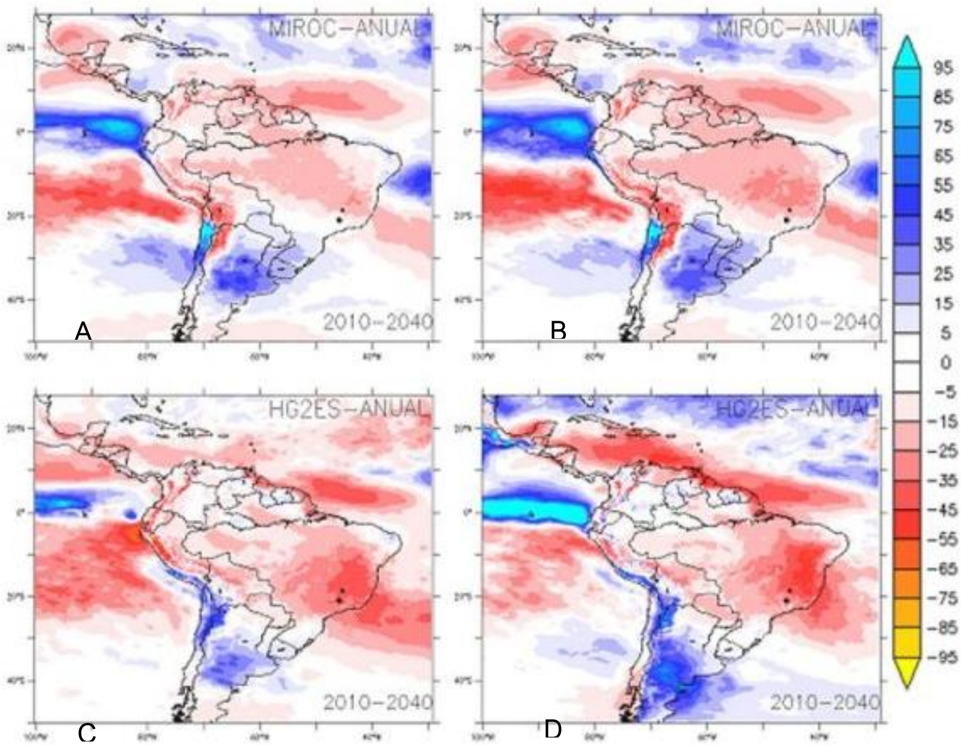
The IPCC, in its most recent report, AR6 (IPCC, 2022), points to an average temperature increase between 1.2° and 1.8°C in the scenario RCP4.5 and 1.3° to 1.9° C in the scenario RCP8.5 until 2040. However, this temperature increase will not be perceived uniformly across the planet.

According to the report, the so-called South American Monsoon region, which comprises part of the Midwest and the Brazilian Amazon, could experience temperature increases in the hottest season of the year of up to twice the global rate. The report also points out the possibility of occurrence of a 4.8 times greater number of extreme heat events with decadal recurrence, in relation to the current pattern until the 19th century.

Regarding the rise in mean sea level (until 2040), this could be from 28 cm to 55 cm, in the most optimistic scenario (RCP1.9) or from 63 cm to 1.02 m (RCP8.5, worst case scenario).), compared to the 1995-2014 average.

Regarding precipitation anomalies, Chou et al. (2014) pointed out negative variations between 5% and 45% for the entire Midwest and Amazon region in scenarios designed by two global climate models (MIROC and HADGEM) with regionalization by the ETA model (Figure 1). Such a reduction in precipitation implies a systematic reduction of flows in the Amazon basin, especially the Tocantins River basin, an important contributor to the fluvial-estuarine regime of Marajó Bay.

Figure 1: Precipitation anomalies for South America to 2040: a) MIROC RCP4.5; b) MIROC RCP8.5; c) HADGem RCP4.5; d) HADGem RCP8.5.



Source: Chou et al.,2014.

CLIMATE SCENARIOS

For analyses that wish to understand stressed exposure to plausible risks from physical climate change in the period from today to mid-century, scenarios consistent with RCP8.5 should be considered, as they more closely reflect a path of conditions normal business practices, in line with failures to properly implement mitigation policies.

For this study, RCP's 4.5 and 8.5 were adopted, aiming to contrast two scenarios, one being realistic and the other pessimistic. The first assumes that measures will be adopted to reduce emissions across the planet, with emissions peaking and subsequent stabilization in 2060. The second predicts a global context in which greenhouse gas emissions increase until 2100, reaching levels twice greater than the RCP 4.5 scenario.

PROJETA is a system developed by INPE, which regionalized climate change projections for South America, using the ETA model, which is the most advanced in relation to climate projections.

For the construction of climate scenarios, data from climate variables available on the **PROJETA**[2] platform were used, provided by the National Institute for Space Research (INPE). This platform provides data on 59 climate variables, with historical data for the period from 1961 to 2005, and projected data based on the RCP scenarios for the period 2006-2099.

To assess sea level rise, data from the **Climate Central**[3] platform were considered. The platform uses elevation data from Climate Central's CoastalDEM®, which was reviewed and published in Kulp and Strauss (2018) and improved in Kulp and Strauss (2021).

The main characteristics of the climate scenarios developed to assess climate risks in the study municipalities, located in the Marajó archipelago, are presented below.

2 https://projeta.cptec.inpe.br/#/dashboard

3 https://coastal.climatecentral.org/

TIME HORIZON

According to the World Meteorological Organization, climate can be characterized by conditions that occur over a period of at least 30 years. These measurements make it possible to create a reference so that past and future climates can be compared.

For the construction of the climate scenario and the identification of future climate vulnerabilities, it is necessary to establish a base period for comparison. Based on the technical-scientific literature, the climate of the past was defined from the average of the period between 1961-1990 (normal climate standards records), as it characterizes a period without, or with minimal, interference from global climate change. The future climate was defined for the period between 2021-2050, in line with the implementation period of the proposed adaptation project. This division meets the basic meteorological requirements for climate characterization.

Table 1 summarizes the periods defined for the construction of climate scenarios.

Table 35 - Time periods to characterize past and future climates

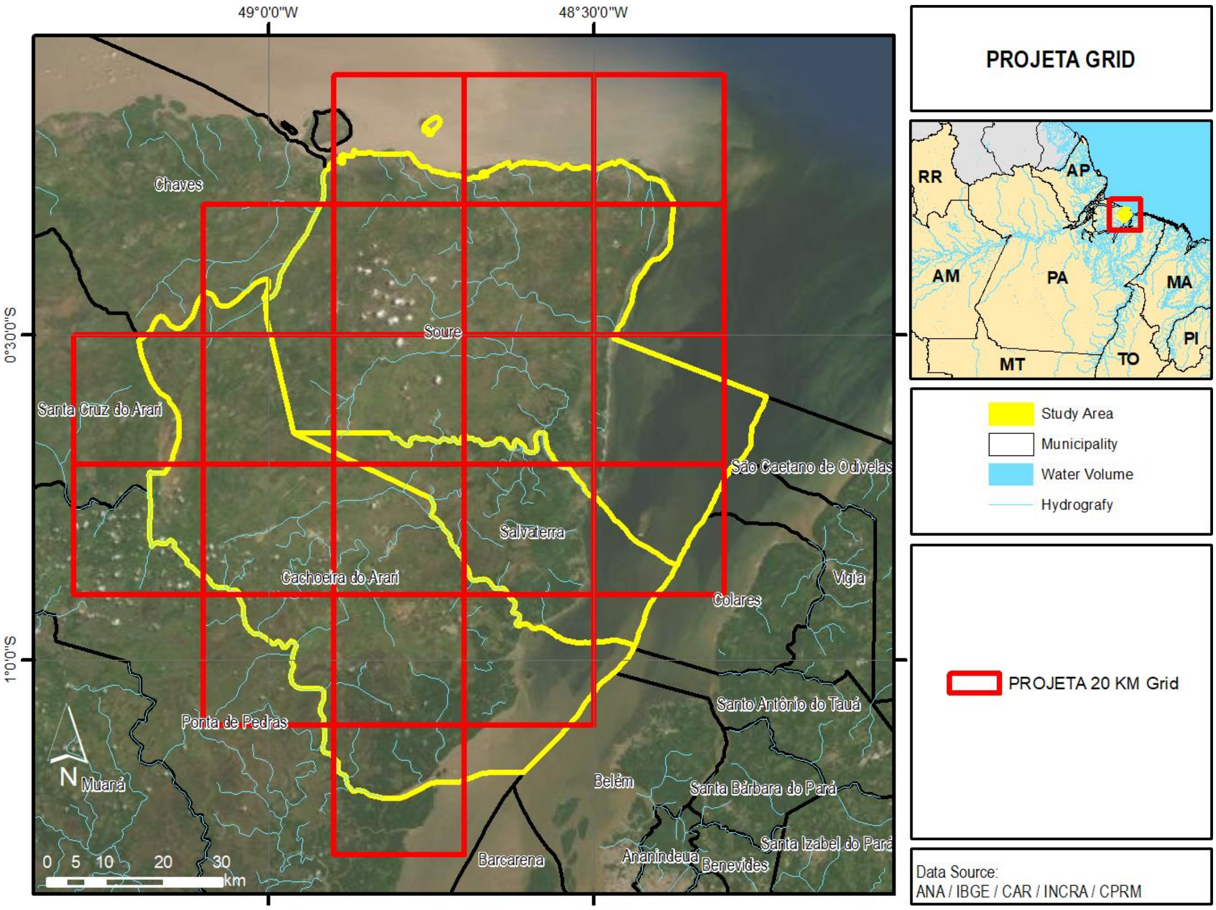
Climate Characterization	Period of time	PROJOTA data series
Past	1961 – 1990 (30 years)	Observed (Historical)
Future	2021 – 2050 (30 years)	Projected

STUDY AREA

The PROJETA platform makes its data spatialized in 20 km x 20 km squares. For the projection of climatic variables in the study area, 21 squares were considered that overlap the cities studied. Each square has a value for the evaluated climate variable, in each period considered.

Figure 1 shows the grid used for the present study.

Figure 9: Atmospheric solar radiation trajectories - RCP's Scenarios



CLIMATE VARIABLES OF INTEREST

For the construction of climate scenarios, the climate variables of interest were selected for the analysis of vulnerabilities in the region. The variables were selected from the climate changes already identified in the climate diagnosis, and confirmed in the field visit, such as the reduction of annual precipitation volumes, and elevation of temperature values.

Table 2 presents the climatic variables considered in the study.

Table 36 - Summary of climate variables evaluated in the RCP scenarios

Variable	Description	Source
PRCPTOT	Annual total precipitation	PROJETA (INPE)
CDD	Consecutive days without rain	PROJETA (INPE)
RX1Day	Maximum daily precipitation	PROJETA (INPE)
TP2m	Air temperature at 2 meters	PROJETA (INPE)
Sea Level	Flooded areas with sea level rise	Climate Central (CoastalDEM)

CLIMATE DIAGNOSIS AND PROGNOSIS

The characterization of the past climate (1961-1990) is represented by the climate diagnosis, used as a basis for comparison, and the characterization of the future climate (2021-2050) is represented by the climate prognosis in the RCP 4.5 and RCP 8.5 scenarios.

The climate diagnosis and prognosis were built for the four climate variables of interest, for the area of the municipalities of Soure, Salvaterra and Cachoeira do Arari. The data used have a daily frequency, being the basis for monthly, seasonal, and annual values.

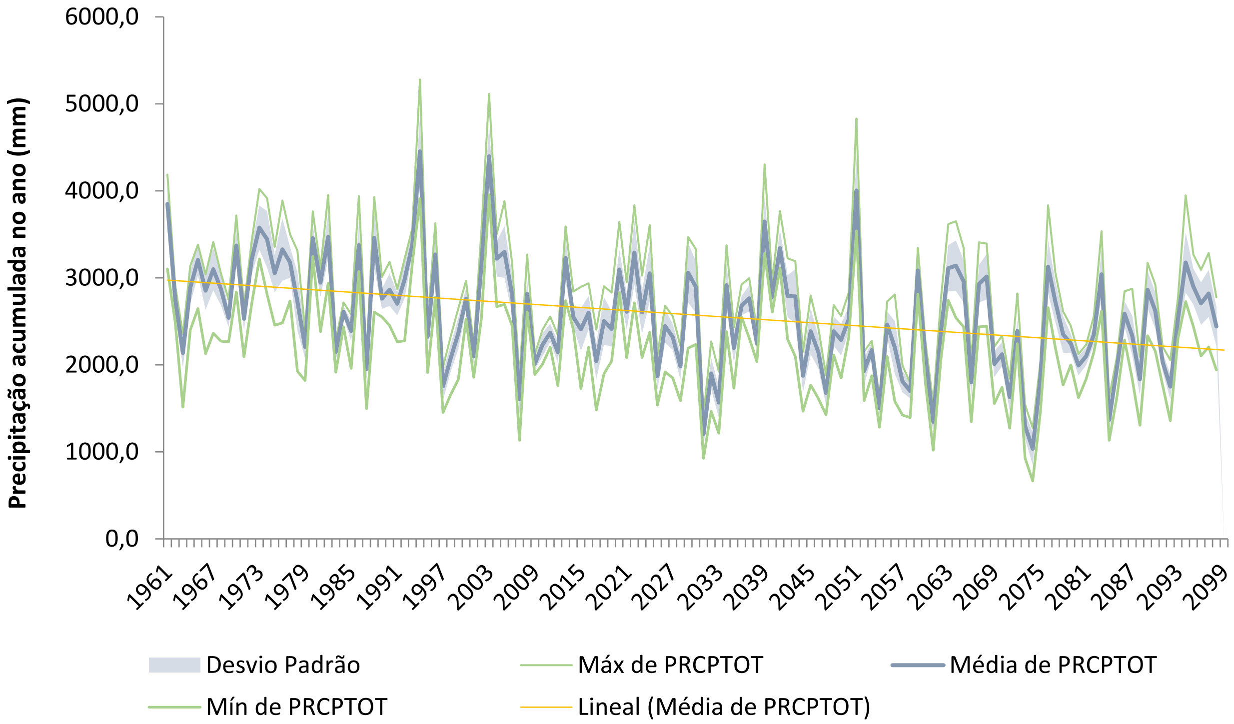
By projecting the climate variables in the study region for the past (diagnosis) and future (prognosis) period, it is possible to observe the changes projected for the future in relation to a baseline.

Below are graphs that show the behaviour of the selected climate variables in the past period and their projections in the two future climate scenarios.

TOTAL ANNUAL PRECIPITATION

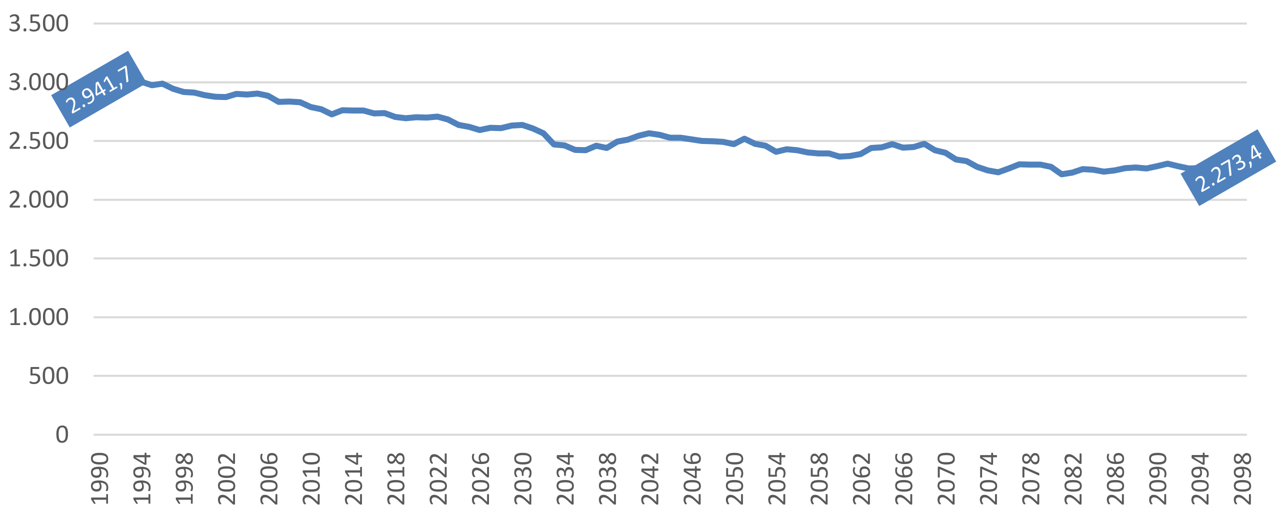
Graph 2 shows the behaviour of the PRCPTOT variable in the RCP 4.5 scenario, from 1961 to the end of the century, in 2100, as well as its trend line, in red.

Graph 46: PRCPTOT – RCP 4.5 (1961-2100)



To evaluate the observed trend, the concept of moving average of 30 years was used, for the average values of total annual precipitation, considering the definition of climatological normal for characterization of the climate in a given period, presented in graph 3.

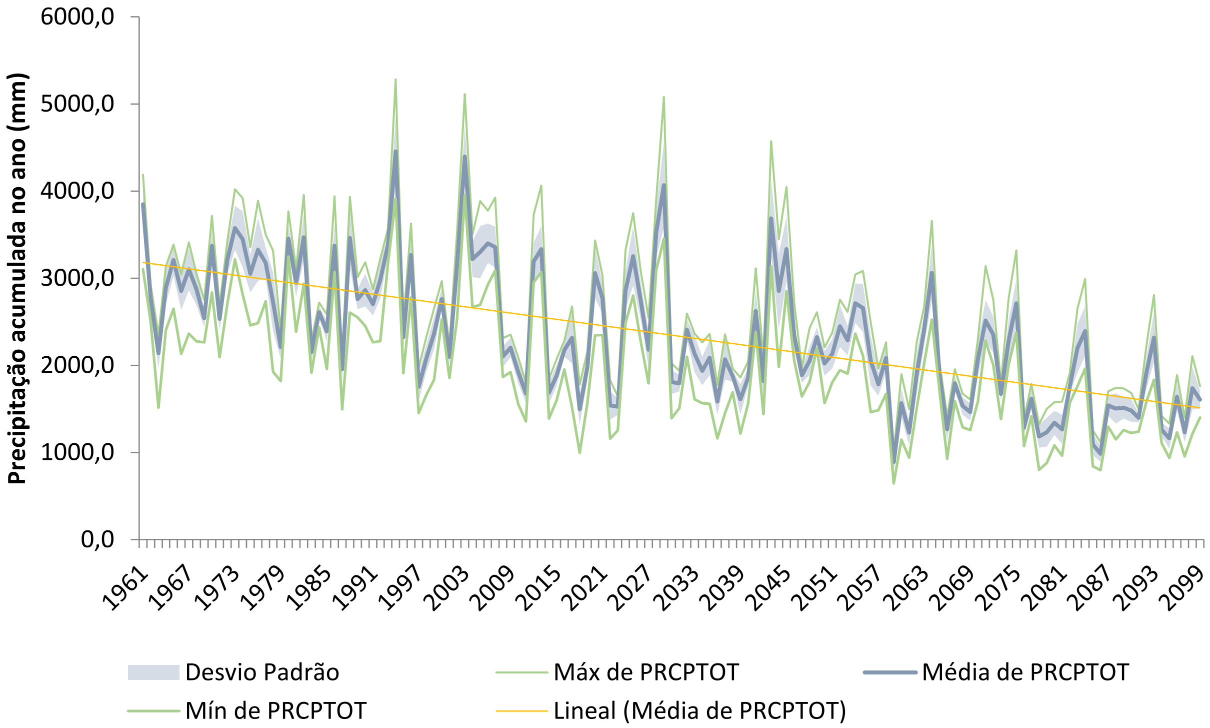
Graph 47: PRCPTOT – RCP 4.5 – Moving Average of 30 years



It is observed that, in the RCP 4.5 scenario, a reduction of about 668 mm in annual rainfall is projected until the end of the century, equivalent to a reduction of 23% in relation to the average for the period 1961-1990.

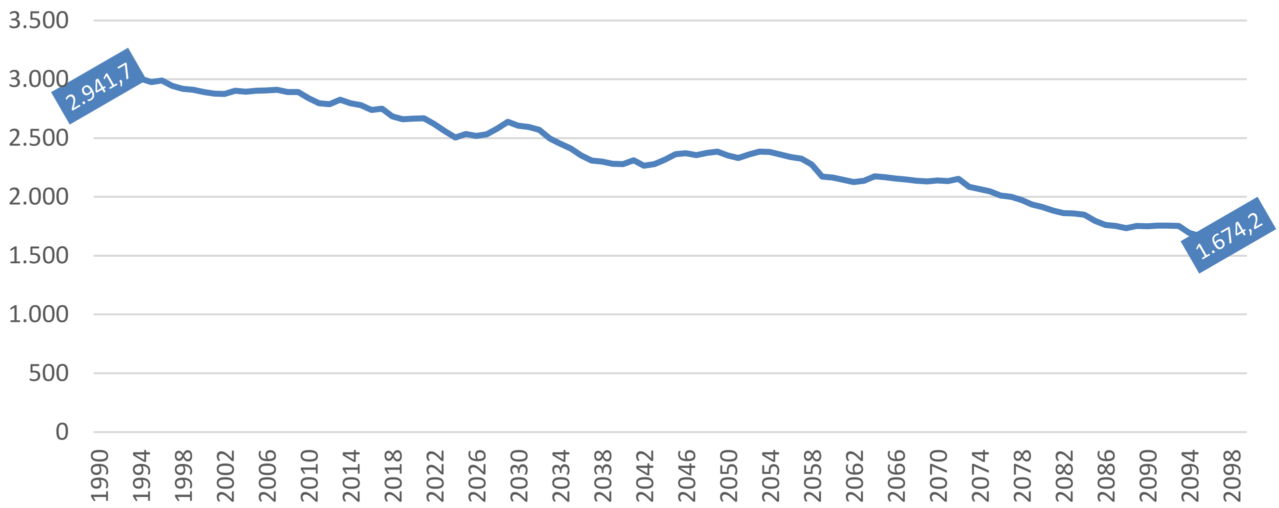
Graph 4 shows the behavior of the PRCPTOT variable in the RCP 8.5 scenario, from 1961 to the end of the century, in 2100, as well as its trend line, in red.

Graph 48: PRCPTOT – RCP 8.5 (1961-2100)



To evaluate the observed trend, the 30-year moving average of the average values of total annual precipitation was used, shown in graph 5.

Graph 49: PRCPTOT – RCP 8.5 – Moving Average of 30 years

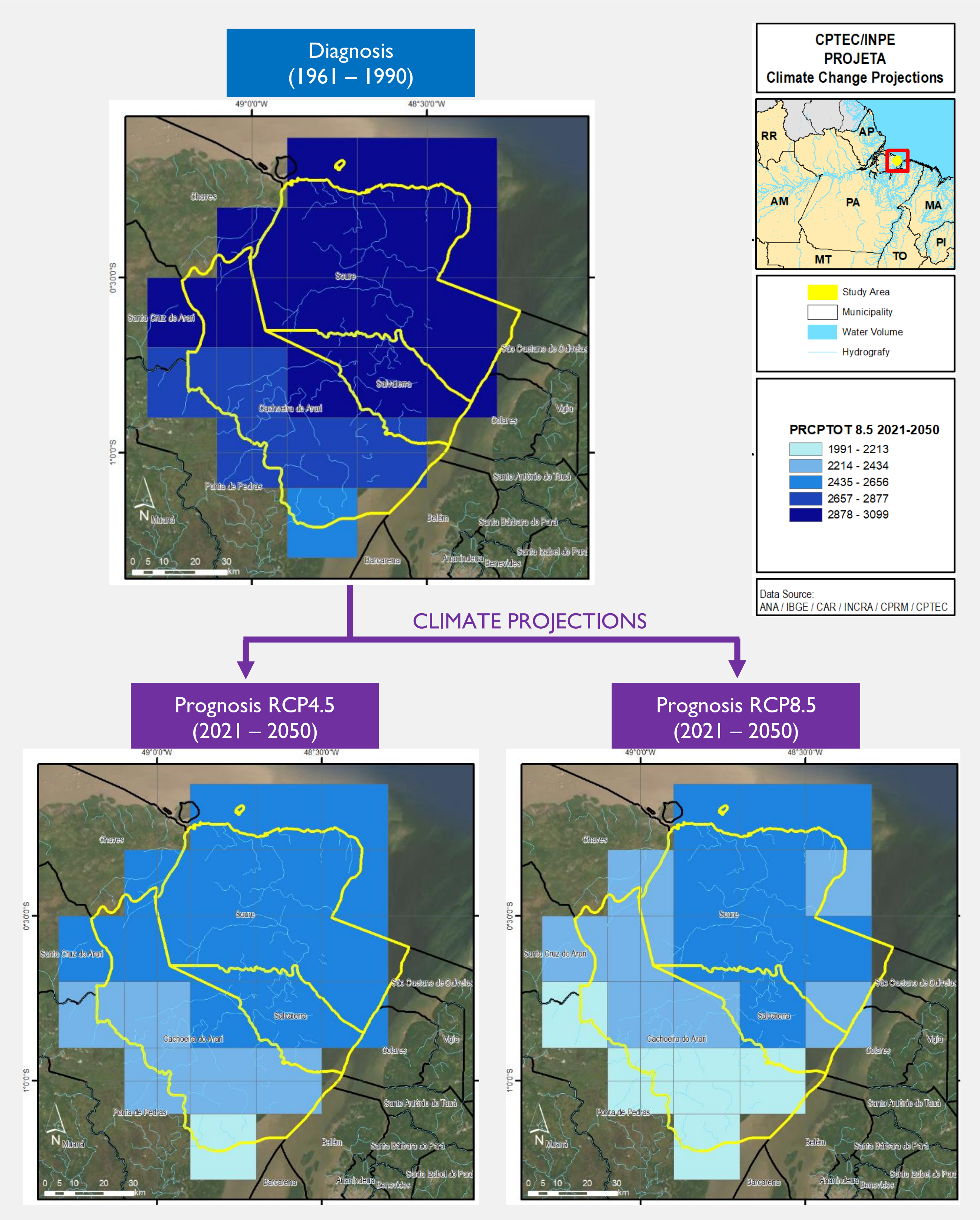


In the RCP 8.5 scenario, a reduction of about 1,268 mm in annual rainfall is projected for the end of the century, equivalent to a reduction of 43% in relation to the average for the period 1961-1990.

The spatial distribution of this climate variable in the study area is shown below.

The maps in figure 2 present the diagnosis and climate prognosis, in the RCP 4.5 and RCP 8.5 scenarios, for the variable annual total precipitation. The variable values are presented in the unit of millimeters of rainfall per year (mm/year).

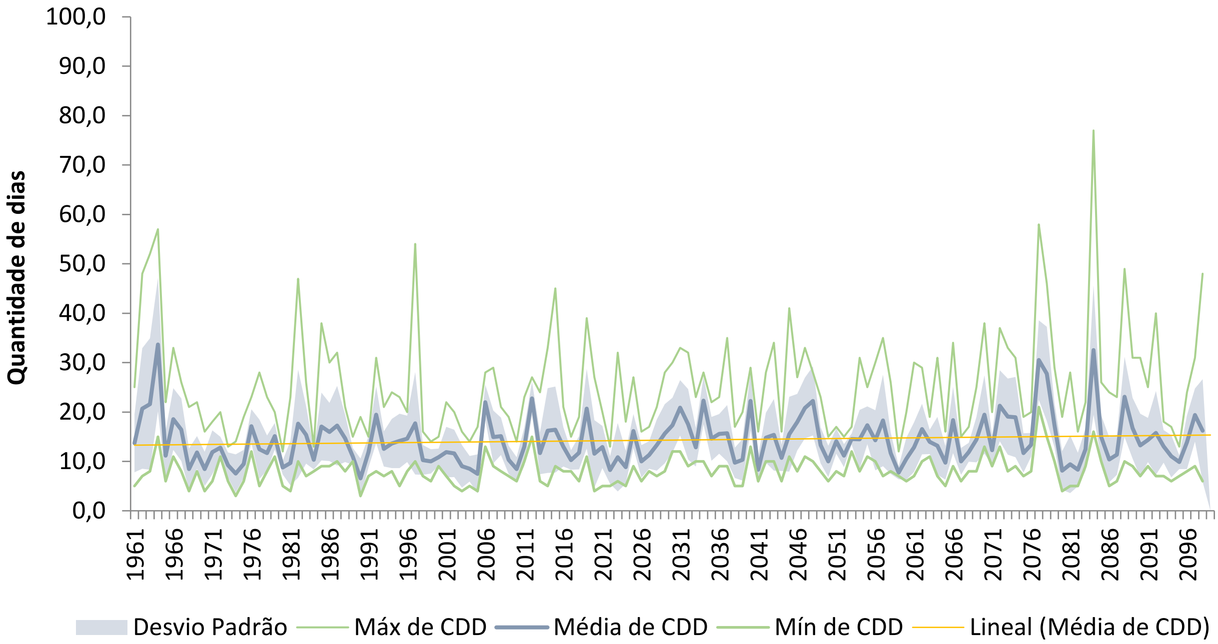
Figure 10: Maps of the PRCPTOT variable in the RCP 4.5 and RCP 8.5 scenarios



CONSECUTIVE DAYS WITHOUT RAIN

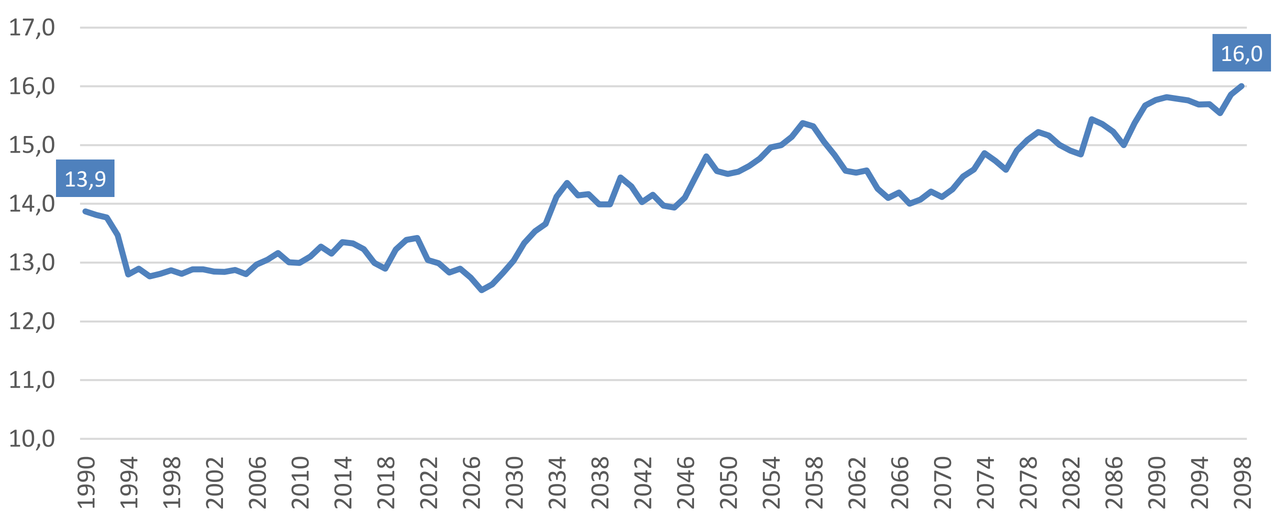
Graph 6 shows the behaviour of the CDD variable in the RCP 4.5 scenario, from 1961 to the end of the century, in 2100, as well as its trend line, in red.

Graph 50: CDD – RCP 4.5 (1961-2100)



To evaluate the observed trend, the 30-year moving average of the average values of consecutive days without rain was used, shown in graph 7.

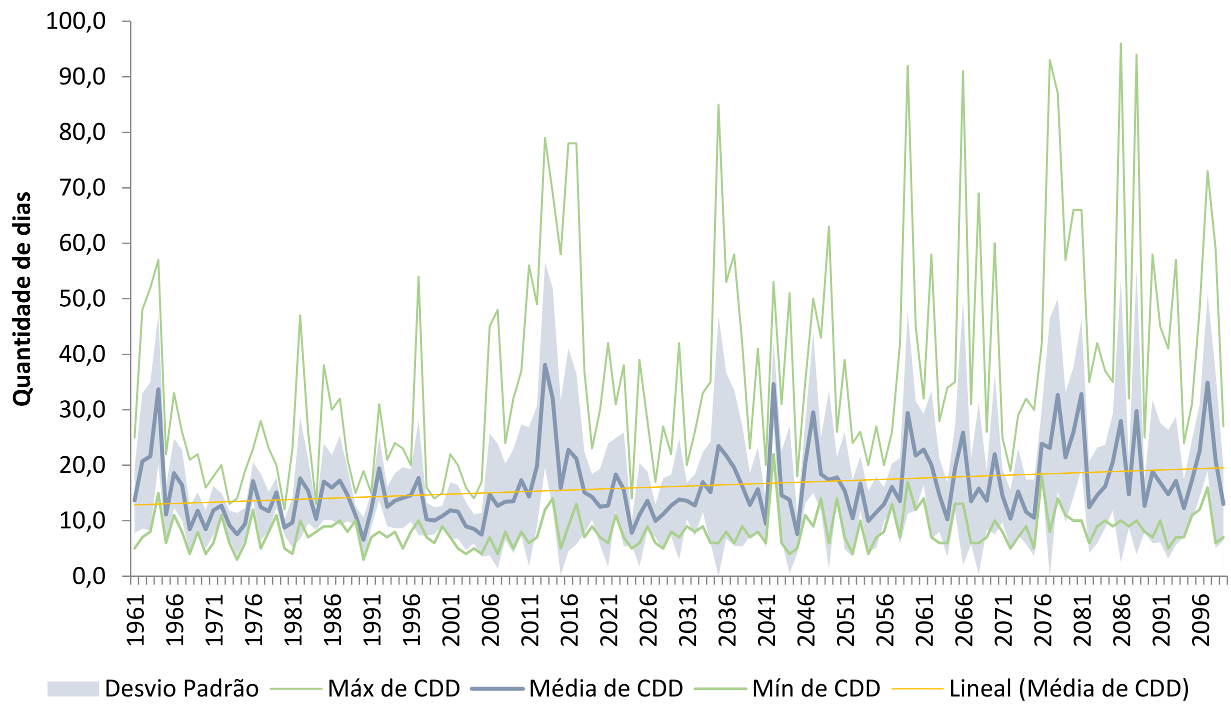
Graph 51: CDD – RCP 4.5 – Moving Average of 30 years



There is an upward trend of up to 15% in the average of consecutive days without rain in the region studied in this scenario.

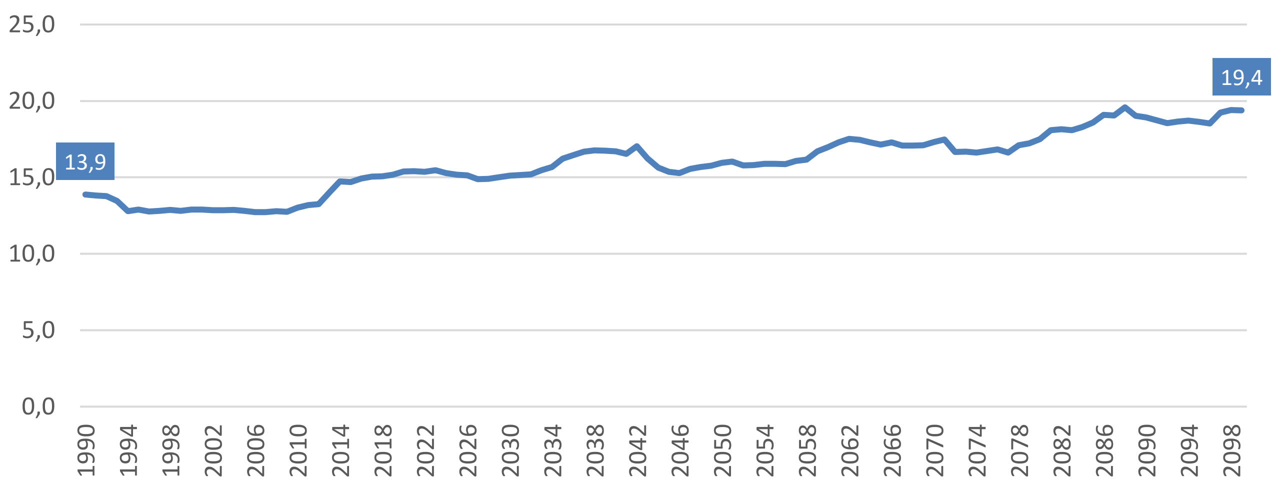
Graph 8 shows the behaviour of the CDD variable in the RCP 8.5 scenario, from 1961 to the end of the century, in 2100, as well as its trend line, in red.

Graph 52: CDD – RCP 8.5 (1961-2100)



To confirm the observed trend, the 30-year moving average of the average values of total annual precipitation was used, shown in graph 9.

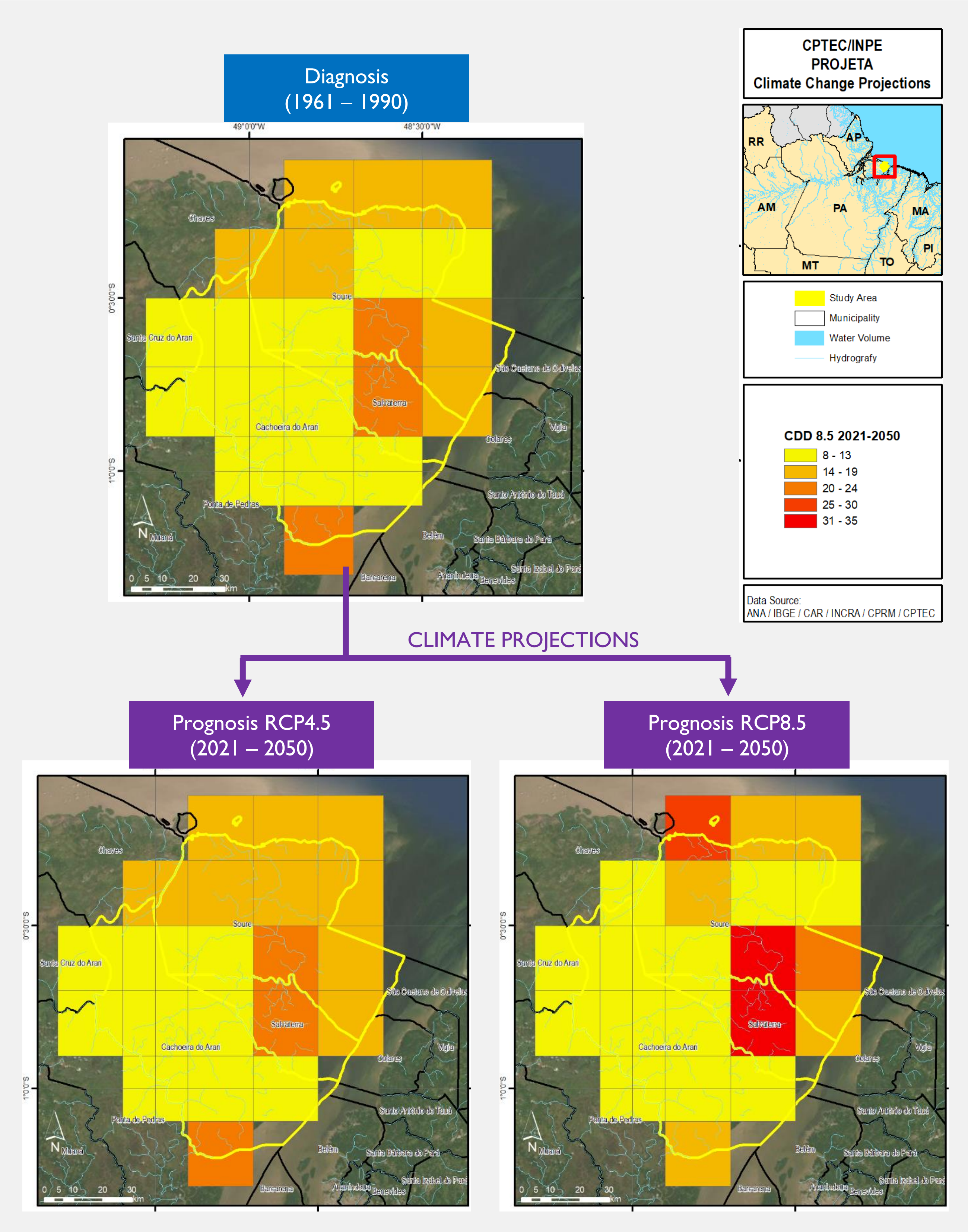
Graph 53: CDD – RCP 8.5 – Moving Average of 30 years



In the RCP 8.5 scenario, the tendency for consecutive days without rain to increase is greater, since in this scenario there is also a greater reduction in annual precipitation volumes. Consecutive days without rain could increase by up to 40% by the end of the century.

The maps in figure 3 present the climate diagnosis and prognosis, in the RCP 4.5 and RCP 8.5 scenarios, for the variable of consecutive days without rain. The variable values are displayed in the unit of days.

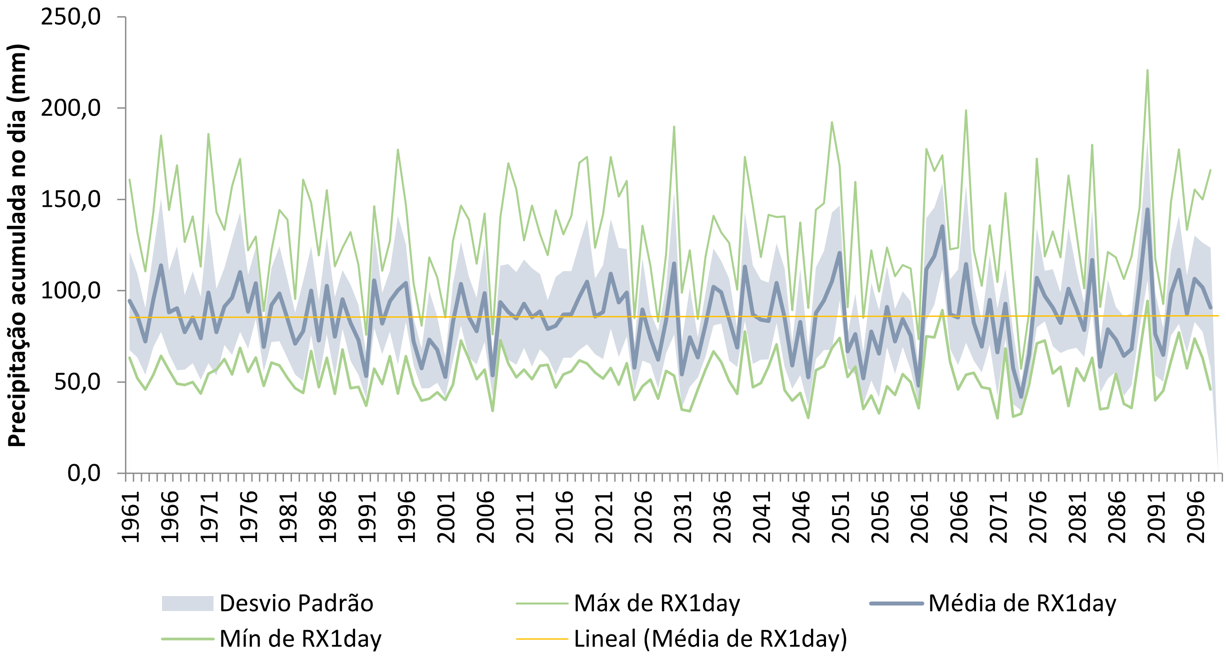
Figure 11: Maps of the CDD variable in the RCP 4.5 and RCP 8.5 scenarios



MAXIMUM DAILY RAIN

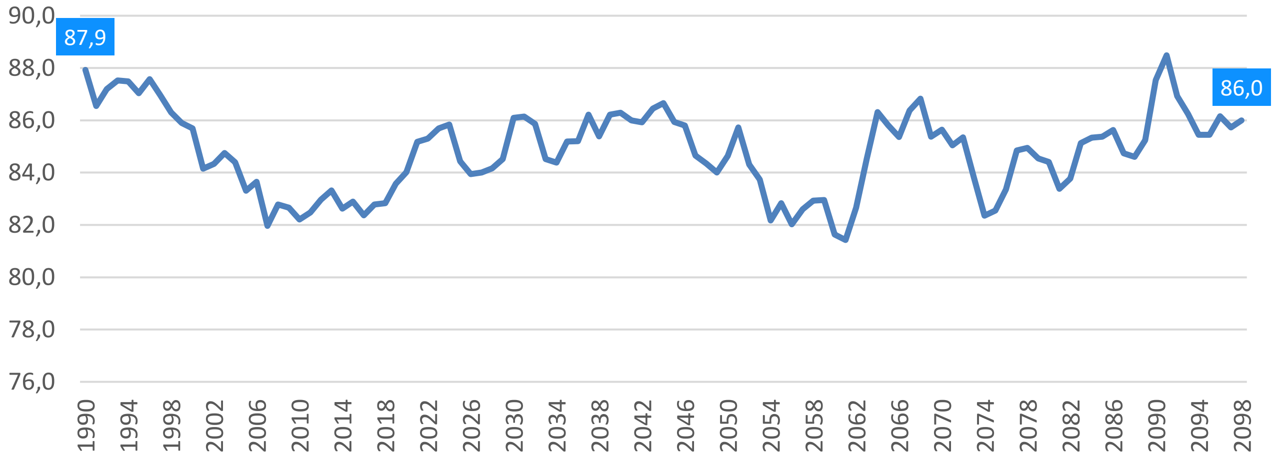
Graph 10 shows the behaviour of the variable RX1Day in the RCP 4.5 scenario, from 1961 to the end of the century, in 2100, as well as its trend line, in red.

Graph 54: RX1Day – RCP 4.5 (1961-2100)



To assess the trend in the behaviour of this variable, the 30-year moving average of its average values was used, shown in graph 11.

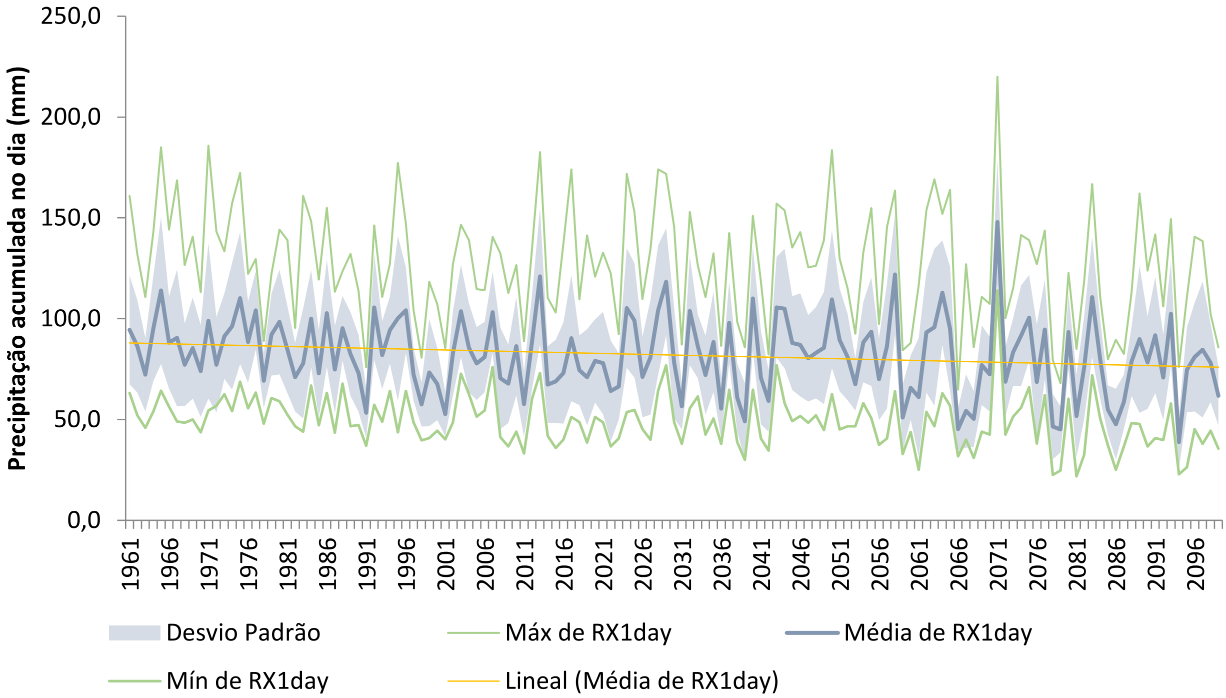
Graph 55: RX1Day – RCP 4.5 – Moving Average of 30 years



In the RCP 4.5 scenario, this variable shows little variation in future periods. Thus, despite the reduction in annual precipitation volumes (-23%), it is projected that the maximum daily rainfall will continue to present high intensities. Still, the upper extremes may be intensified.

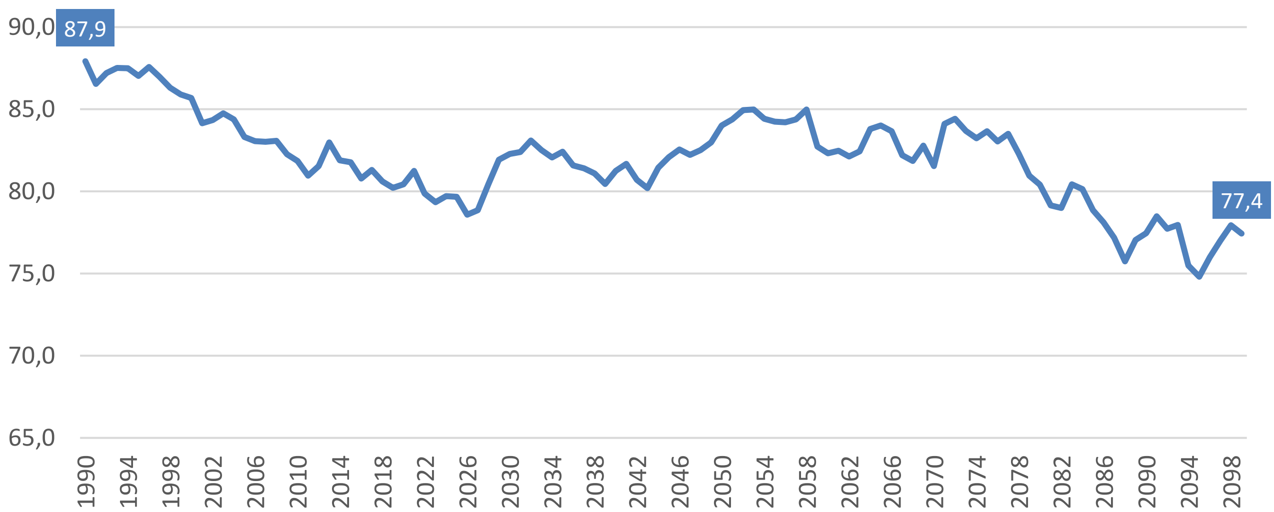
Graph 12 shows the behavior of the CDD variable in the RCP 8.5 scenario, from 1961 to the end of the century, in 2100, as well as its trend line, in red.

Graph 56: RX1Day – RCP 8.5 (1961-2100)



To assess the observed trend, the 30-year moving average of the average values of total annual precipitation was used, shown in graph 13.

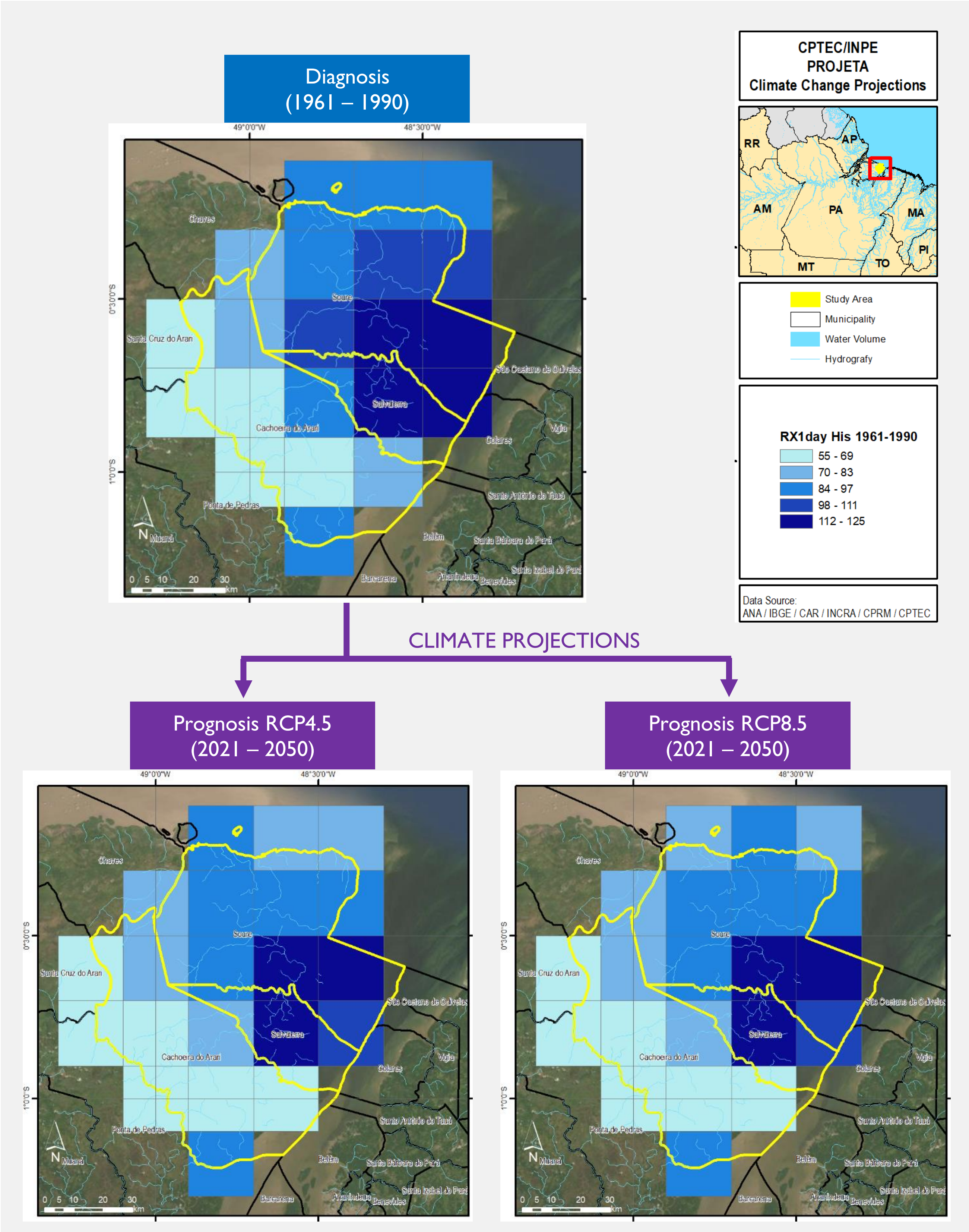
Graph 57: RX1Day – RCP 8.5 – Moving Average of 30 years



In the RCP 8.5 scenario, since annual rainfall should be reduced more drastically (-43%), maximum daily rainfall should also be mitigated, albeit to a lesser extent (-12%).

The maps in figure 4 present the climate diagnosis and prognosis, in the RCP 4.5 and RCP 8.5 scenarios, for the variable of maximum daily precipitation. The variable values are displayed in millimeters.

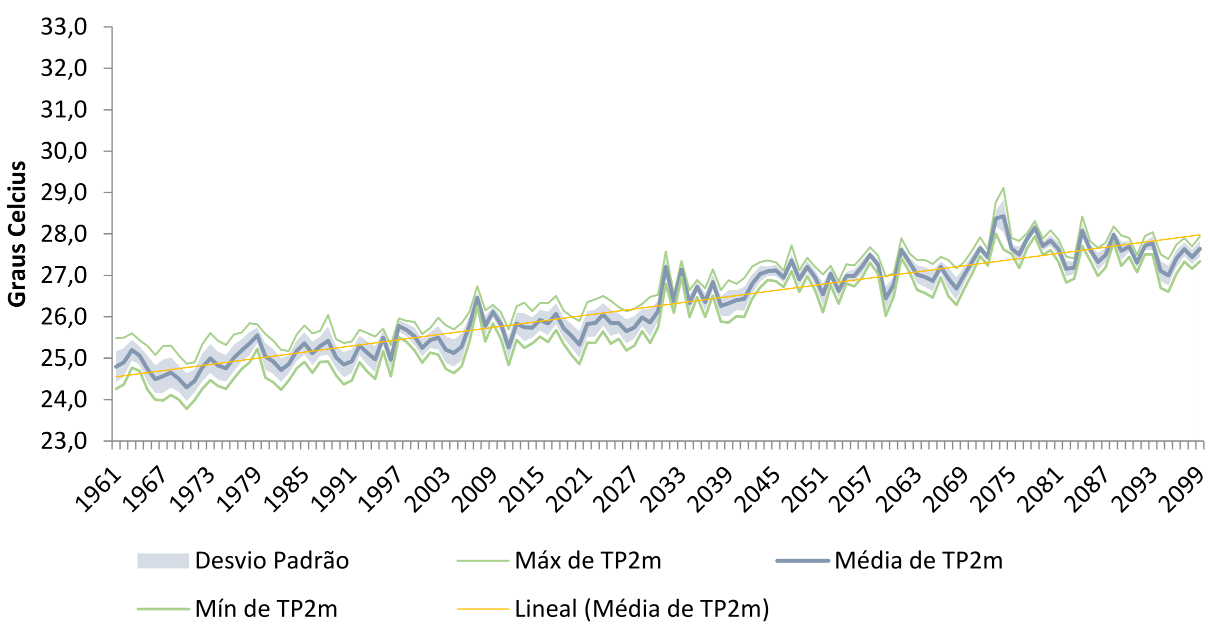
Figure 12: Maps of the RX1Day variable in the RCP 4.5 and RCP 8.5 scenarios



AIR TEMPERATURE AT 2 METERS

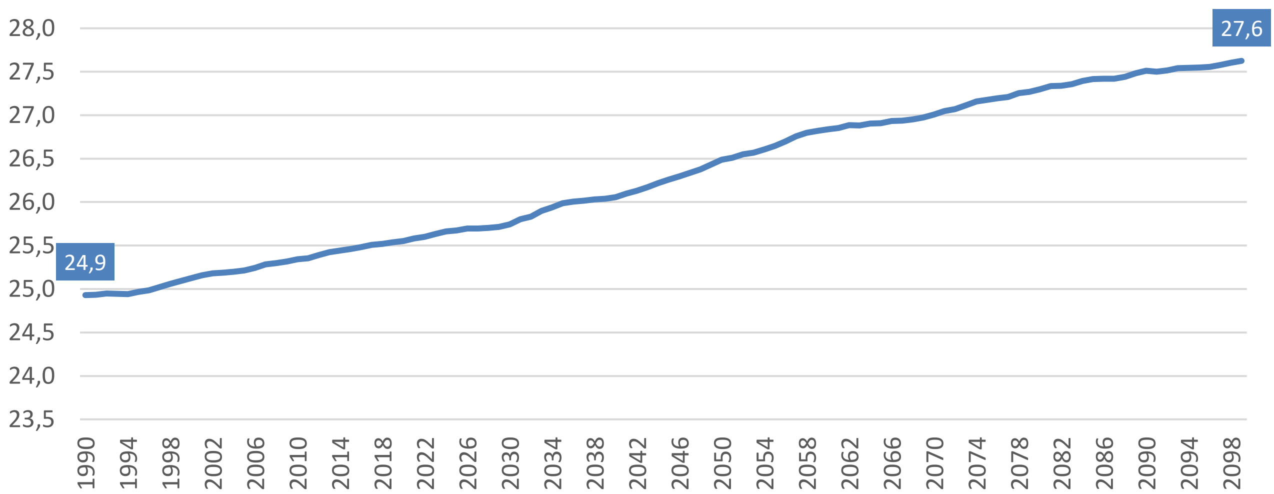
Graph 14 shows the behaviour of the TP2m variable in the RCP 4.5 scenario, from 1961 to the end of the century, in 2100, as well as its trend line, in red.

Graph 58: TP2m – RCP 4.5 (1961-2100)



To confirm the observed trend, the 30-year moving average of the average values of air temperature at 2 meters was used, shown in graph 15.

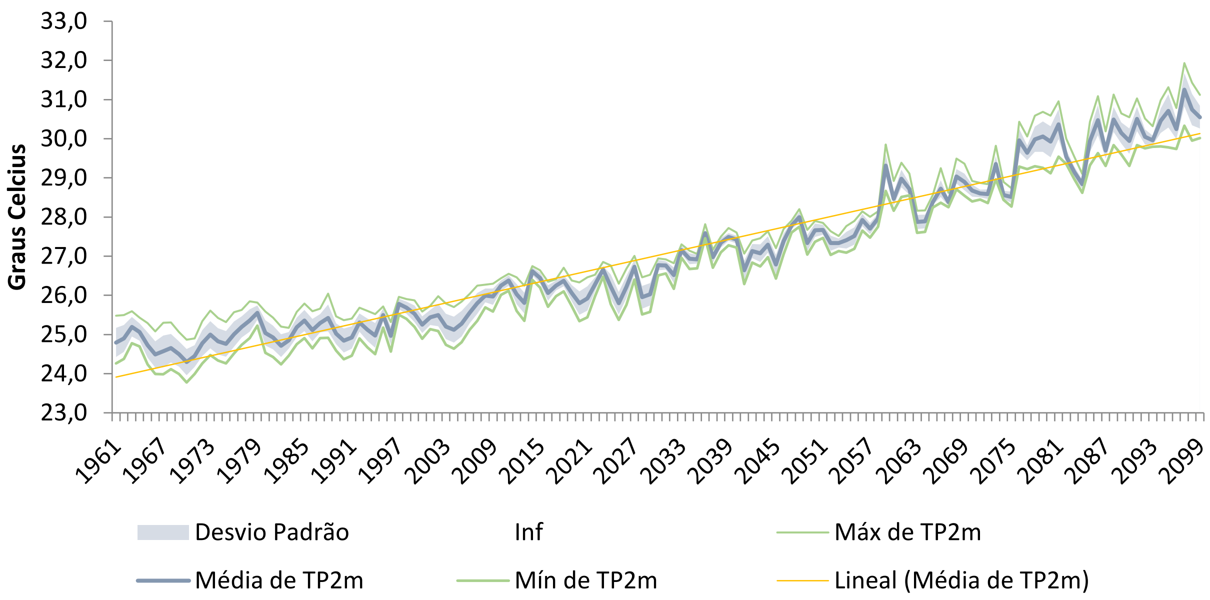
Graph 59: TP2m – RCP 4.5 – Moving Average of 30 years



The trend of rising temperature values is clear. It is observed that, in the RCP 4.5 scenario, an average temperature rise of 2.7ºC is projected by the end of the century.

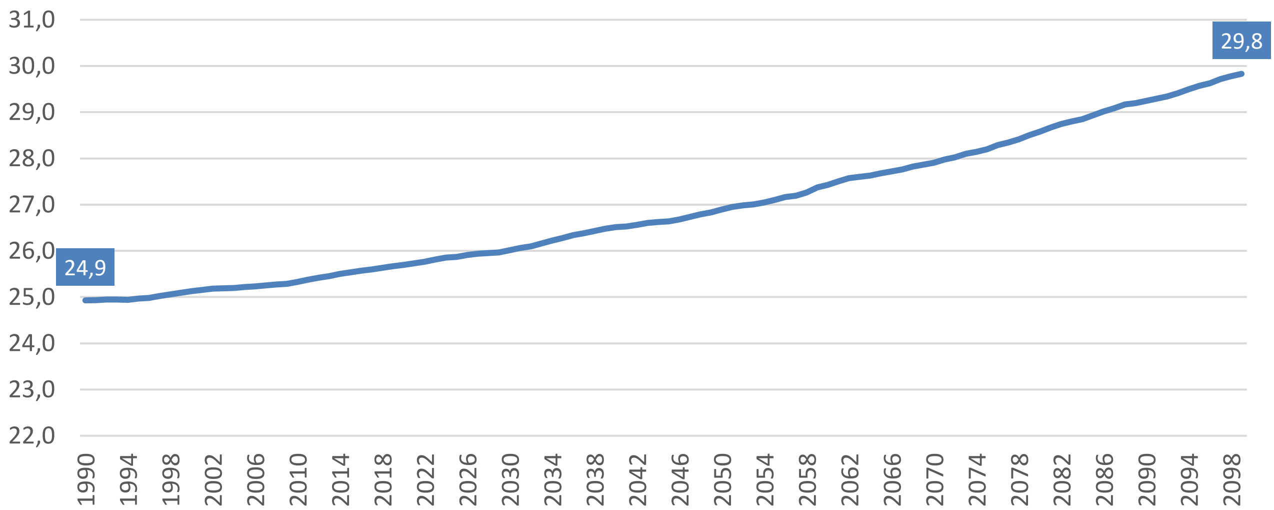
Graph 16 shows the behavior of the TP2m variable in the RCP 8.5 scenario, from 1961 to the end of the century, in 2100, as well as its trend line, in red.

Graph 60: TP2m – RCP 8.5 (1961-2100)



To confirm the observed trend, the 30-year moving average of the average values of air temperature at 2 meters was used, shown in graph 17.

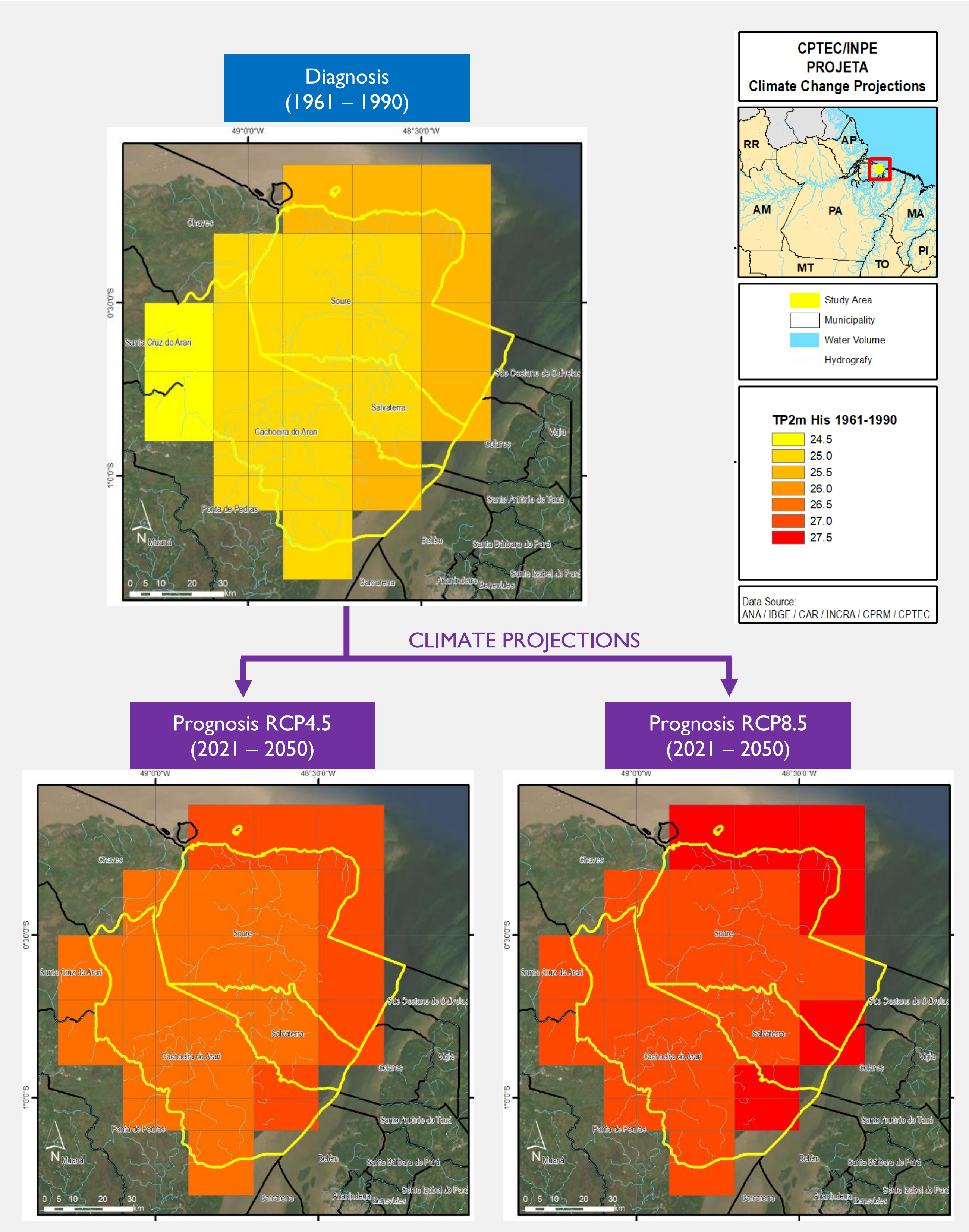
Graph 61: TP2m – RCP 8.5 – Moving Average of 30 years



It is observed that, in the RCP 8.5 scenario, the temperature rise is more intense, with an average temperature rise of 4.9ºC being projected by the end of the century, for the study region.

The maps in figure 5 present the climate diagnosis and prognosis, in the RCP 4.5 and RCP 8.5 scenarios, for the variable air temperature at 2 meters. The variable values are presented in the unit of degrees Celsius (ºC).

Figure 13: Maps of the TP2m variable in the RCP 4.5 and RCP 8.5 scenarios



SEA LEVEL RISE

To assess the projections of sea level rise in the study region, data from the Climate Central platform, which uses the digital elevation model for coastal regions (CoastalDEM), were considered. This model was made using artificial intelligence to improve elevation data developed by NASA. The horizontal resolution of CoastalDEM elevation data is one arc-second, or about 30 meters (100 feet).

> **Areas below water level and with an unobstructed path to the ocean are shaded red. By default, areas below water level, but which appear to be protected by ridges, are not shaded.**

The platform facilitates the mapping of any scenario and well reflects the threats of permanent sea level rise in the future. However, the accuracy of these maps drops when assessing the risks of extreme flood events. The maps are not based on physical simulations of storms and floods and do not account for factors such as erosion, future changes in storm frequency or intensity, inland flooding, or contributions from rainfall or rivers.

Table 3 presents the sea level rise values in each scenario.

Table 37 - Sea level rise in RCP scenarios

Scenario	Projected sea level rise
RCP 4.5	0,5 meters
RCP 8.5	1,0 meters

The municipality of Soure is the one that presents most of its territory inundated due to the advance of the sea level over Marajó Island. In the RCP 4.5 scenario, the municipality would have more than half of its territory exposed to tidal floods, and above 60%, in the RCP 8.5 scenario. In Salvaterra, the floodable areas are concentrated on the border with Soure and on part of its coast, close to the urbanized area of the municipality. In the RCP 8.5 scenario, up to 7% of the municipality's area would be exposed to tidal floods, with the urban area being the most affected. In Cachoeira do Arari, in the RCP 4.5 scenario, less than 1% of its area would be exposed to tidal floods. In the RCP 8.5 scenario, these areas would exceed 5% of the area of the municipality, and the most affected regions are where the PAE (Extractive Settlement Projects) Urubuquara and Xipaiá are located.

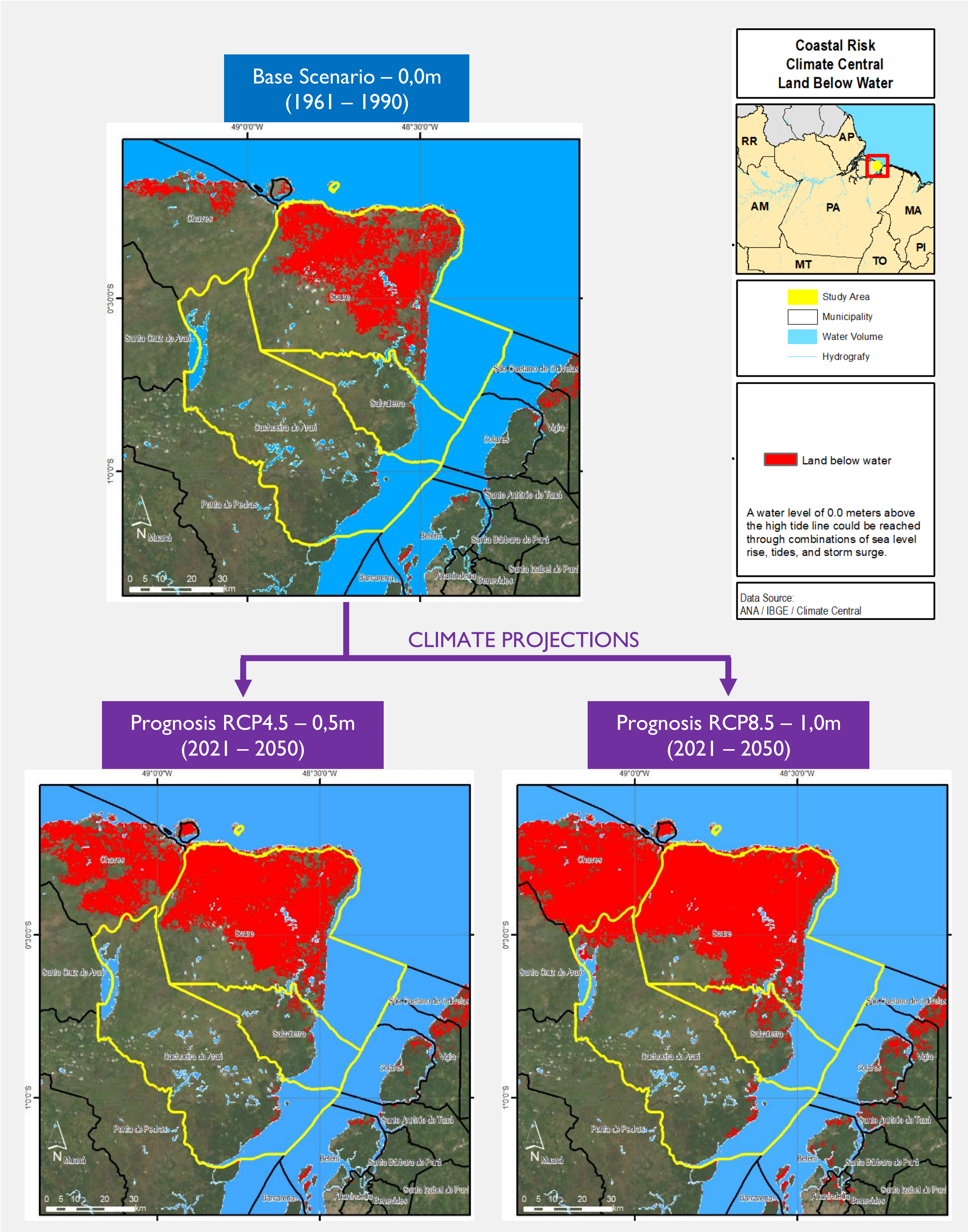
Table 4 presents the percentages of area for each municipality that would be exposed to tidal floods for the two sea level rise scenarios.

Table 38 - Sea level rise in RCP scenarios

City	Flooded area in relation to city area (%)		
	Base Scenario – 0,0m	RCP 4.5 – 0,5m	RCP 8.5 – 1,0m
Soure	34,1	51,6	61,0
Salvaterra	0,2	2,1	7,0
Cachoeira do Arari	0,1	0,6	5,6

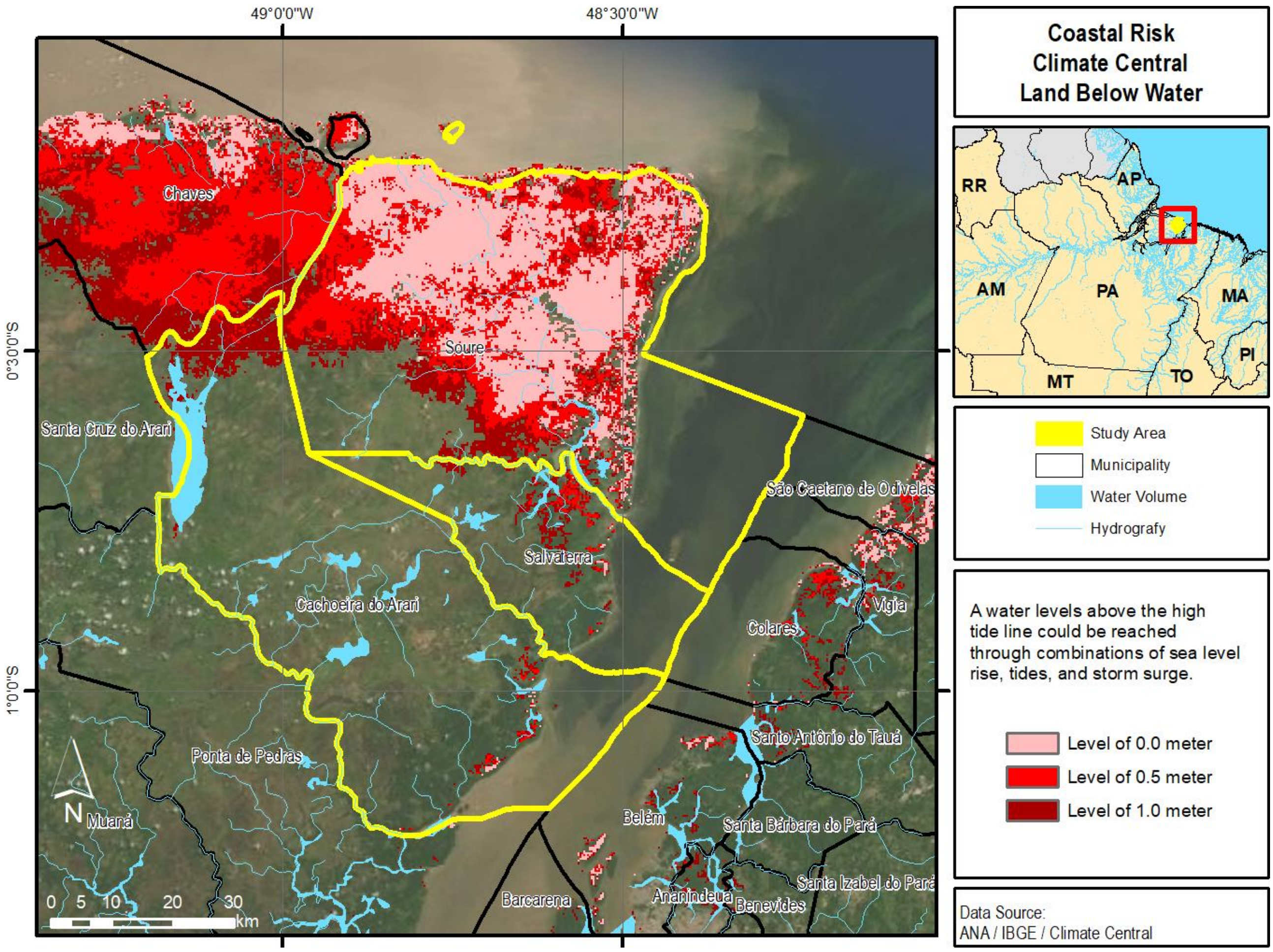
The maps in figure 6 present the climate diagnosis and prognosis, in the RCP 4.5 and RCP 8.5 scenarios, for the sea level rise.

Figure 14: Maps of sea level rise in the RCP 4.5 and RCP 8.5 scenarios



The map in Figure 7 superimposes the floodable areas in each scenario of sea level rise, facilitating the identification of areas referring to each scenario.

Figure 15: Map of sea level rise in the RCP 4.5 and RCP 8.5 scenarios



CLIMATE IMPACTS

Based on the results of the presented climatic projections, the trend observed in the climatic diagnosis stage, of reduction of annual precipitation volumes and increase in temperature in the study region, is confirmed. In the RCP 4.5 scenario, annual precipitation volumes are predicted to decrease by around 23% by the end of the century. In the RCP 8.5 scenario, this reduction should reach around 43% in the same period.

According to the climate diagnosis (Product A.1), with analysis of the historical series of meteorological stations in the region, from 1968 to 2020, there has already been a reduction of approximately 11% in annual precipitation. The already observed reduction is closer to the path presented by the RCP 8.5 scenario. Also, according to the spatialization of climate projections for this variable, Cachoeira do Arari and Salvaterra may have the greatest reductions in precipitation.

This climate impact may have an effect on crops in the region that demand greater volumes of water during the year, and irrigation may be required at specific periods.

Along with the reduction of precipitation, two associated secondary effects were also evaluated, the consecutive days without rain, which represent longer periods of water scarcity, and the intensity of the maximum daily rainfall. With the reduction of annual rainfall, the two scenarios evaluated show an increase in consecutive days without rain in the region, this effect being more intense in the RCP 8.5 scenario. It was identified that the regions of Salvaterra, where most quilombola communities are located, will be more affected by longer periods of scarcity, as well as the southern portion of Cachoeira do Arari, where the Gurupá quilombola community is located. The rains of greater daily intensity should continue to occur in the vicinity of the urban areas of Soure and Salvaterra.

Regarding the temperature values, in the RCP 4.5 scenario, an average temperature rise of about 2.7ºC is projected by the end of the century, in relation to the average value of 1961-1990. In the RCP 8.5 scenario, the temperature rise can reach up to 4.9 ºC for the same period. In the climate diagnosis, it was observed that in the period from 1968 to 2020, an average increase in temperature of approximately 0.3ºC is already noticed. In the months of May to June, this increase already reaches 0.5ºC. This effect causes higher temperatures to be perceived before the beginning of summer by the population.

The combination of the effects of the reduction of annual precipitation and the increase of the average temperature in the region should contribute to accentuate the already observed trend of reduction of the water surface areas in the studied municipalities. As evaluated, in the present period, this effect has a greater impact on the municipality of Soure, which has already lost about 30% of these areas, in relation to the values of 1985. According to projections, this effect should be accentuated in Soure, and should intensify in the municipalities of Salvaterra and Cachoeira do Arari.

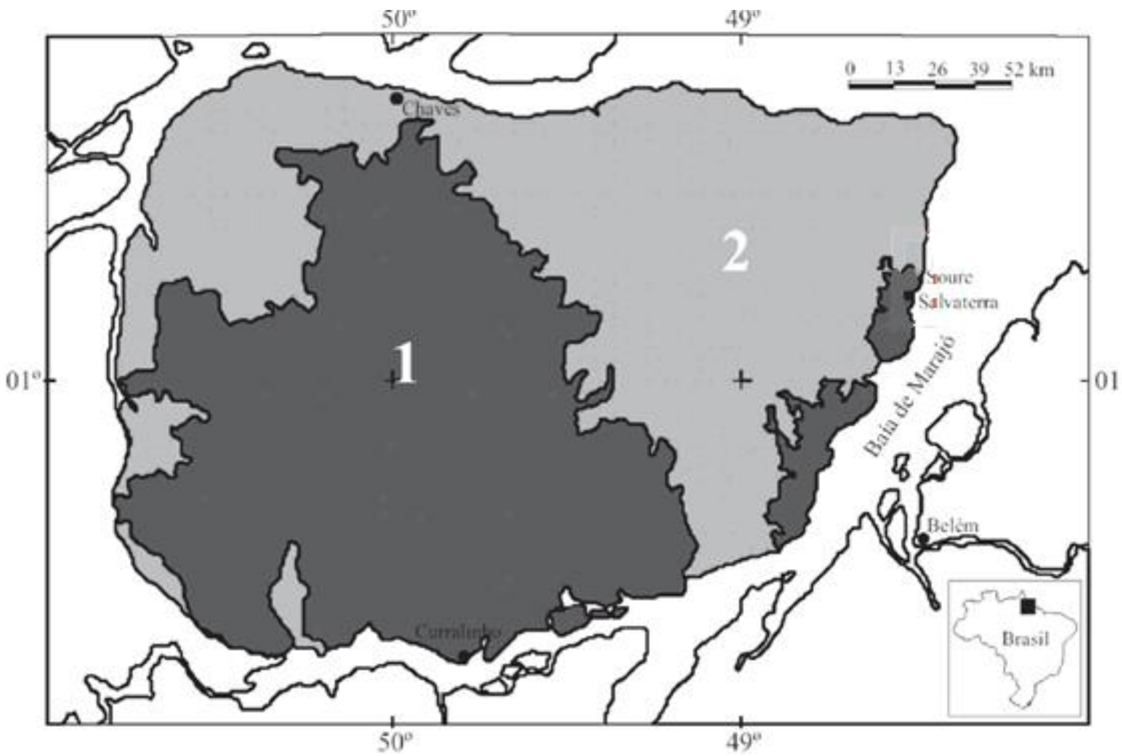
According to sea level rise projections, the municipality most vulnerable to this climate impact is Soure, which could have more than 50% of its territory exposed to tidal floods in the RCP 4.5, and more than 60% in the RCP 8.5. According to the land structure of Soure, evaluated based on the CAR, most of the areas that will be exposed to tidal floods in Soure, mainly in the central and northern region of the municipality, are medium and large properties that develop activities related to buffalo livestock. This situation can cause these properties to exert greater pressure on the higher areas of the region, occupied by traditional communities.

In relation to the traditional communities, target of the present study, a good part of the RESEX, including communities of Pesqueiro, Céu, Caju Una and Pedral, in addition to the urban area of the municipality, should be affected by the increase in sea level. In Salvaterra, this effect will have a greater impact on the urban area close to the border with Soure, including some quilombola communities such as Caldeirão, being more significant in the RCP 8.5 scenario. In Cachoeira do Arari, the sea level rise will be felt in part of its coast, close to the Urubuquara and Xipaiá PAEs. In the RCP8.5 scenario, the increase in sea level will also reach the northern region of the municipality, on its border with Soure and Chaves, and it may even reach Lake Arari, a place of importance for the way of life of the extractive population.

These projections affect the eastern portion of the Marajó archipelago in different ways, sometimes conditioned to geomorphological characteristics, sometimes related to fluvio-coastal hydrodynamic conditions, or associated with the region's land cover and uses.

From the geomorphological point of view, the impacts differ in relation to the plateau and the plain, illustrated in the figure 8.

Figure 8: Illustration of the geomorphological regions of the Marajó Archipelago: 1) Plateau; 2) Plain



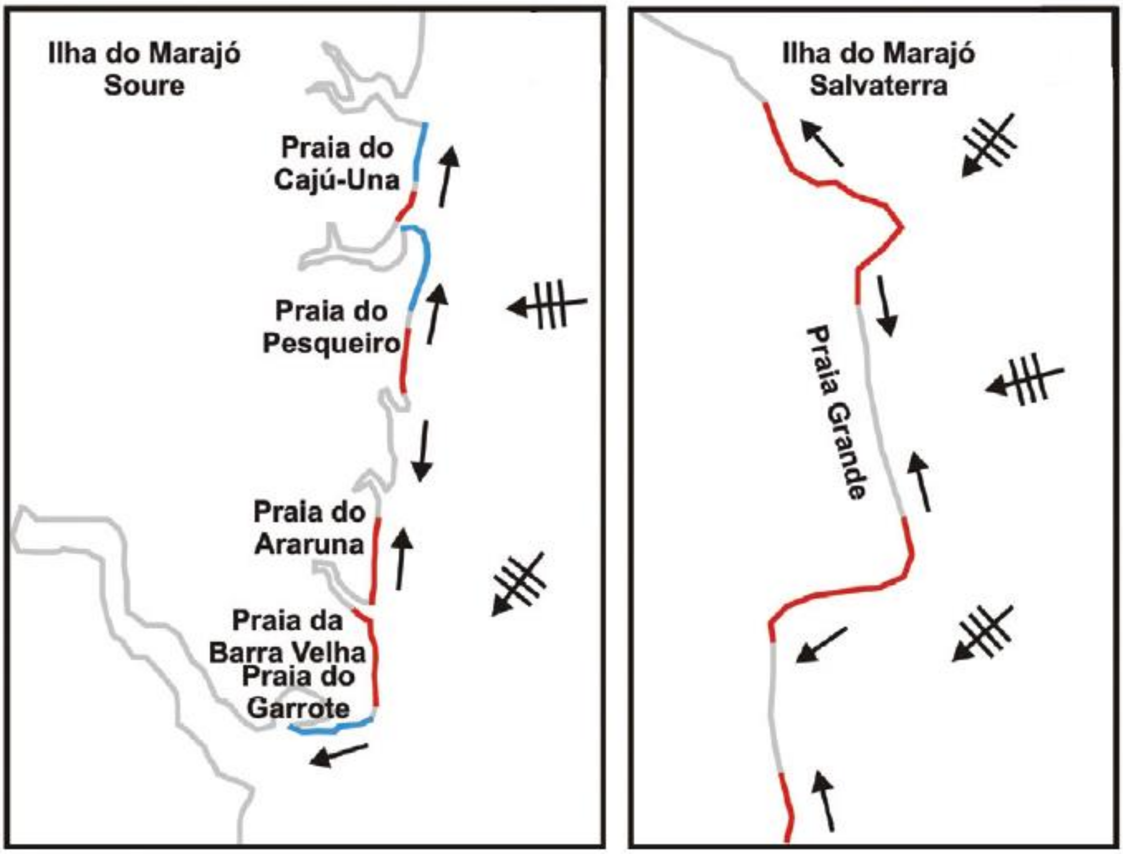
Source: França, 2003.

On the higher edges (Plateau), present to a greater extent in the municipality of Salvaterra, the action of coastal erosion is pronounced on the escarpments, having an effect possibly amplified with the rise in sea level, especially in the dry period, when the marine influence prevails in the fluvial-coastal dynamics. Some communities are in proximity to these places and may suffer the effects of these erosive processes.

In the lower portions of the coastal plain, where there are estuarine bays, cut by streams and tidal channels, mangroves represent an element of protection, although they are constantly altered due to local morphodynamics. In these locations, the erosion and progradation dynamics are influenced by the wave and tidal regime, with a tendency to increase coastal erosion with sea level rise and reduction of fluvial sedimentary discharge due to the reduction of precipitation in continental basins.

The erosion and progradation regime, which tends to be amplified with sea level rise, is illustrated in Figure 9.

Figure 9: Coastal drift: wave incidence and erosion (red) and progradation (blue) of beach environments in eastern Marajó



Source: El-Robrini et al., 2015.

According to França (2003), the entire eastern bank of Marajó Island (Soure and Salvaterra) has suffered a predominance of erosion in the last 15 years, with a total of 2.02 km^2 of eroded areas and 0.61 km^2 of prograded areas.

Regarding the fluvial input and its importance in the fluvial-coastal morphodynamics in the east of Marajó, a study carried out by Costa (2014) indicates that the Tocantins, Jacaré and Pará rivers form an exporting environment of sediments for to Marajó Bay, with annual volumes estimated between 3.7 and 5.4 million tons. A possible reduction of this continental fluvial input, due to a decrease in precipitation in climate change scenarios, could lead to a greater impact of coastal erosion in the east of Marajó.

The rainfall regime is directly related to the fluvio-estuarine dynamics in the region and salinity variations. According to studies by Ferreira (2013), the Paracauari river system, which divides Salvaterra from Soure, was mainly related to the seasonality of rainfall. During the dry season, the influence of marine waters is modulated by the tides and reaches the confluence areas with the Saco and Mangueiras rivers, with a net flow to Marajó Bay of 98,594 m^3/s in the tidal cycle studied, with salinity average of 6 at the mouth of the Paracauari River.

In the rainy season, the net flow to Marajó Bay was 65,269 m^3/s at the end of the tidal cycle, with salinities always lower than 2 in the sections studied. In a future regime in which the penetration of the tide in the dry period is increased (due to a lower fluvial input), there may be a greater reach of the brackish waters in the interior of the bay.

In the interior of the archipelago, in most part of Soure and Cachoeira do Arari, where the plains and swamps predominate, an important part of the area has levels below the relative mean sea level and will be subject to the elevation of the water table due to the increase hydrostatic pressure from the higher marine environment.

On the other hand, in these areas there may be a reduction in flood support in cases of the conjunction of extreme tidal and precipitation events, which tend to occur more frequently, according to the IPCC (2021). A few communities mapped in the municipality of Soure are in conditions susceptible to these extremes.

A final aspect about climate change scenarios in eastern Marajó is related to the increase in temperature. With a predicted average increase of around 1.5°C by 2040, but with the possibility of higher temperature extremes, the climate change can affect the number of fires that occur annually, the duration of the fire season, the area burned by fires and can increase fire intensity.

Changes in these fire properties mean more frequent and more intense seasonal fires and therefore greater fire potential.

Oliveira et al. (2022) investigated the determinants of the impact of fire in the Brazilian biomes. The Amazon was considered a High Impact Fire (HIF) area, and 25% of the wildfire occurrence is related to climate and the other 75% to land-use change. Simulations of future climate and land-use change pointed to a dramatic increase in HIF by 2050. Under the RCP4.5 and strong environmental governance scenario, HIF in the Amazon would expand from 0.7 to 1.2%

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ANNEX – MAPS

The maps used in the construction of the climate projection diagrams are presented below.

Figure 16: PRCP (Annual Total Rainfall) variable map - History (1961-1990)

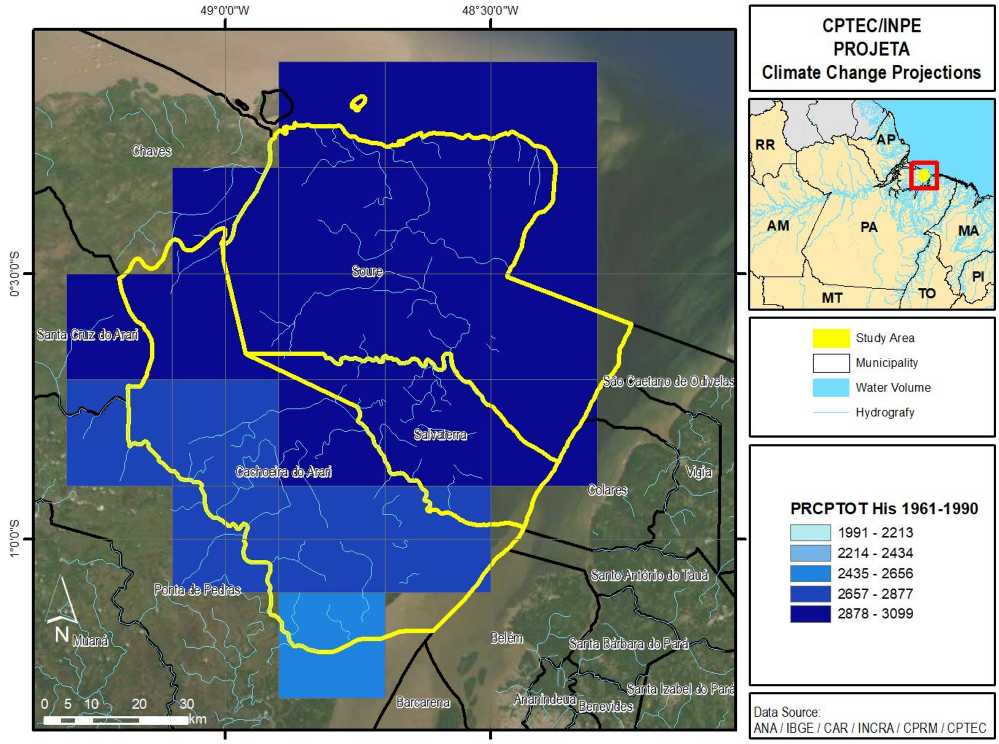


Figure 17: PRCP (Annual Total Rainfall) variable map – RCP 4.5 (2021- 2050)

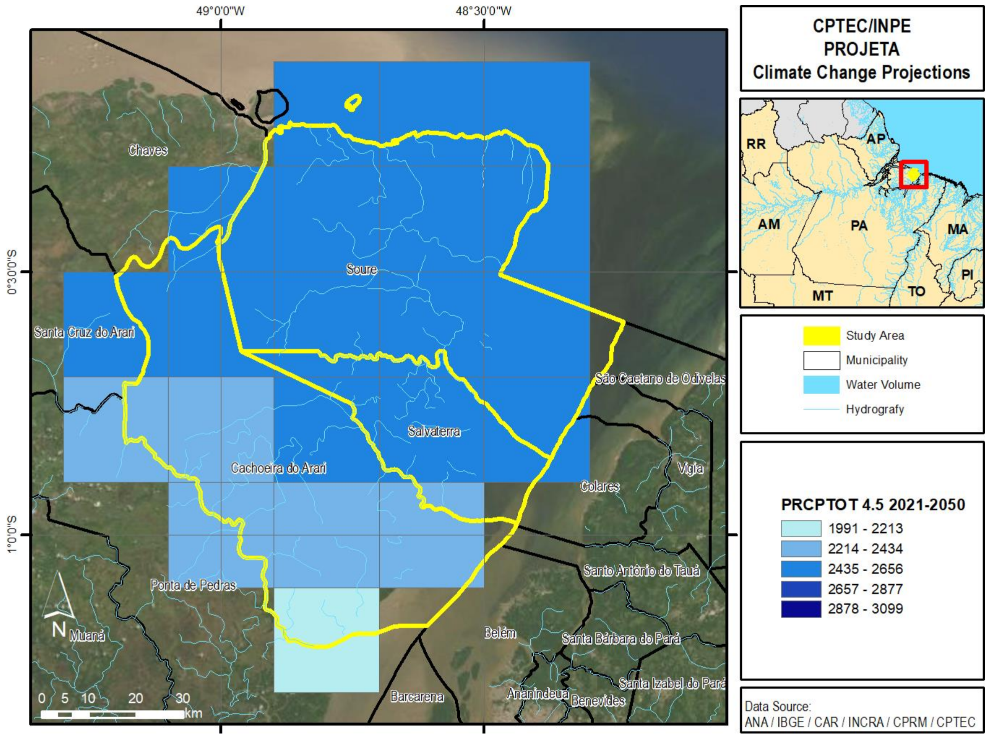


Figure 18: PRCP (Annual Total Rainfall) variable map – RCP 8.5 (2021- 2050)

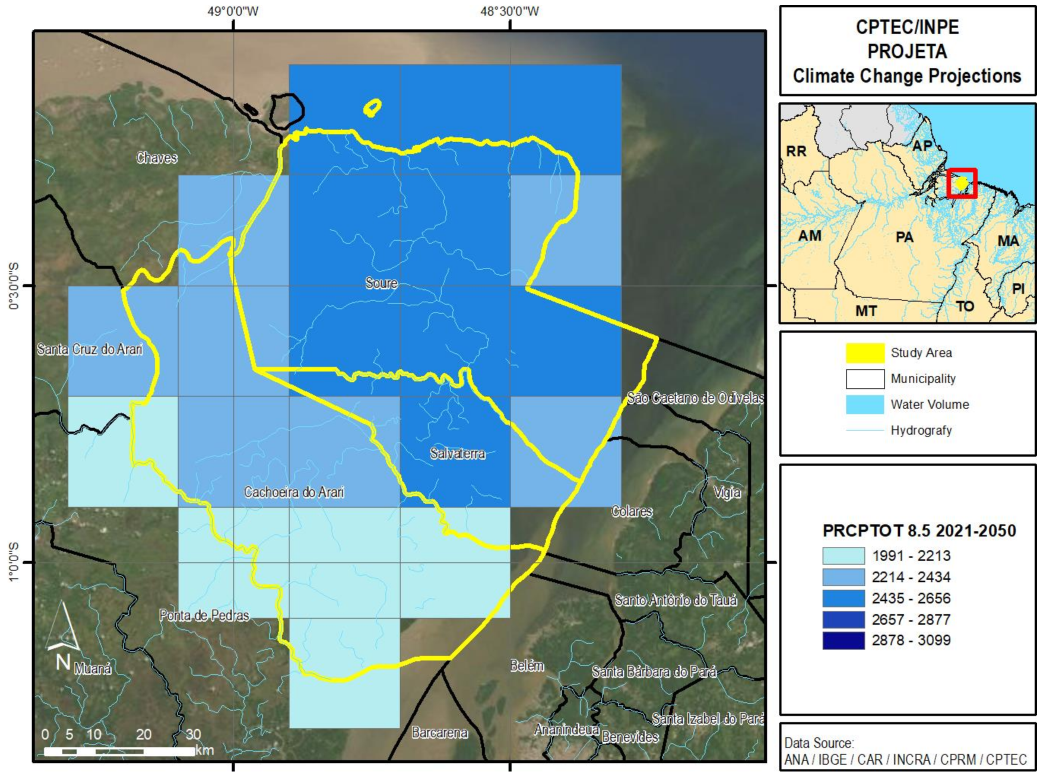


Figure 19: CDD (Consecutive Dry Days) variable map - History (1961-1990)

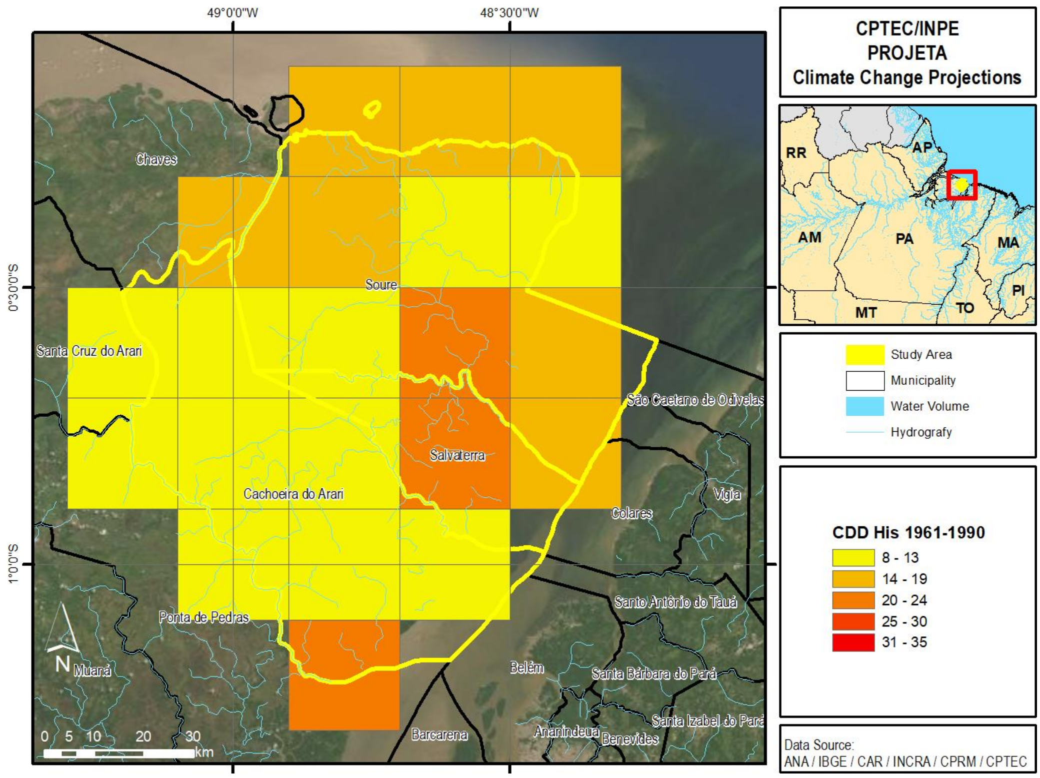


Figure 20: CDD (Consecutive Dry Days) variable map – RCP 4.5 (2021- 2050)

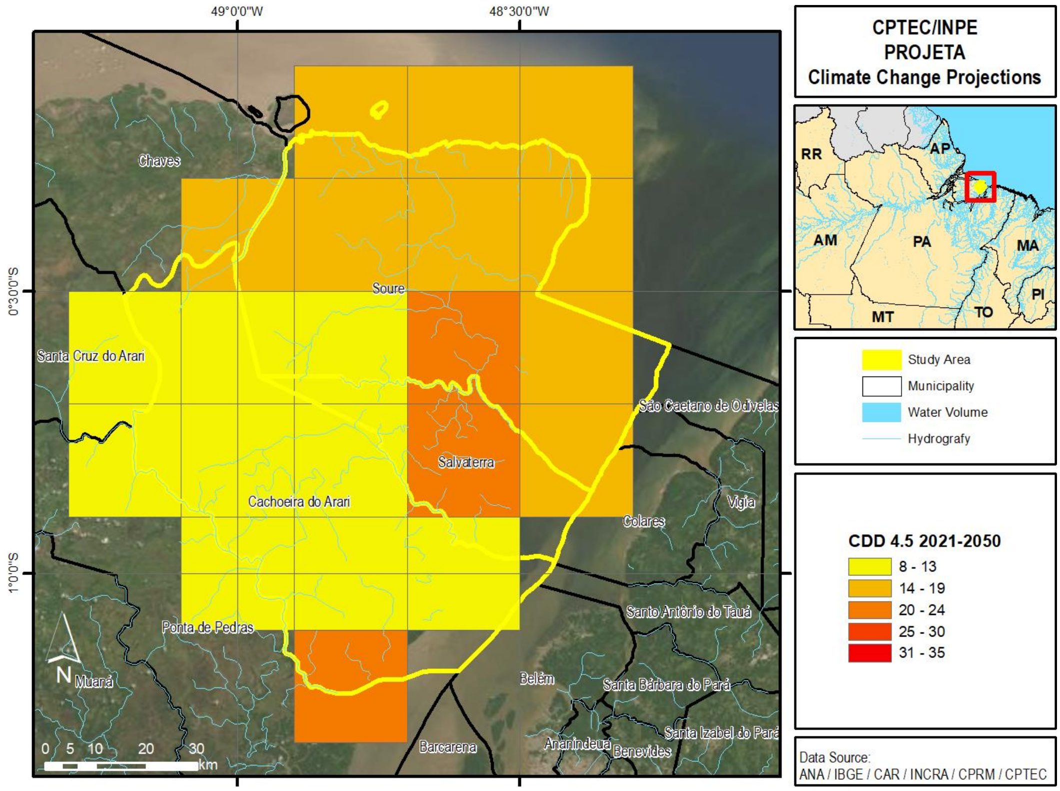


Figure 21: CDD (Consecutive Dry Days) variable map – RCP 8.5 (2021- 2050)

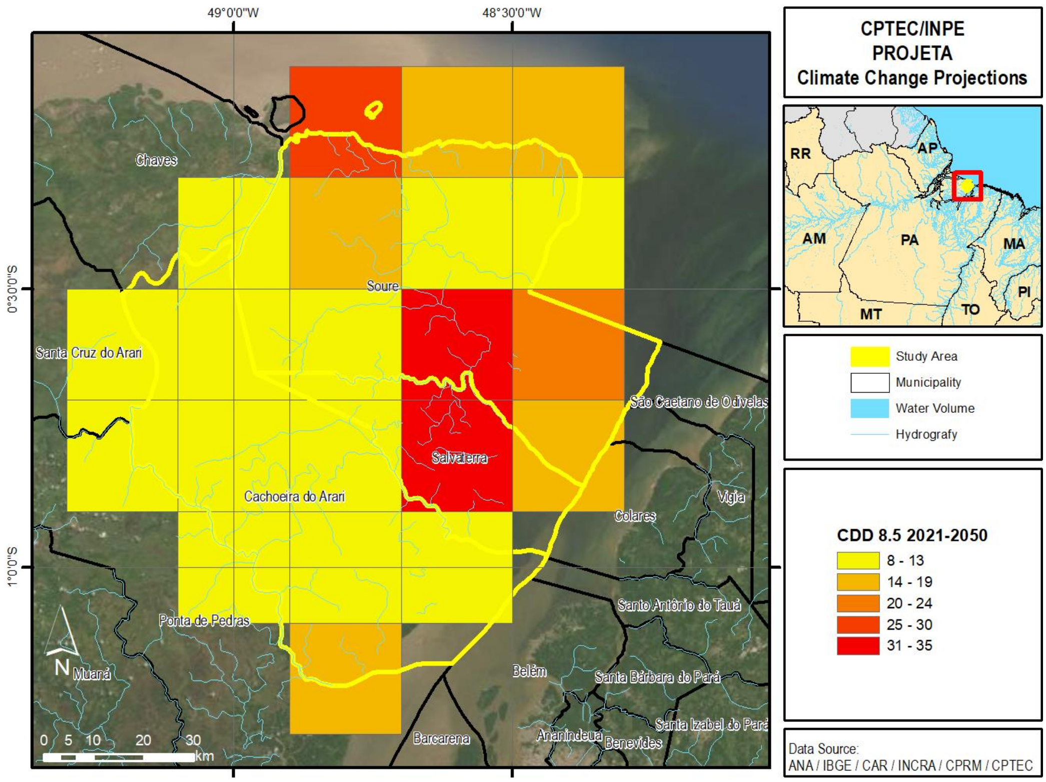


Figure 22: RX1Day (Maximum Daily Rainfall) variable map - History (1961-1990)

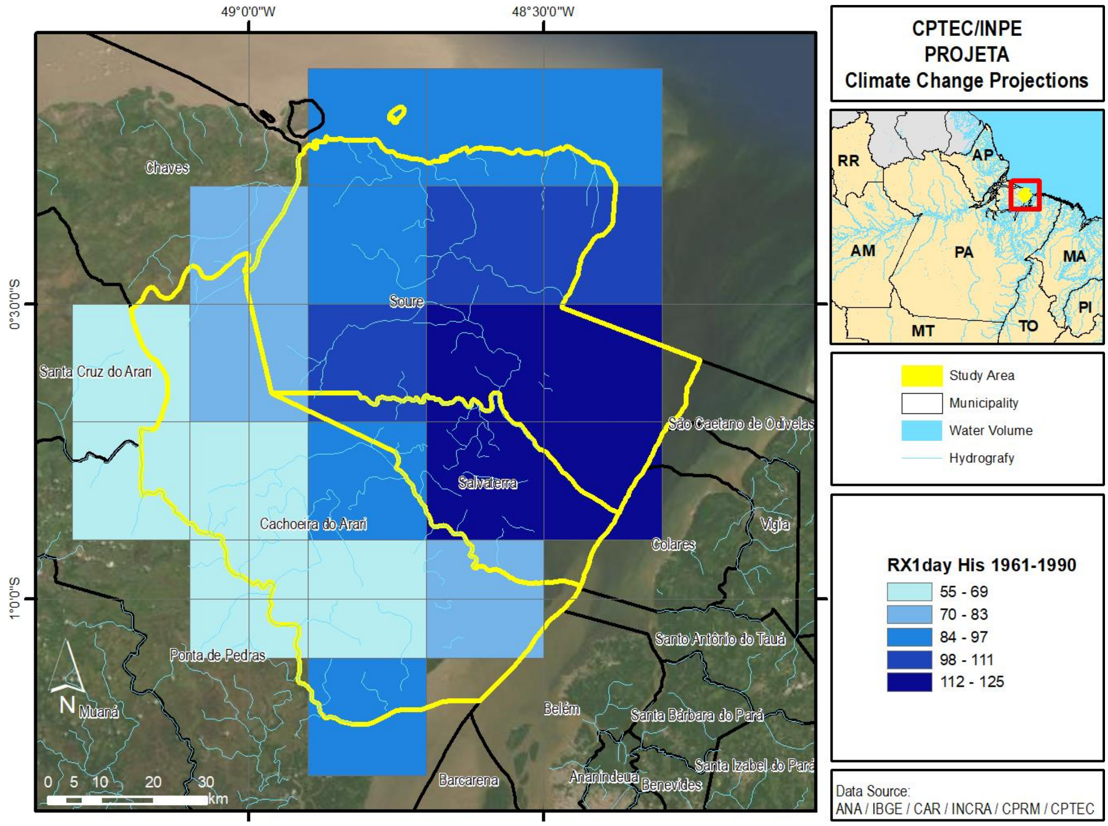


Figure 23: RX1Day (Maximum Daily Rainfall) variable map – RCP 4.5 (2021- 2050)

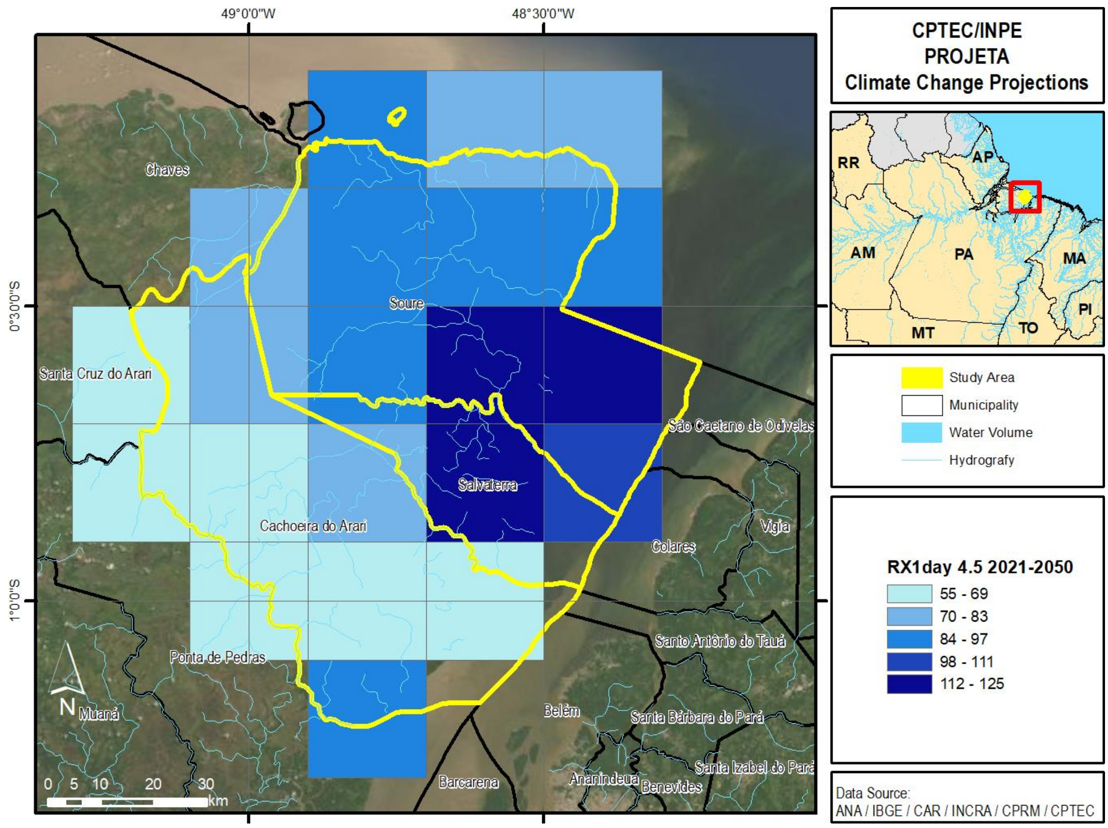


Figure 24: RX1Day (Maximum Daily Rainfall) variable map – RCP 8.5 (2021- 2050)

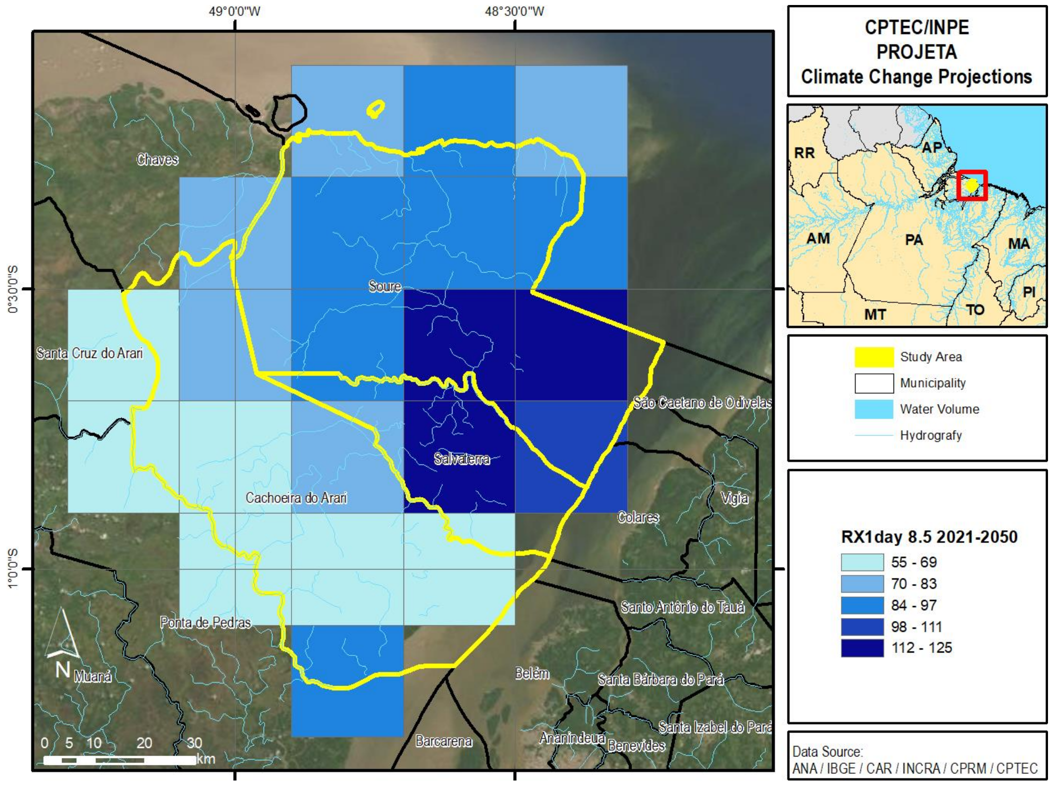


Figure 25: TP2m (Air Temperature at 2 Meters) variable map - History (1961-1990)

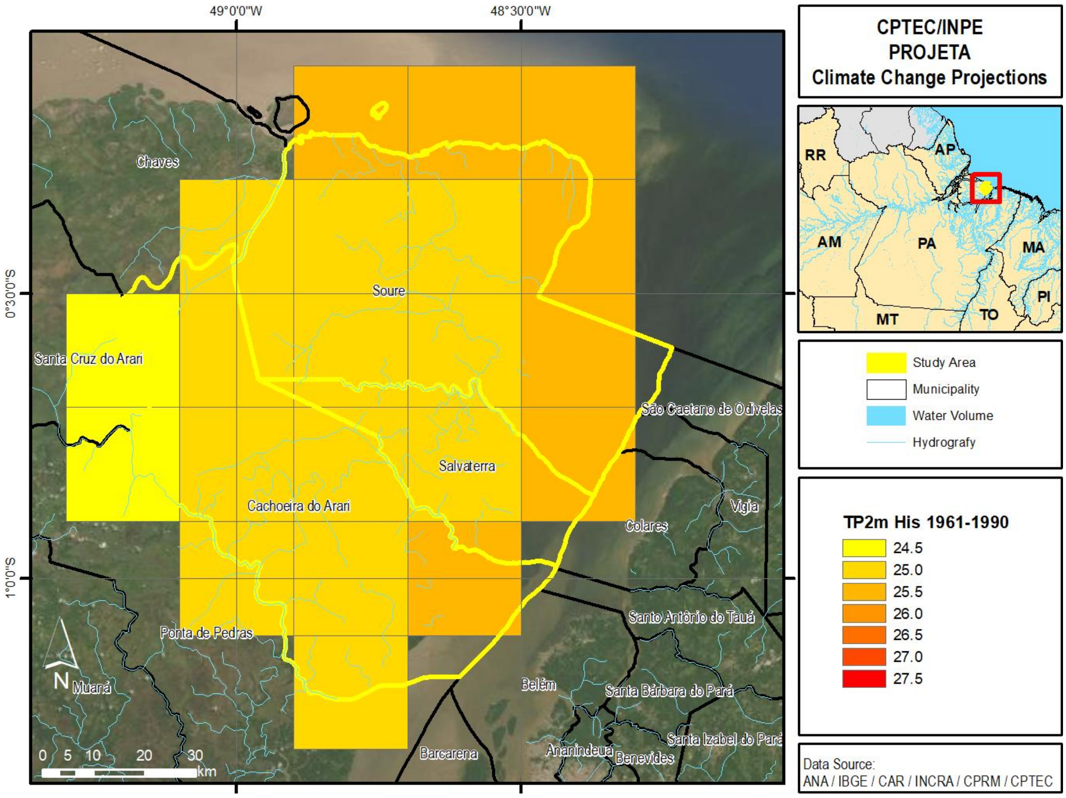


Figure 26: TP2m (Air Temperature at 2 Meters) variable map – RCP 4.5 (2021- 2050)

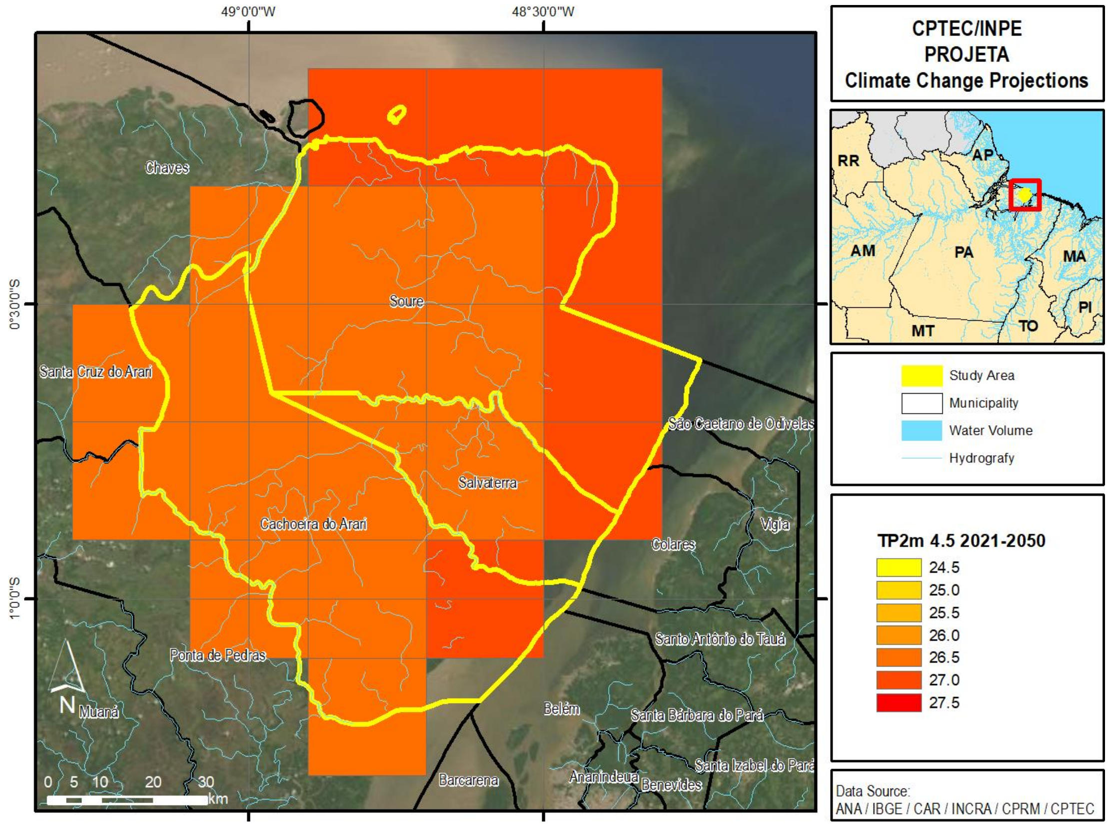


Figure 27: TP2m (Air Temperature at 2 Meters) variable map – RCP 8.5 (2021- 2050)

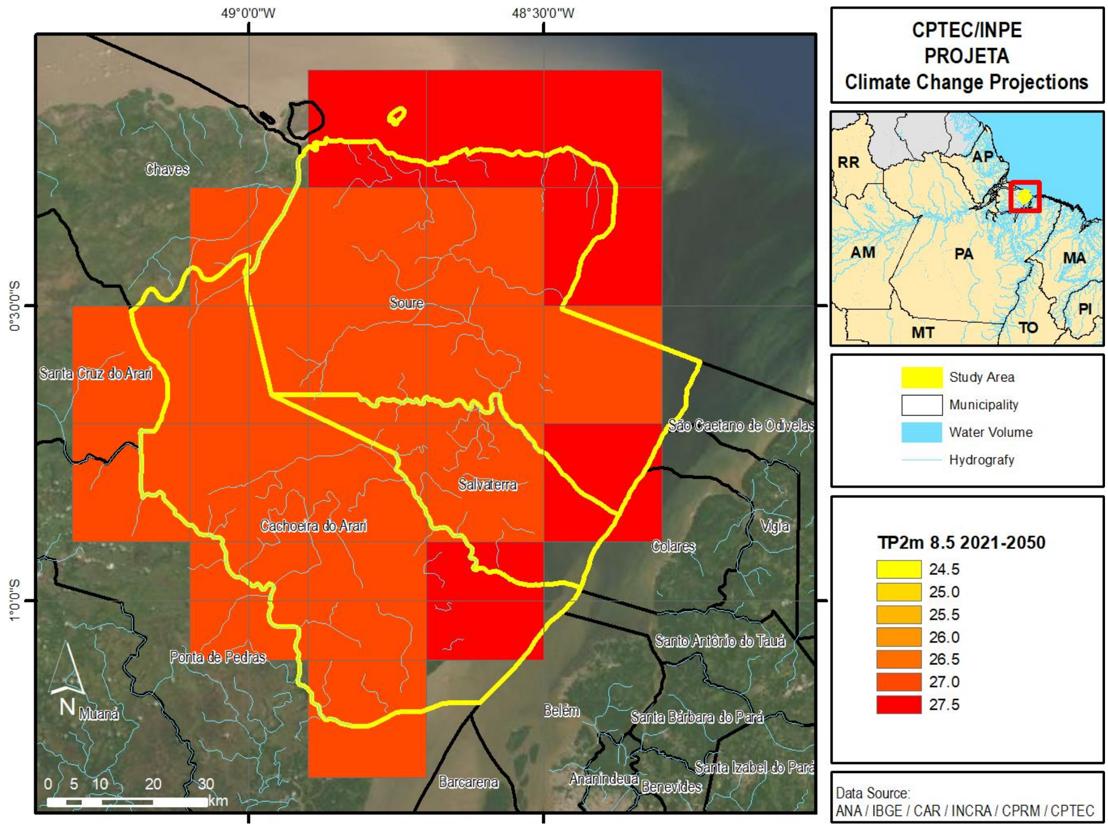


Figure 28: Map of sea level rise - Base Scenario: 0,0m

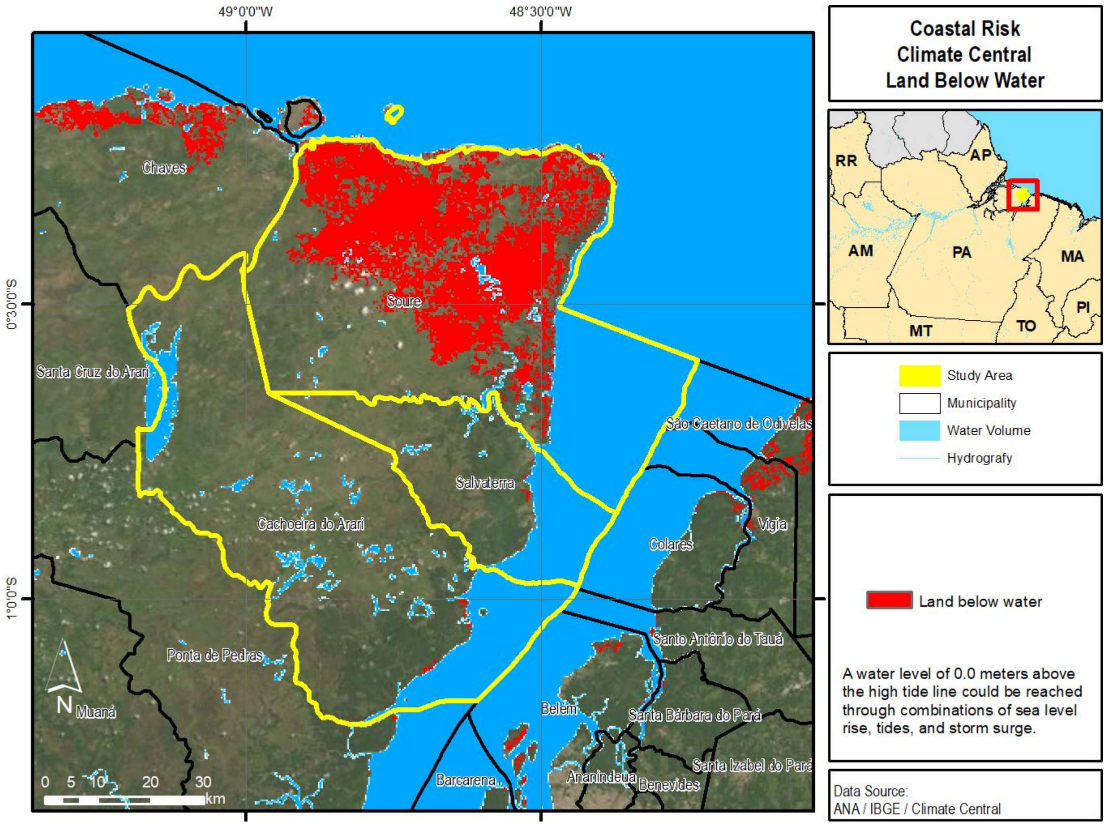


Figure 29: Sea level rise map – RCP 4.5: 0,5m

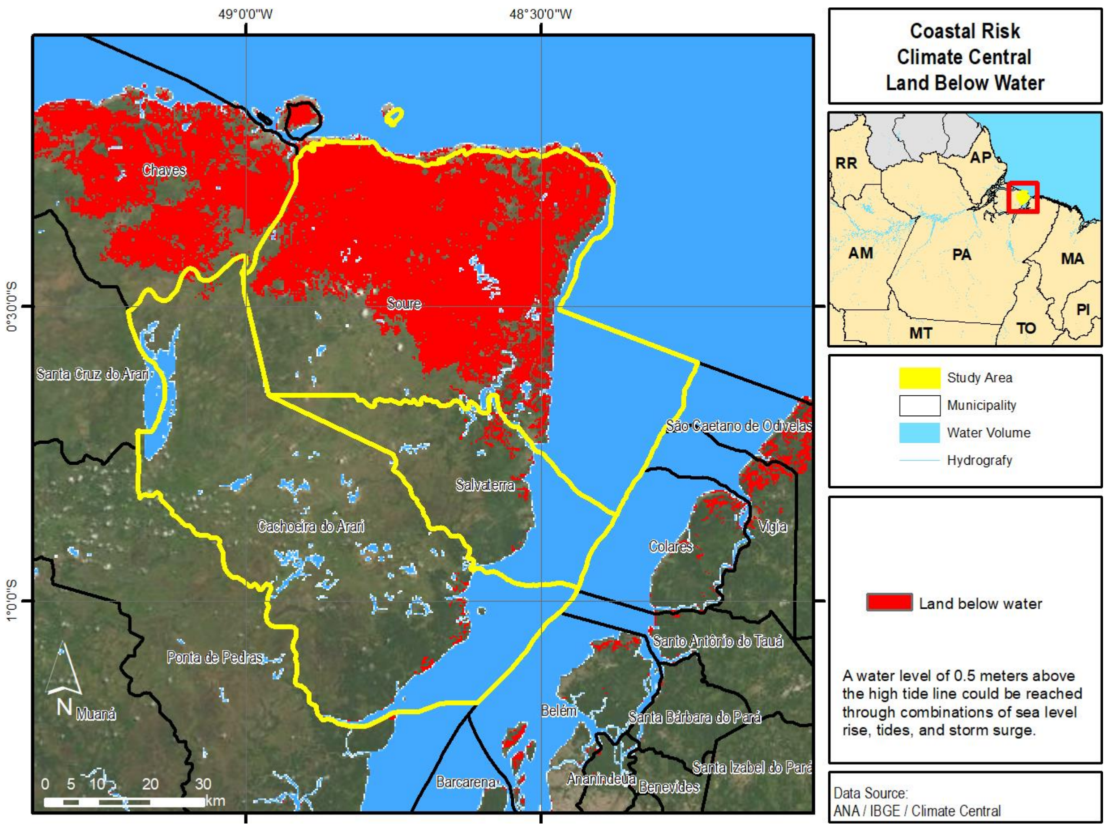
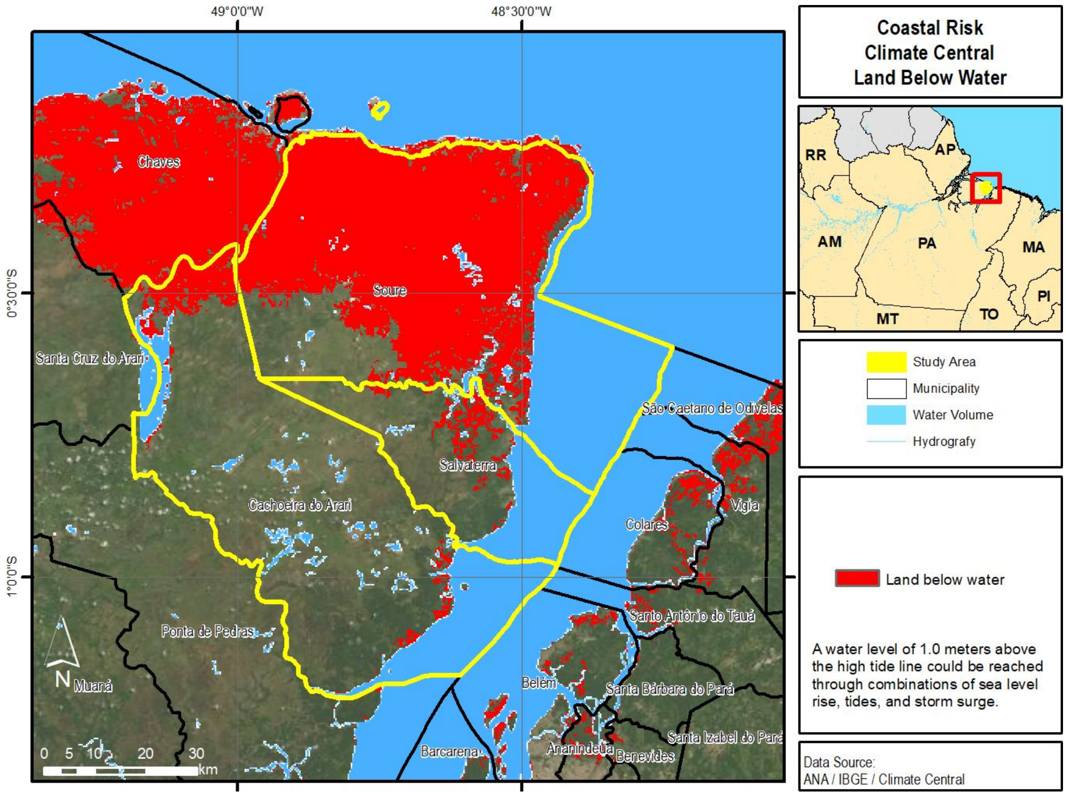


Figure 30: Sea level rise map – RCP 8.5: 1,0m



Fundación Avina

CLIMATE VULNERABILITY ANALYSIS IN ILHA DO MARAJÓ / PA

PRODUCT B.2

Developed by:

H2O Company

2022

CLIMATE VULNERABILITY ANALYSIS IN ILHA DO MARAJÓ / PA

2022

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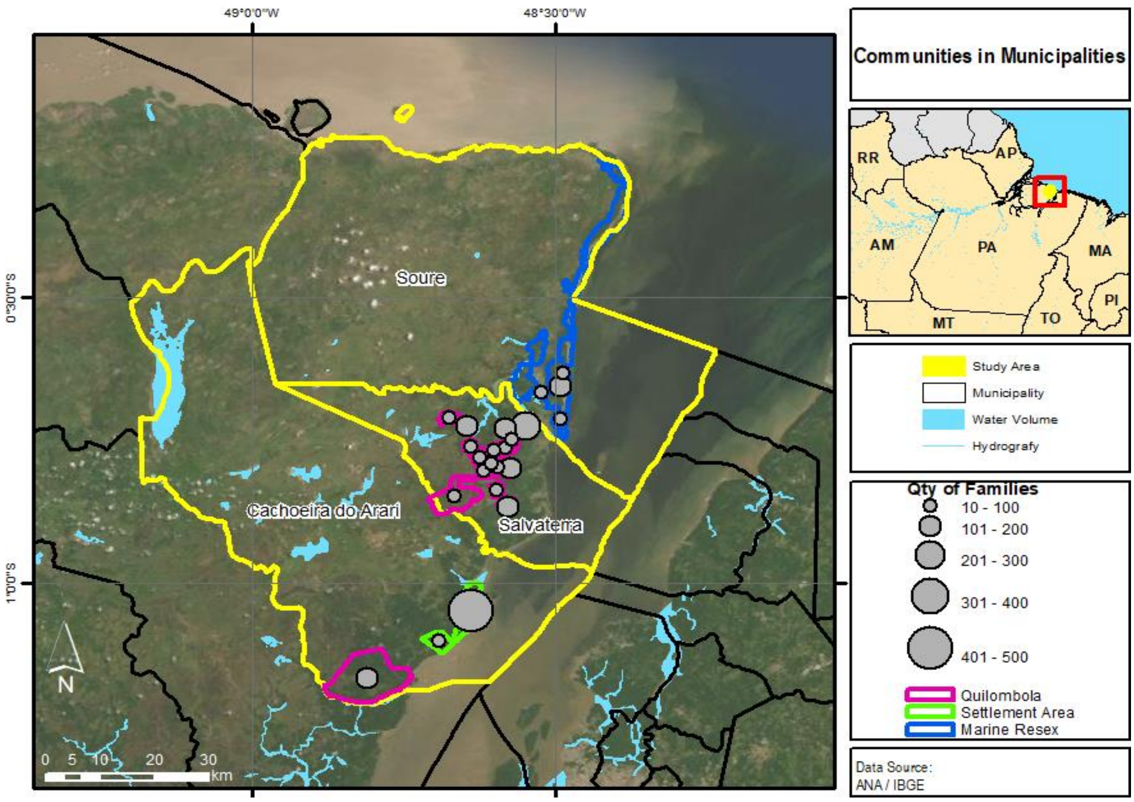
INTRODUCTION

This report presents the main results of the climate vulnerability analysis developed for the municipalities of Soure, Salvaterra and Cachoeira do Arari, on Ilha do Marajó.

STUDY AREA

Figure 1 presents the map of the study area, identifying the three evaluated municipalities and the mapped communities that were considered for the vulnerability analysis. The size of the circle representing each community is proportional to the number of resident families.

Figure 1 - Study area map and mapped communities



The effects of climate change are expected to impact the way of life of communities in different ways. Communities located close to floodplain areas will feel more the effects of rising sea levels and reduced rainfall, resulting in salinization of areas of agricultural interest and eventual production losses. Communities that are in terra firme areas are expected to be more impacted by changes in temperature and precipitation, increasing the need for irrigation for more sensitive crops.

Thus, it is of interest to identify communities that are in floodplain areas and communities in terra firme areas. The map in figure 2 presents the communities in each of these areas.

Figure 2 - Communities in floodplain areas and in upland areas

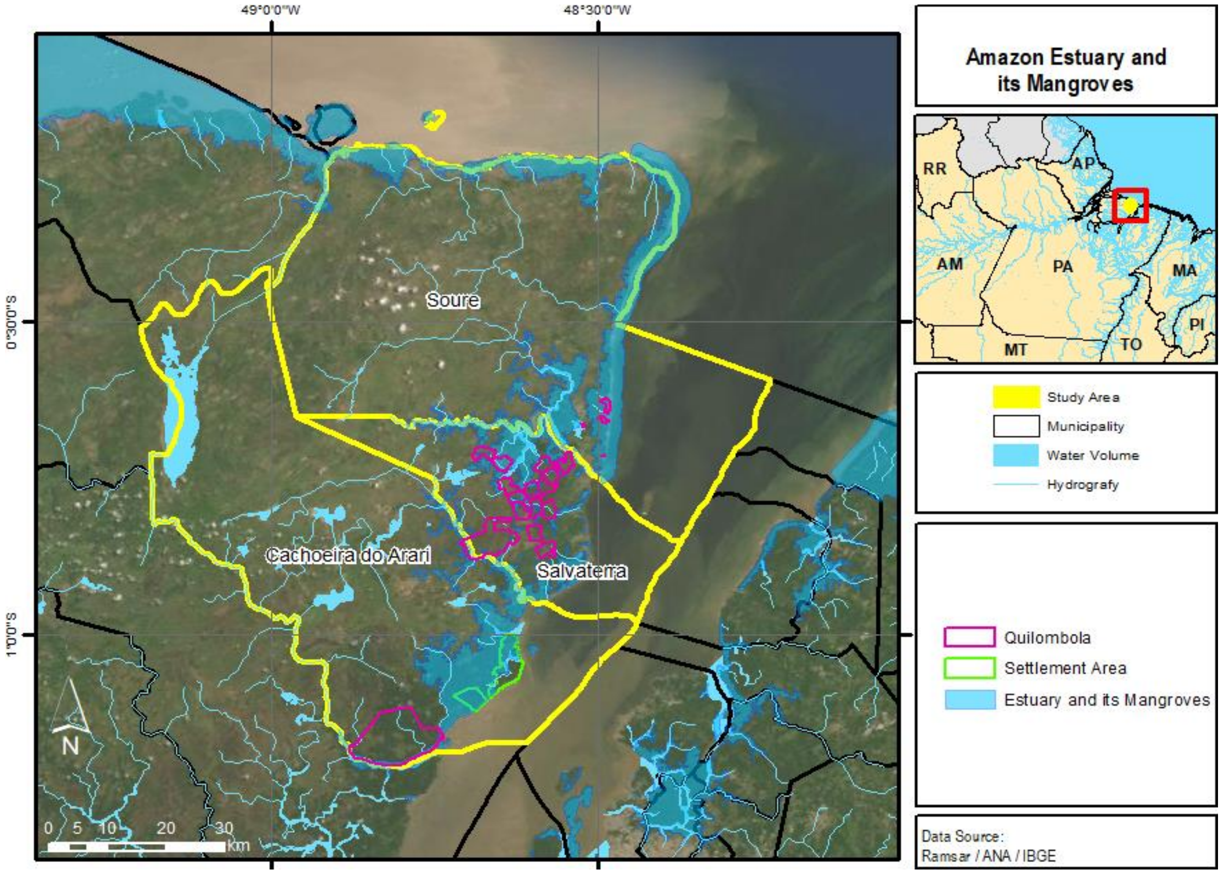


Table 1 presents the number of families in each community, highlighting in shades of red the communities that have the largest number of families and people. These communities may have a greater number of people exposed to the effects of climate change. The table also identifies the portion of the community area that is located in a floodplain area, differentiating them in blue tones.

Table 1 - Location and number of families in the communities

Community	Municipality	Floodplain Area (%)	Nº Families	Nº People
Araruna	Soure	100%	100	440
BACABAL	Salvaterra	7%	90	396
Bairro Alto	Salvaterra	13%	120	528
Boa Vista	Salvaterra	0%	115	506
Caldeirão	Salvaterra	7%	210	924
Céu / Caju Una	Soure	100%	95	418

Deus Ajude	Salvaterra	46%	65	286
GURUPA	Cachoeira do Arari	9%	198	871
Mangueiras	Salvaterra	100%	180	792
PAE Ilha Urubuquara	Cachoeira do Arari	51%	482	2.121
PAE Ilha Xipaiá	Cachoeira do Arari	96%	96	422
Paixão	Salvaterra	0%	42	184
Pau Furado	Salvaterra	8%	55	242
Pedral	Soure	0%	100	440
Pesqueiro	Soure	100%	110	484
Providência	Salvaterra	6%	13	57
ROSÁRIO	Salvaterra	5%	63	277
Salvá	Salvaterra	17%	10	44
SANTA LUZIA	Salvaterra	35%	15	66
São Benedito da Ponta	Salvaterra	43%	35	154
São Cristóvão	Salvaterra	19%	100	440
Siricari	Salvaterra	17%	40	176
Vila União/Campina	Salvaterra	0%	180	792

Through table 1, it is observed that the communities with the highest number of families are:

- PAE Ilha Urubuquara (Cachoeira do Arari) with 482 families and 2,121 people;
- GURUPA (Cachoeira do Arari) with 198 families and 871 people;
- Mangueiras (Salvaterra) with 180 families and 792 people;
- Caldeirão (Salvaterra) with 210 families and 924 people.

It can also be identified in table 1 that, in general, there are five communities in floodplain areas (above 90%) and sixteen communities in low risk of flooding zone. The municipality of Soure stands out, where there are 305 families, totaling 1342 people, living in a floodplain area (above 90%), and 100 families, with 440 people, living in low risk of flooding zone. Also noteworthy is the municipality of Salvaterra, where there are 180 families, with 792 people, living in a floodplain area (above 90%), and 1118 families, with 4,918 people, living in low risk of flooding zone.

BASELINE

The communities of the three municipalities are already feeling impacts from climate change related to sea level rise, changes in precipitation and temperature and extreme events of consecutive days without rain or heavy rains. As an example, the change in the rainfall regime and the increase in the thermal sensation in certain periods of the year have affected the productivity of cupuaçu, according to the report of directors of the Cooperativa da Agricultura Familiar Salvaterra, as well as the reduction of precipitation is generating demand for irrigation. of cassava, watermelon, tomato and pineapple crops, according to farmers. In addition, representatives of the Peabiru Institute reported that the flavor of açaí is being affected by reduced precipitation combined with the process of soil salinization associated with rising sea levels. Another impact identified is the reduction of hours worked in the field, when farmers have to stop around 11:00 am due to excessive heat. Table 2 summarizes the impacts identified through reports associated with climate change.

Table 2 – Identified impacts resulting from climate change

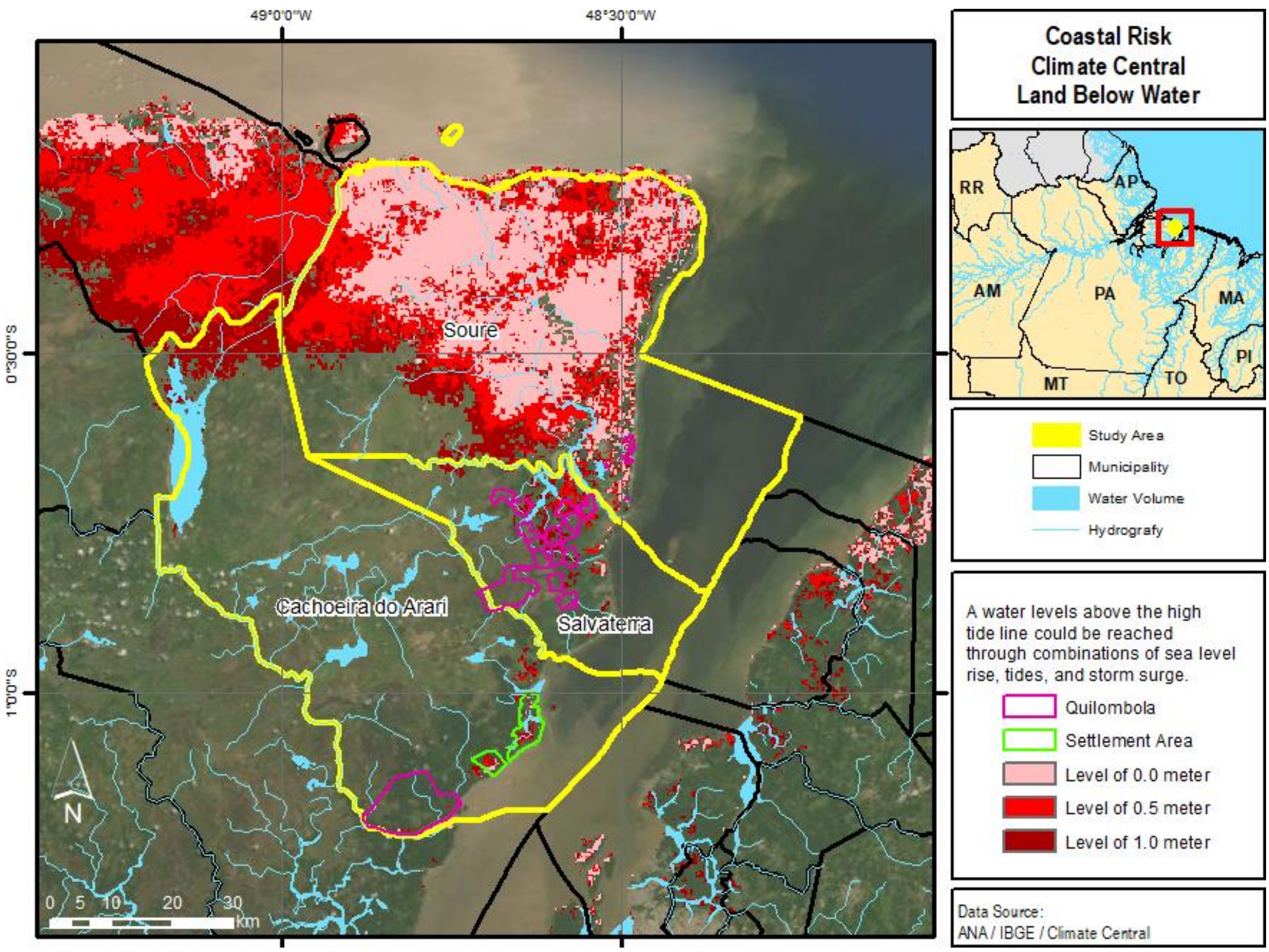
	Temperature Rise	Precipitation Reduction	Extreme Events	Sea Level Rise
Cachoeira do Arari		• Change in açaí flavor due to reduced precipitation combined with rising sea levels		• Change in açaí flavor due to reduced precipitation combined with rising sea levels • Loss of 323.32 ha (0.82%) of arable areas already affected by sea level rise
Salvaterra	• Reduction in cupuaçu production due to the increase in temperature • Reduction of working hours in field areas due to excess heat	• Need for irrigation of crops (cassava, watermelon, tomato and pineapple) • Increase in the occurrence of pests (cochineal) in the pineapple crop	• Reduction in cupuaçu production due to heavy rains out of season • Landslides on the banks of the river • Periodic flooding • Reduction in the quality of water for human consumption • Reduction of working hours in field areas due to excess heat	• Change in açaí flavor due to reduced precipitation combined with rising sea levels • Loss of 152.60 ha (0.80%) of arable areas already affected by sea level rise
Soure	• Reduction of working hours in field areas due to excess heat		• Reduction of working hours in field areas due to excess heat	• Loss of 5299.67ha (29.44%) of arable areas already affected by sea level rise

Table 3 shows the percentage of arable areas with potential for AFS already affected by the rise in sea level in each municipality. In this case, the municipality of Soure already has 29.44% of its area impacted by high tides. These data confirm the impacts from climate change in municipalities that are already occurring and tend to increase in the coming years. The 0.5 meter and 1.0 meter sea level rise scenarios were evaluated and the potential losses of arable land in each municipality are presented in table 3.

Table 3 - Percentage of arable areas with potential for AFS affected by sea level rise

	Current Scenario Level 0 meter	Scenario RCP4.5 Level 0.5 meter	Scenario RCP8.5 Level 1.0 meter
Cachoeira do Arari	0.82%	2.25%	4.71%
Salvaterra	0.80%	5.70%	15.60%
Soure	29.44%	45.63%	55.26%

Figure 3: Climate scenarios for sea level rise and impact-susceptible communities.



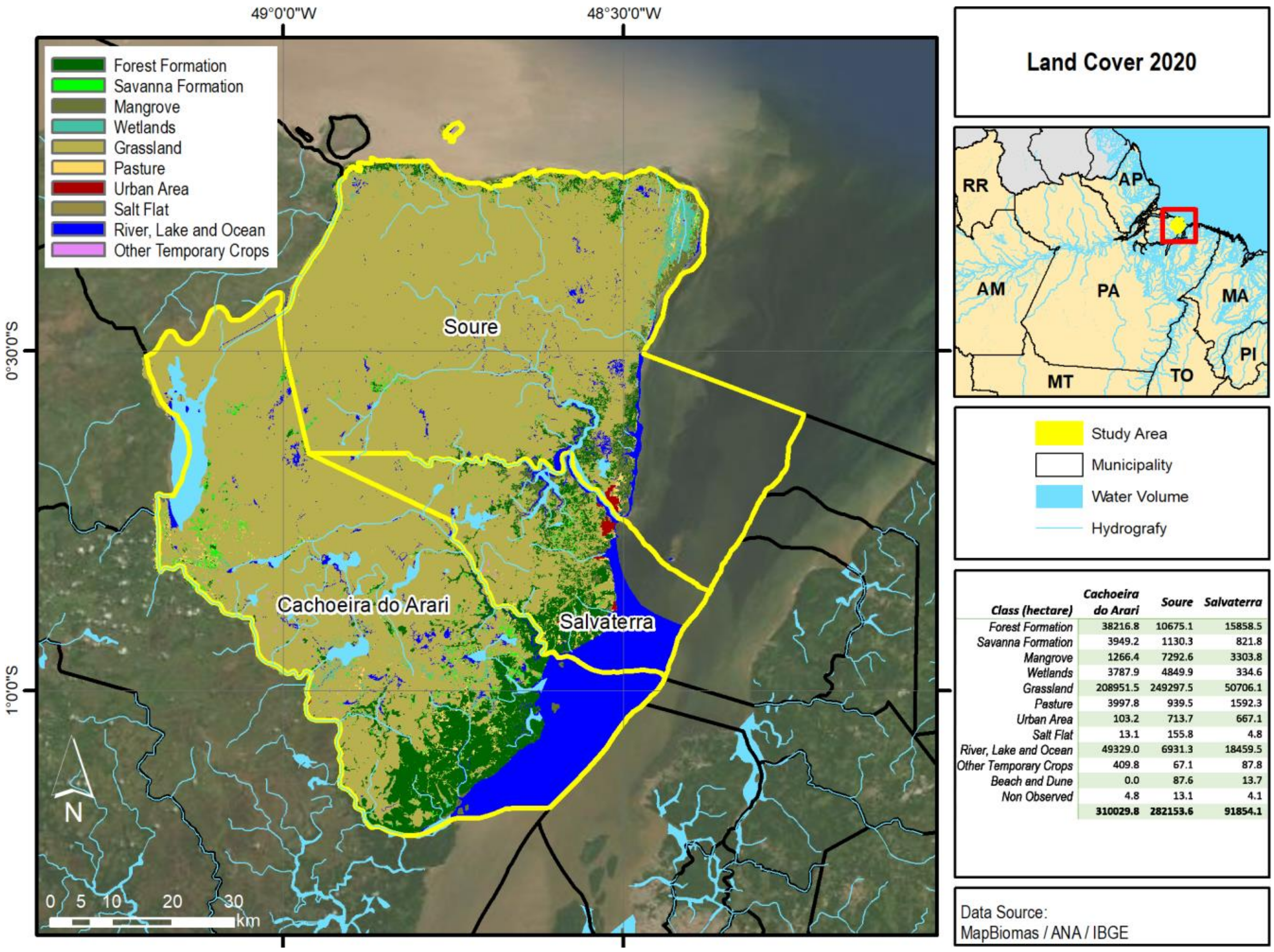
Therefore, municipalities already have a degree of vulnerability to climate change, given by vegetal cover, transition of areas to AFS and losses of potential AFS areas, which will be described below. The impacts are already felt by the communities due to factors such as the increase in the average annual temperature, the reduction of precipitation and the advance of the sea level.

VEGETAL COVER

Communities located in regions with greater vegetation cover are less exposed to the effects of climate change, such as changes in temperature and precipitation, due to the environmental services provided by these coverages, such as local climate regulation, in addition to representing areas with greater availability of natural resources for communities of small farmers. These areas also represent potential areas for AFS application.

The map in figure 5 shows the vegetation cover identified in the regions of each municipality, such covers cover the following vegetation: forest formation; savanna formation; mangrove; wetlands; prairie; pasture; urban area; saline; river, lake and ocean; other temporary plantations.

Figure 4: Land Cover Map



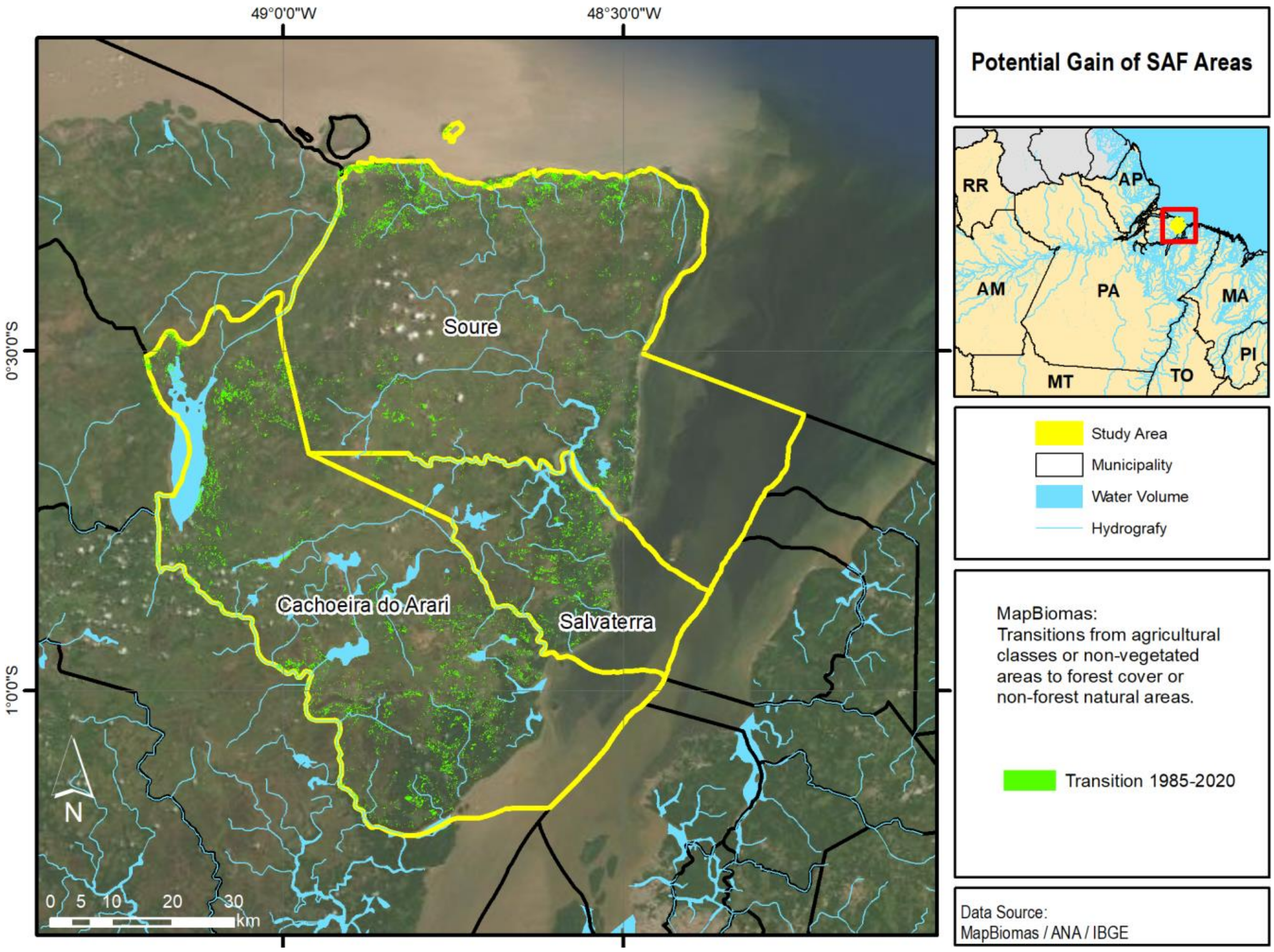
Class (hectare)	Cachoeira do Arari	Soure	Salvaterra
Forest Formation	38216.8	10675.1	15858.5
Savanna Formation	3949.2	1130.3	821.8
Mangrove	1266.4	7292.6	3303.8
Wetlands	3787.9	4849.9	334.6
Grassland	208951.5	249297.5	50706.1
Pasture	3997.8	939.5	1592.3
Urban Area	103.2	713.7	667.1
Salt Flat	13.1	155.8	4.8
River, Lake and Ocean	49329.0	6931.3	18459.5
Other Temporary Crops	409.8	67.1	87.8
Beach and Dune	0.0	87.6	13.7
Non Observed	4.8	13.1	4.1
	310029.8	282153.6	91854.1

TRANSITION OF AREAS TO AFS

The transition areas for AFS are areas of previous use associated with agriculture or non-vegetated areas and that have been managed by the communities in order to expand forest cover and agricultural production in these areas.

The map in figure 6 shows the areas considered to be in transition to AFS's for each municipality. On the map, the areas indicated as transition may be related to revegetation associated with the communities' experiences with AFS.

Figure 5: Transition Areas for AFS



LOSSES OF POTENTIAL AFS AREAS

The potential areas for AFS implementation were defined based on the MapBiomas classifications, considering the areas with the presence of “Forest Formation” and “Mangrove”. These natural systems are commonly found in regions occupied by communities and their surroundings. The advance of sea water, according to the climate scenarios considered, should impact regions of potential implantation of AFS, resulting, for example, in loss of fertility and salinization of soils. Communities located in municipalities that will have the greatest loss of potential AFS areas are more sensitive to the effects of climate change.

The maps in figures 8 and 9 illustrate the spatial representation of these areas with potential for the implementation of AFS's and which should be under threat, according to the projections of sea level rise in scenarios RCP4.5 AND RCP8.5.

Figure 6: Losses of Potential AFS Areas (RCP4.5)

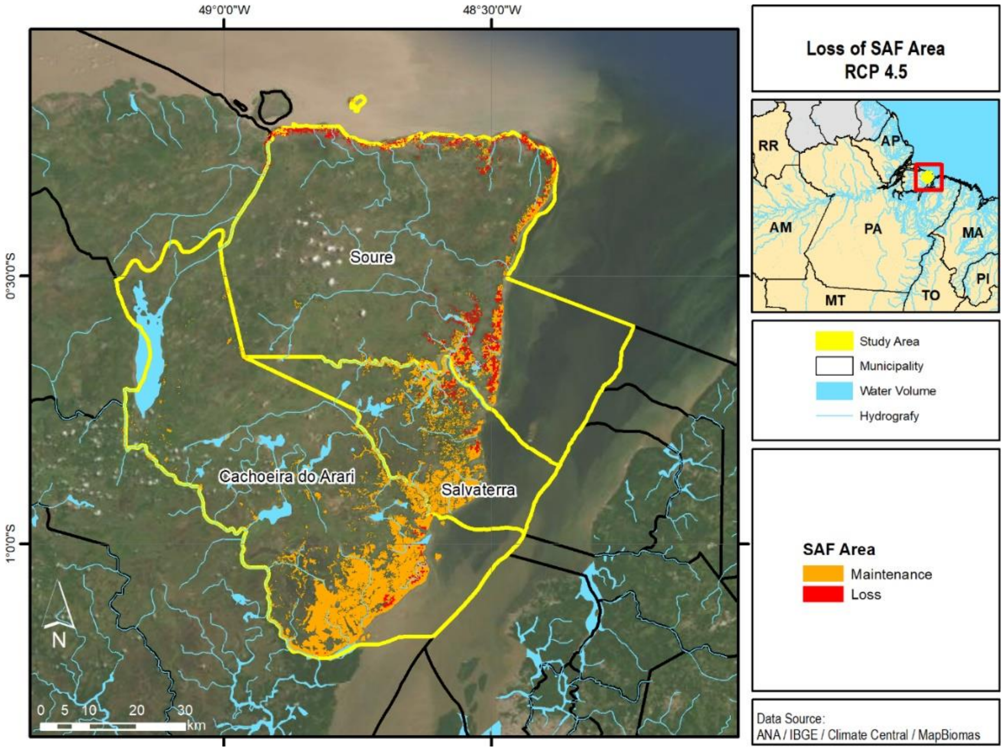
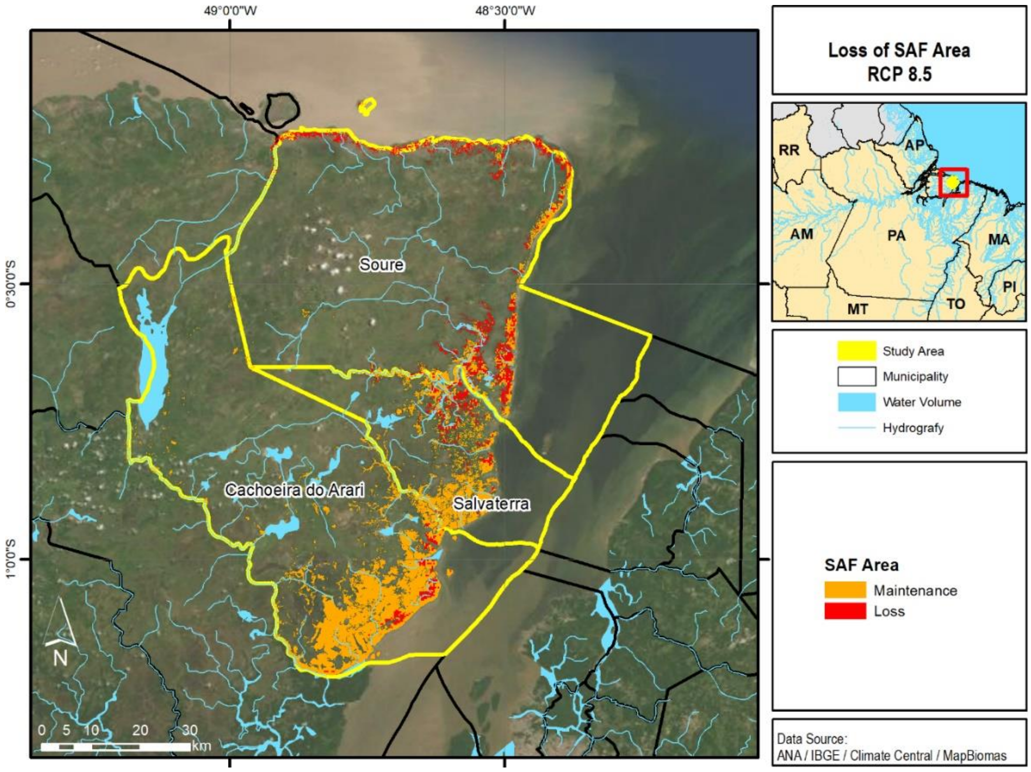


Figure 7: Losses of Potential AFS Areas (RCP8.5)



CONCLUSIONS

Communities living in this region are already being impacted by the effects of climate change (reduction in annual precipitation, increase in average annual temperature and sea level rise). Some of these impacts are: irrigation demand, açaí production affected by reduced rainfall, reduced working hours due to excessive heat.

The areas to be implemented in the municipality must be defined according to field studies and agreements with the families that will receive the project and will be responsible for the maintenance and management of the Agroforestry Systems. Deployment areas may vary according to the AFS selection criteria presented in report A.2 and complemented by the WRI economic feasibility study.

The reduction of climate vulnerability occurs mainly due to the adaptation of the agricultural production model, and by the reduction of subsistence expenses of the families that receive the project. During the course of the project, in contact with the families that will receive the AFS, subsistence expenditures must be evaluated quantitatively, in order to monitor the reduction of these expenditures by the families. This information can be obtained at the beginning of the project with research with the families that will receive the AFS, and must be monitored according to the evolution and development of the AFS.