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THE HILEIA BAIANA IN THE ATLANTIC RAINFOREST BIOME: HAS THE TRANSITION FROM FORESTS TO MONOCULTURES ALTERED THE VOLUME OF RAINFALL?

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ABSTRACT

Human activities have been affecting the climate all over the globe, making extreme weather events increasingly common. In the controversial relationship between man and the environment, a particular region within the Atlantic Rainforest Biome, the Hileia Baiana, stands out as one of the richest and most fragile hotspots on the globe. Despite its biological importance, this region has suffered decades of indiscriminate deforestation, reducing the original biome to less than 10%. Therefore, it was checked whether the loss of natural vegetation caused significant rainfall changes. To this end, the present study evaluated the rainfall stations in the area of influence of this study between 1943 and 2020, with a buffer of 30 km beyond its boundaries. The results showed 14 stations with a reduction in rainfall volumes at the 5% significance level. Between 1984 and 2021, there was a reduction in 3,542.15 km² of Atlantic Forest, in contrast to an increase of 4,845.45 km² in silviculture areas, in the Hileia Baiana region. Our findings indicate rainfall changes coinciding with areas that are no longer covered by the Atlantic Rainforest and gave way to pastures, agriculture, and forestry, concluding that the landscape changes are directly related to climate behavior in the region.

Keywords: Climate change. Land use. Rainfall reduction. MapBiomas.

A HILÉIA BAIANA NO BIOMA MATA ATLÂNTICA: A TRANSIÇÃO DAS MATAS PARA AS MONOCULTURAS ALTEROU O VOLUME DE CHUVAS?

RESUMO

As ações antrópicas vêm modificando o clima ao longo de todo o globo, provocando a ocorrência de eventos climáticos extremos. Nas controversas relações entre homem e meio ambiente, chama atenção uma região do bioma Mata Atlântica, a Hileia Baiana, por ser um dos *hotspots* mais ricos e frágeis do planeta. Mesmo com tal importância biológica, essa região sofreu décadas de desmatamento indiscriminado, reduzindo-se a menos de 10%. Por isso, verificou-se se a perda de vegetação natural provocou alterações pluviométricas significativas. Para atingir os objetivos o estudo avaliaram-se, entre os anos de 1943 e 2020, estações pluviométricas na área de influência recorte deste estudo, com um buffer de 30 km além de seus limites. Os resultados mostram 14 estações com redução dos volumes precipitados ao nível de significância de 5%. Entre 1984 e 2021 ocorreu a redução de 3.542,15 km^2 de Mata Atlântica, contra o aumento de 4.845,45 km^2 de áreas de silvicultura, na região da Hileia Baiana. O trabalho encontrou alterações pluviométricas coincidentes com áreas que deixaram de ser cobertas com a Mata Atlântica e deram lugar a pastagens, agricultura, e silvicultura, concluindo que as alterações paisagísticas têm relação direta com o comportamento do clima na região.

Palavras-chave: Mudanças climáticas. Uso e ocupação do solo. Redução das chuvas. MapBiomas.

INTRODUCTION

Climate change is part of the planet's entropy and is inherent in the processes of natural symbiotic equilibrium. In recent times, more precisely in the last 100 years, the pace and amplitude of climate variations, driven by the increase in human activities, have been increasing, dramatically (CORDEIRO; SOUZA; MENDONZA, 2008). The IPCC report highlights the expected impacts of rising temperatures around the globe, currently at 1.1 degrees Celsius over the pre-industrial period, heading towards 1.5 degrees, mainly due to greenhouse gas (GHG) emissions into the atmosphere (IPCC, 2021). And this scenario is set to get worse, because according to the report by the Intergovernmental Panel on Climate Change (IPCC, 2021), we should expect an increase of another 1.5°C by 2050, which could be higher due to the rate of deforestation, GHG emissions, degradation of soil and water bodies, and air pollution, etc.

The consequence is the increasingly recurrent emergence of extreme and atypical events brought about by climate change, which mainly affect the poorest countries. Extremes of natural instability are becoming more and more frequent. In places where it used to be uncommon, severe droughts or floods, heat waves, and freezing cold, for example, are appearing (Marengo et al., 2022).

Obviously, Brazil is not left out of this dystopia. Climate models indicate that the country is not free from the catastrophic effects of climate change. During the last decade, for example, the country has experienced a lack of rainfall in areas of the Atlantic Rainforest, and the Brazilians have seen large urban agglomerations suffer from a lack of drinking water, as it has happened in the states of São Paulo and Bahia (ESCOBAR, 2015; MARENGO et al., 2009; 2018). According to forecasts, temperatures are expected to rise from 2°C to 3°C by 2070, mainly affecting the Midwest, North, and Northeast regions (SALAZAR et al., 2007; PBMC, 2014).

The Global Precipitation Measurement - GPM (2018) highlights that changes in the natural landscape (removal of native forest) resulting from human activities contribute to altering a region's rainfall regime. However, for any country where the economy and environment are closely linked to rainfall, as is the case in Brazil, the damage caused by climatic extremes is even worse. The problems caused by climate extremes are even bigger in the coastal region, which is predominantly an Atlantic Rainforest region and where most of Brazil's population lives.

Due to its biological richness and threat levels, along with 33 other regions located in different parts of the planet, the Atlantic Rainforest is one of the priority hotspots for biodiversity conservation worldwide (MITTERMEIER et al., 2004; PINTO et al., 2022).

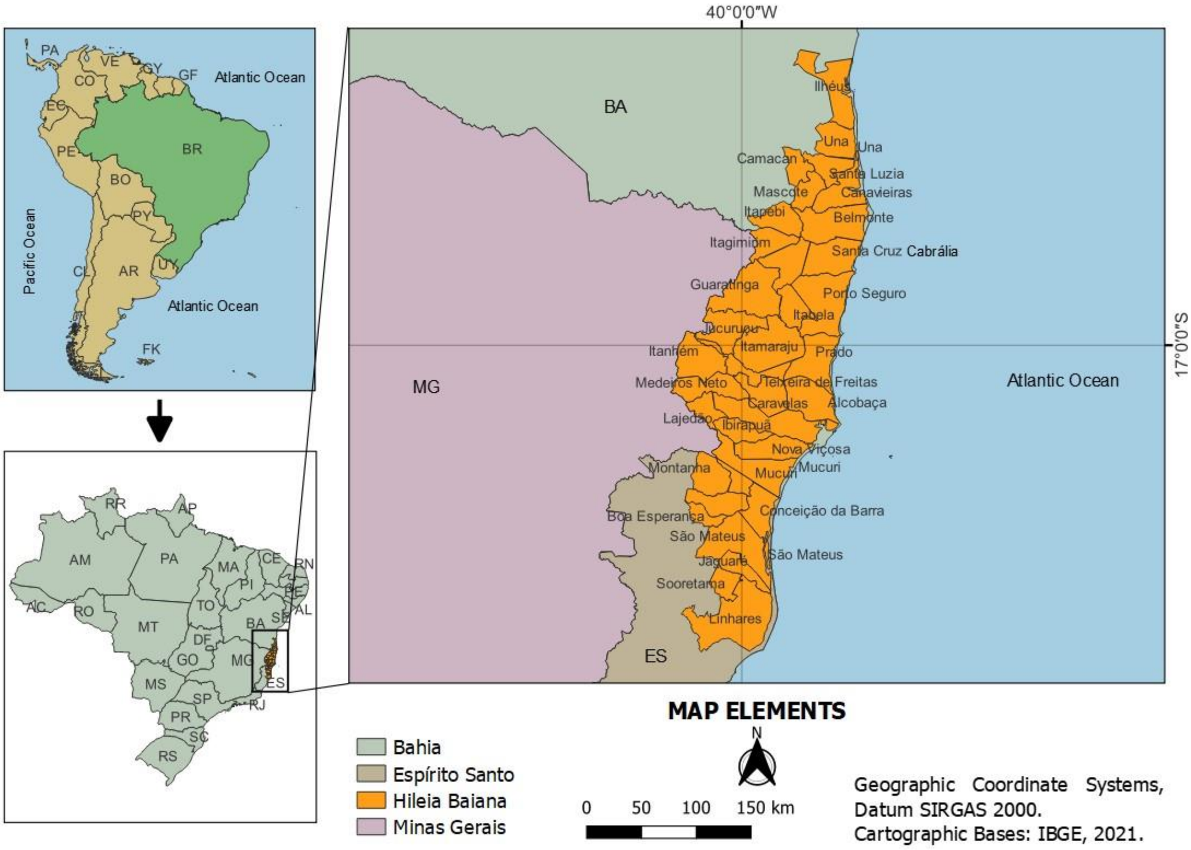
As it lies within the Atlantic Rainforest Biome, the coastal area of the south of the state of Bahia and the north of the state of Espírito Santo show high levels of diversity and endemism (LAGOS and MULLER, 1994). Because of its similarity to the Amazon Rainforest, this part of the Atlantic Rainforest was named "Hileia Baiana" by Andrade Lima (1966). It is also called Tabuleiros Forest, due to the edaphoclimatic facts pointed out in the Heinsdijk classification (TORRESAN et al., 2020).

Hileia Baiana (Figure 1) is the area geographically delimited by 27 municipalities in Bahia (Alcobaça, Belmonte, Camacan, Canavieiras, Caravelas, Eunápolis, Guaratinga, Ibirapuã, Ilhéus, Itabela, Itagimirim, Itamaraju, Itanhém, Itapebi, Jucuruçu, Lajedão, Mascote, Medeiros Neto, Mucuri, Nova Viçosa, Porto Seguro, Prado, Santa Cruz Cabrália, Santa Luzia, Teixeira de Freitas, Una, and Vereda) and 9 municipalities in Espírito Santo (Boa Esperança, Conceição da Barra, Jaguaré, Linhares, Montanha, Pedro Canário, Pinheiros, São Mateus, and Sooretama) covering a territory of around 48.045.22 km² (TORRESAN et al., 2020).

For some time, the Hileia Baiana remained one of the most preserved regions of the Atlantic Rainforest, especially in the area located in southern Bahia. It remained fully preserved until the middle of the last century, when roads were opened, which led to the start of large-scale logging activity, triggering an accelerated and intense process of deforestation (BARBOSA and SAKURAGUI, 2019; SOUZA and Martins, 2022). Today, only 8.5% of the Atlantic Rainforest remains, making this ecosystem one of the most threatened on Earth (INPE, 2014).

The environmental transition that replaced the forest with monocultures occurred because the region has favorable soil and climate conditions for various crops, with some fruit trees showing excellent aptitude for economic interest, especially for the commercial production of watermelon, papaya, passion fruit, pumpkin, and coffee (SILVA JUNIOR, 2021; ARAÚJO et al., 2007, 2010). This is how the Hileia Baiana currently comprises land used for agriculture and extensive livestock farming, as a result of the socio-economic development choices made by the majority of its municipalities. This results in the opening of new areas through the suppression of native vegetation.

Figure 1 - Location of the municipalities in the Hileia Baiana territory



Prepared by the authors (2023).

Therefore, the impact of commercial monocultures is believed to have exerted sufficient pressure on the climate to alter the rainfall in the region. To help us think about the problem, we make inferences based on data from numerous weather stations that have a substantial rainfall history. Such data helps to form the climatic profile of the region, and the samples allow us to understand whether, respecting the natural instabilities of any biome, we are following a pattern. This reflection allows us to establish the climatic trend of how the rainfall regime in the region must be, or at least should be, and to understand how much the Atlantic Rainforest Biome is being impacted by landscape changes associated with human deforestation. This study aimed to show the changes in the rainfall and land use in the Hileia Baiana territory.

MATERIAL AND METHODS

This work processes field data from rainfall and meteorological stations available through the official government portals of Brazil, Hidroweb, and Inmet, and correlates them with theories to make inferences about the behavior of the volume of precipitation from rainfall stations in the territory of the Hileia Baiana. The following methodological steps were taken to capture and preliminarily analyze the data:

1. Identification of existing rainfall stations in the area of influence with data available from official government portals;
2. Analysis of the historical series of rainfall stations in the area, with more than 20 years of operation, with records up to at least 2010;
3. Verification of the spatial homogeneity of the data sources to cover the entire intended area of influence in a coherent manner;

4. Quantification of total annual rainfall;
5. Execution of the stationarity test (Student's t-test for two paired samples) for the total annual rainfall volumes, dividing between older and more recent data;
6. Quantification of land use areas between 1984 and 2021 with MapBiomas data.

The procedure of acquiring and processing climate data for the chosen study area was carried out using data obtained from the network of meteorological stations of the Brazilian National Agency for Water and Basic Sanitation (ANA) provided by the "Portal HidroWeb" website and the Brazilian National Meteorological Institute (INMET). This source comprises an integral tool of the Brazilian National Water Resources Information System (SNIRH) and allows access to the database containing all the information collected by the Brazilian National Hydrometeorological Network (RHN), bringing together data on river levels, flows, rainfall, climatology, water quality, and sediment.

For our analysis, we obtained raw data from 112 rainfall stations, distributed over three states: Bahia, 71; Espírito Santo, 34; and Minas Gerais with 7 stations. These stations were selected because they are located in the area of influence of the Hileia Baiana – 30 km from the limit of the Hileia Baiana.

Analysis and Preliminary Selection

To compose an annual data series with annual rainfall totals, only rainfall stations with a series longer than 20 years and with records up to at least 2010 were used. Of the 112 rainfall stations analyzed, 45 fit the chosen selection criterion (Table 1).

Table 1 - Rainfall stations with more than 20 years of data and with records up to at least 2010 in the area of influence of the Hileia Baiana. The acronym "Points" is used as an identification legend in Figure 2 for the rainfall stations

Municipality	Points	ST	Code	Start	End	Series years ***	Municipality	Points	ST	Code	Start	End	Series Years ***
Alcobaça	P1	BA	01739010	1955	2020	65	Umburatiba	P24	MG	01740026	1978	2020	42
Teixeira de Freitas	P2	BA	01739021	1995	2020	25	Aracruz	P25	ES	01940021	1970	2019	49
Camacan	P3	BA	01539022	1973	2020	47	São Gabriel da Palha	P26	ES	01940016	1969	2020	51
Teixeira de Freitas	P4	BA	01739020	1993	2020	27	São Mateus	P27	ES	01839006	1971	2020	49
Itaju do Col.	P5	BA	01539016	1971	2020	49	São Mateus	P28	ES	01840026	1997	2020	23
Mucuri	P6	BA	01839003	1959	2006*	47	João Neiva	P29	ES	01940005	1949	2020	71
Camacan	P7	BA	01539014	1963	2020	57	Colatina	P30	ES	01940006	1969	2020	51
Prado	P8	BA	01739022	1993	2020	27	Nova Venécia	P31	ES	01840019	1977	2020	43
Itaju do Col.	P9	BA	01539008	1963	2020	57	Ecoporanga	P32	ES	01840011	1970	2009*	39
Itajuípe	P10	BA	01439023	1945	2020	75	Montanha	P33	ES	01840012	1970	2020	50
Itanhém	P11	BA	01740008	1967	2020	53	São Mateus	P34	ES	01840003	1949	2020	71
Itapebi	P12	BA	01539006	1945	2020	75	Aracruz	P35	ES	01940022	1971	2020	49
Jordânia	P13	BA	01540019	1996	2019	23	Pedro Canário	P36	ES	01839000	1951	2020	69
Jucuruçu	P14	BA	01640012	1993	2020	27	Lindenberg	P37	ES	01940013	1969	2019	50
Barro Preto	P15	BA	01439001	1972	2020	48	Ecoporanga	P38	ES	01840015	1971	2018	47
Mascote	P16	BA	01539010	1945	2020	75	Nova Venécia	P39	ES	01840016	1970	2020	50
Medeiros Neto	P17	BA	01740005	1953	2020	67	Jaguaré	P40	ES	01840008	1973	2018	45
Eunápolis	P18	BA	01639000	1973	2020	47	Aracruz	P41	ES	01940003	1949	2018	69
Gongogi	P19	BA	01439006	1951	2020	69	Rio Bananal	P42	ES	01940023	1971	2020	49
Potiraguá	P20	BA	01539048	2007	2020	13**	Nova Venécia	P43	ES	01840020	1983	2020	37

Municipality	Points	ST	Code	Start	End	Series years ***	Municipality	Points	ST	Code	Start	End	Series Years ***
São José da Vitória	P21	BA	01539002	1970	2020	50	Pinheiros	P44	ES	01840017	1971	2020	49
Vereda	P22	BA	01740006	1955	2020	65	Gov. Lindenberg	P45	ES	01940025	1970	2009*	40
Nanuque	P23	MG	01740001	1943	2020	77							

* Despite having data records before 2010, these rainfall stations were used because their series were longer than 20 years and there were no other rainfall stations available in their area. ** Despite having a data series of less than 20 years, this station was used because there are no stations close to the location and the data is recent. *** Series size in years.
Prepared by the authors (2023)

As a selection criterion for using data from the stations, in addition to the time frame, the geographical distribution of the points in the area of influence surveyed was also considered important. They would need to be spread out more evenly in the area of influence. The stations were cataloged and georeferenced using QGIS software, to represent their spatial distribution.

Processing the data series

With the preliminary analysis and selection made, only four exceptions did not meet our selection criteria for the rainfall stations to be studied. Three of them were considered to maintain the homogeneity of the spatial distribution: 01840011 (Ecoporanga-ES), 01839003 (Mucuri-BA), and 01940025 (Governador Lindenberg-ES), even though they contain data that ends in 2009, 2006 and 2009, respectively. These stations were used because their series are longer than 20 years and there are no other rainfall stations available in their area. The fourth station, 01539048 (Potiraguá-BA), although it has a data series of less than 20 years, was also used because there are no other stations near its area, and its data is recent.

Once the information from the 45 stations had been preliminarily selected, the data were subjected to a Student's t-test, specifically the t-test for two paired samples or "two paired samples for averages", assigning 0 (zero) to the hypothesis of a difference in means, as these were groups of equal samples. It also considers samples with one-tailed P-values (T<t) of less than 5% ($p < 0.05$) to be relevant or significant. The Student's t-test has been adopted by various hydrology and climatology studies (SANCHES et al., 2017; CABRAL JÚNIOR et al., 2017; FRAUCHES et al., 2020) and has proved very useful for decision-making. For the stations with significant differences, the reduction or rise in rainfall was calculated.

With the comparative inferences of our statistical analysis, we checked whether the rainfall amounts for the locations showed statistically significant differences. The results and discussions show the findings of the research.

Also, a dispersion comparing sets of rainfall data values was made to show the relationships between the sets of values throughout the spatio-temporal distribution in the Hileia Baiana region between the initial and final years of the data series. A trend line was plotted to evidence the tendencies.

Changes in land use and occupation in the Hileia Baiana

In order to analyze changes in land use and occupation in the territorial area of the Hileia Baiana, we used the data available from MapBiomas in the 1985 to 2021 collection (SOUZA et. al, 2020), by computing the changes in land use and occupation. This data was used to compare the locations that showed significant changes in rainfall volumes.

RESULTS AND DISCUSSIONS

As for stationarity analysis of the data from the selected rainfall stations (Table 2), 14 rainfall stations showed significant differences between the data records of the oldest and newest annual rainfall volumes (Figure 2). Of these 14 stations with differences, all showed a reduction in the total rainfall volume for the most recent years.

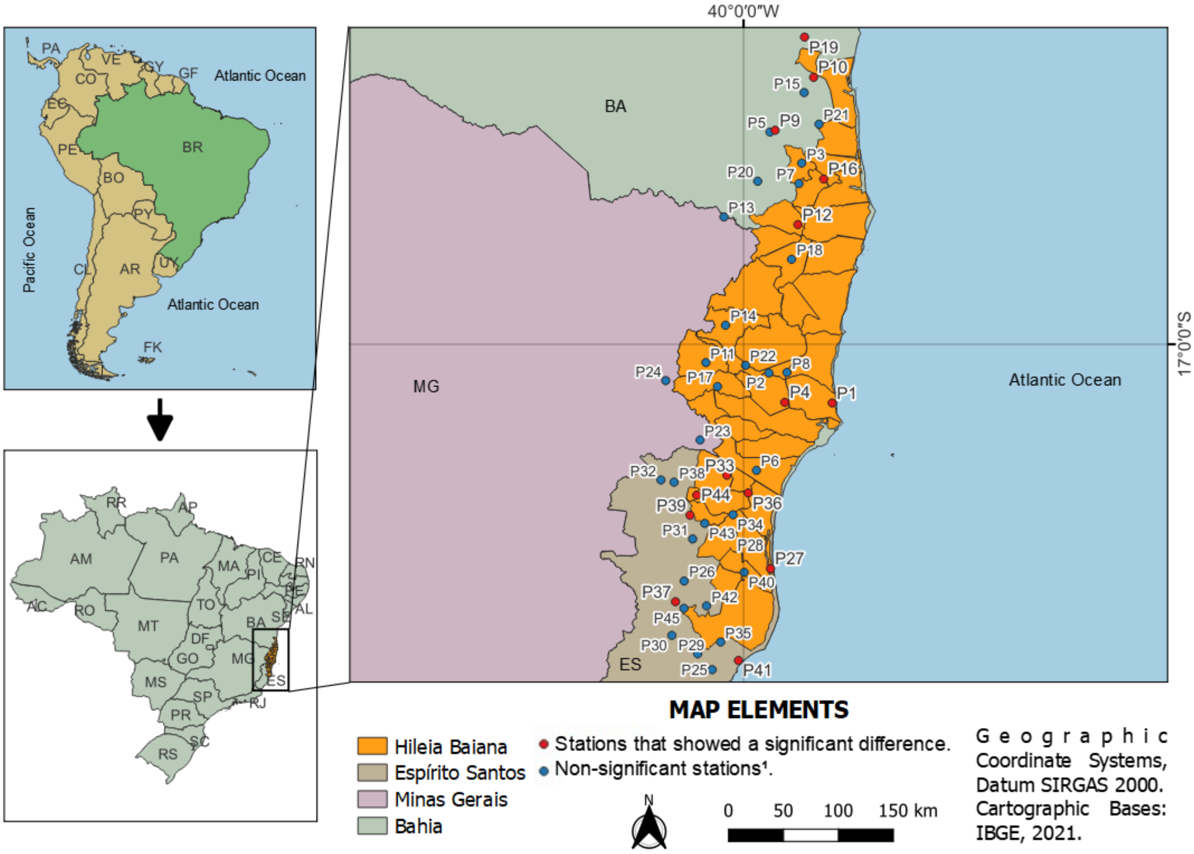
Table 2 - Stationarity analysis of the selected stations, with the size of the series in years (n), the oldest and most recent average rainfall (mm/year), the difference between the oldest and most recent average volumes, and the p-value of the t-test

Municipality	ST	Code	Series size (years)	Old P Mean (mm/ year)	Recent P Mean (mm/ year)	Difference in P (mm/year) (Recent-Old)	p-value
Alcobaça	BA	01739010	65	1567.62	1380.48	-187.13*	0.0470
Aracruz	ES	01940021	49	1318.32	1340.34	22.02	0.4248
São Gabriel da Palha	ES	01940016	51	1154.38	1095.12	-59.25	0.1721
São Mateus	ES	01839006	49	1229.15	1091.31	-137.84*	0.0268
São Mateus	ES	01840026	23	1067.88	868.01	-199.88	0.0595
Teixeira de Freitas	BA	01739021	25	1098.74	1235.41	136.67	0.1277
Camacan	BA	01539022	47	1494.18	1420.71	-73.47	0.2395
João Neiva	ES	01940005	71	1350.32	1257.81	-92.51	0.1222
Colatina	ES	01940006	51	1015.76	963.54	-52.22	0.2271
Nova Venécia	ES	01840019	43	1038.95	962.94	-76.01	0.1772
Ecoporanga	ES	01840011	39	1052.53	1081.64	29.11	0.3547
Teixeira de Freitas	BA	01739020	27	1410.31	982.79	-427.52**	0.0014
Montanha	ES	01840012	50	1116.27	975.55	-140.72*	0.0471
Itaju do Col.	BA	01539016	49	803.15	791.68	-11.48	0.4380
Mucuri	BA	01839003	47	1191.91	1072.41	-119.50	0.1115
Camacan	BA	01539014	57	1162.18	1051.02	-111.17	0.1134
Prado	BA	01739022	27	1098.76	1046.89	-51.87	0.3691
Itaju do Colônia	BA	01539008	57	903.74	723.24	-180.51***	0.0009
Itajuípe	BA	01439023	75	1638.46	1468.87	-169.59*	0.0211
Itanhém	BA	01740008	53	1158.08	1080.25	-77.83	0.0913
Itapebi	BA	01539006	75	1251.53	1150.24	-101.29*	0.0439
São Mateus	ES	01840003	71	1092.29	1009.60	-82.69	0.0678
Aracruz	ES	01940022	49	1225.06	1134.42	-90.64	0.0909
Jordânia	BA	01540019	23	881.20	833.18	-48.02	0.2325
Jucuruçu	BA	01640012	27	1092.91	926.35	-166.56	0.0539
Barro Preto	BA	01439001	48	1486.90	1389.71	-97.20	0.1538
Mascote	BA	01539010	75	1577.75	1380.73	-197.03**	0.0031
Medeiros Neto	BA	01740005	67	976.52	944.91	-31.61	0.3036
Pedro Canário	ES	01839000	69	1175.70	1006.75	-168.95*	0.0159
Eunápolis	BA	01639000	47	1170.84	1080.73	-90.11	0.0704
Nanuque	MG	01740001	77	961.09	896.89	-64.19	0.1489
Lindenberg	ES	01940013	50	1183.21	1028.98	-154.23*	0.0101
Ecoporanga	ES	01840015	47	1125.10	1004.27	-120.83	0.0546
Nova Venécia	ES	01840016	50	1147.65	968.87	-178.78*	0.0144
Gongogi	BA	01439006	69	1217.73	985.03	-232.69***	0.0009
Jaguaré	ES	01840008	45	1178.50	1218.72	40.22	0.3556
Potiraguá	BA	01539048	13	818.50	721.00	-97.50	0.1251
Aracruz	ES	01940003	69	1328.55	1188.02	-140.53*	0.0106
Rio Bananal	ES	01940023	49	1223.21	1171.07	-52.14	0.2558
Nova Venécia	ES	01840020	37	1058.28	946.25	-112.03	0.1353
Pinheiros	ES	01840017	49	1137.18	920.90	-216.28**	0.0069
São José da Vitória	BA	01539002	50	1398.34	1444.75	46.40	0.2511
Vereda	BA	01740006	65	1113.49	1138.59	25.10	0.3394
Umburatiba	MG	01740026	42	955.10	988.21	33.11	0.3483
Gov. Lindenberg	ES	01940025	40	1228.91	1236.90	7.99	0.4635

Where: * significant differences at $p<0.05$; ** significant differences at $p<0.01$; *** significant differences at $p<0.001$.
Prepared by the authors (2023).

Below is the spatial distribution of the 45 rainfall stations (Figure 2) that met the aforementioned selection criteria for this study. The blue dots represent the stations that showed no significant difference, and the red dots indicate the stations that showed significant differences at the 5% significance level.

Figure 2 - Spatial distribution of the rainfall stations analyzed during the study, with a representation of the stations that showed reduction and did not show a significant difference at the 5% significance level in the stationarity test of the data series



Prepared by the authors (2023).

Among the 45 rainfall stations studied, 14 showed a significant difference in the change in rainfall trends at the 5% significance level (Figure 3). Of the 14 stations with differences, 8 are within the perimeter of the Hileia Baiana, namely: 01539010 (Mascote-BA), 01539006 (Itapebi-BA), 01739020 (Fazenda Cascata/Teixeira de Freitas-BA), 01739010 (Alcobaça-BA), 01840012 (Fazenda Limoeiro/Montanha-ES), 01839000 (Morro D'Anta/Pedro Canário-ES), 01840017 (São João do Sobrado/Pinheiros-ES) and 01839006 (Barra Nova/São Mateus-ES). The other 6 stations with significant differences are located in the area of influence: 01439006 (Pedrinhas/Gongogi-BA), 01439023 (Itajuípe-BA), 01539008 (Itaju do Colônia - BA), 01840016 (Patrimônio XV/Nova Venécia-ES), 01940013 (Novo Brasil/ Lindenberg-ES) and 01940003 (Riacho/Aracruz-ES). Silva et al. (2023) also observed rainfall reduction in 19 stations near the Hileia Baiana area, in Southwest Bahia Identity Territory.

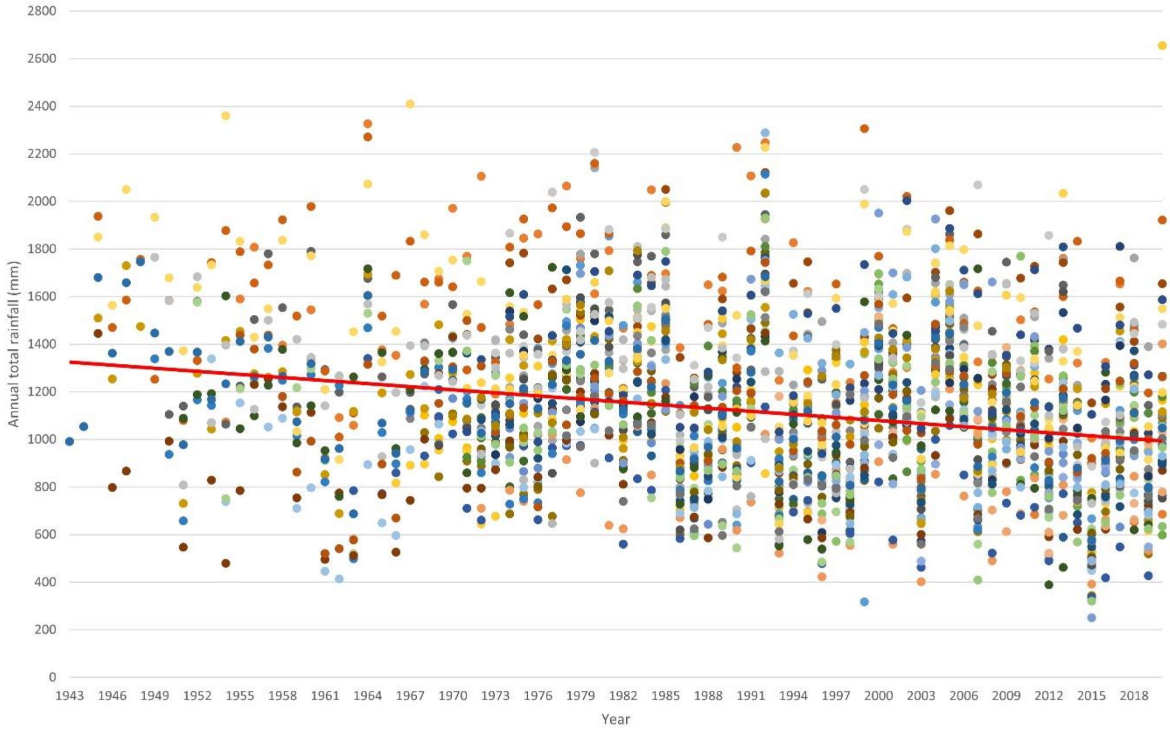
The percentage representation was used to indicate the reduction in the annual rainfall volume at the stations with a significant difference, which makes it possible to compare the average for the oldest period with the average for the most recent period. However, in a visual demonstration, we can see differences in rainfall volumes in the study region, with 37 stations showing lower volumes, but only 14 with significant differences. With the help of point distribution graphs and trend lines, rainfall volumes in the Hileia Baiana have decreased over time (Figure 3).

Considering individual differences, the stations considered by this research to have the highest percentages of change, i.e., over 19% in the reduction of average annual rainfall volumes, were, in descending order, 01739020 (Fazenda Cascata/Teixeira de Freitas-BA), with 30.31%; 01539008 (Itaju do Colônia - BA), with 19.97%; 01439006 (Pedrinhas/Gongogi-BA), with 19.11%; and 01840017 (São João do Sobrado/Pinheiros-ES) with 19.02% (Table 3).

Among the stations with an average annual volume reduction of less than 15%, 01839006 (Barra Nova/São Mateus-ES) stood out, with the lowest percentage reduction, at 7.57%.

Importantly, no studies have been found in the literature that assess changes in the rainfall regime with significant differences for the points discussed here. Only the municipalities of Mascote-BA and Itapebi-BA have a Municipal Plan for the Conservation and Recovery of the Atlantic Rainforest (PMMA) published in 2017. The Plan for these municipalities includes projections for changes and trends in the volume of rainfall based on an analysis of data between 1971 and 2000, with a projection for 2020 (PMMA, 2017a); (PMMA, 2017b). According to their plans, these cities tend to a reduction in average annual rainfall of around 5%, a forecast change attributed to climate change. In contrast, our analysis found that the PMMA forecasts for these municipalities are optimistic since our results showed a trend of reduced rainfall of more than 6%, considerably higher than the municipal forecasts.

Figure 3 - Dispersion comparing sets of data values showing the relationships between the sets of values throughout the spatio-temporal distribution in the Hileia Baiana region between 1943 and 2020



Prepared by the authors (2023).

Table 3 - Reduction in the average annual rainfall volume of the stations with a 5% significance level

Name of the Station	Code	Municipality	ST	Reduction (%)*
Fazenda Cascata	01739020	Teixeira de Freitas	BA	30.31
Itaju do Colônia	01539008	Itaju do Col.	BA	19.97
Pedrinhas	01439006	Gongogi	BA	19.11
São João do Sobrado	01840017	Pinheiros	ES	19.02

Name of the Station	Code	Municipality	ST	Reduction (%)*
Morro D'Anta	01839000	Pedro Canário	ES	14.37
Novo Brasil	01940013	Lindenberg	ES	13.03
Fazenda Limoeiro	01840012	Montanha	ES	12.61
Alcobaça	01739010	Alcobaça	BA	11.94
Mascote	01539010	**Municipality**	BA	12.49
Patrimônio XV	01840016	Nova Venécia	ES	10.59
Riacho	01940003	Aracruz	ES	10.58
Itajuípe	01439023	Itajuípe	BA	10.35
Itapebi	01539006	Itapebi	BA	8.09
Barra Nova	01839006	São Mateus	ES	7.57

* The percentage reduction in rainfall was calculated concerning the two averages, from the oldest period to the most recent period.

Prepared by the authors (2023).

Figure 3 shows that rainfall volumes have been decreasing over time. The trend line for the data sets reveals a downward slope in the volume of rainfall in the study area. The average trend line of the values (red color) indicates an ongoing decrease in the volume of rainfall, and that the behavior of rainfall is not in equilibrium over the years.

Schiavetti & Camargo (2002) raise the hypothesis that exploitative human activities can unbalance the hydrological cycle of a given river basin, in addition to other consequences. Farias et al. (2020) state that the reduction of native vegetation areas for agricultural use influences the physical, chemical, and biological characteristics and the amount of water available in a watershed. The authors report that the Peruípe, Itanhém, and Jucuruçu river basins, located in southern Bahia, have 36% of the total area occupied by pasture, and also have compacted soils with a lower infiltration rate and water residence time, resulting in lower water productivity.

Also, according to Farias et al. (2020), the analysis of the stationarity of minimum flows of the Peruípe, Itanhém, and Jucuruçu river basins, state of Bahia, revealed that 63% of the fluviometric stations showed a tendency to reduce their flows over time, when comparing past average values with average values from more recent periods. The same reasoning occurs when indiscriminate anthropic use has altered the hydrological cycle in the Alto Paraguaçu River basin in Bahia, Ribeirão in Espírito Santo, and João Leite in Goiânia (SANTOS et al., 2010; CALIJURI et al., 2015).

An important municipality in the Hileia Baiana, Teixeira de Freitas (state of Bahia), has 62.12% of its total area devoted to pasture, and 3.98% to agriculture (ALMEIDA; SILVA; NEVES, 2020). Another reference is Itaju do Colônia (state of Bahia), where in 2006, pasture occupied 65.0% of the total area of the basin (CERB, 2011).

In 2006, the municipality of Gongogi (state of Bahia) had more than 50% of the land of agricultural properties occupied by pasture (TEIXEIRA, 2009). The municipality of Pinheiros (state of Espírito Santo), according to the Capixaba Institute for Research, Technical Assistance, and Rural Extension - INCAPER, had 48% of its territory occupied by pasture, with sugar cane as the main agricultural crop, occupying 13.5% of the territory (INCAPER, 2020a). Another report by INCAPER (2020b) shows that Pedro Canário (state of Espírito Santo) has 39.4% of its territory filled with pastures, and the most cultivated crop is also sugar cane, with 25.4% of the total area.

In Lindenberg (state of Espírito Santo), agriculture occupies the largest percentage of the territory's area, accounting for 30.1% (INCAPER, 2020c). INCAPER (2020d) indicates that Montanha (state of Espírito Santo) has around 61.0% of the total area occupied by pasture, and 8.5% of the area is used to grow sugar cane. Also, in the municipality of Alcobaça (state of Bahia), the predominant form of land use is pasture, with 37.68% (SPANGHERO; OLIVEIRA, 2017), and the municipality of Mascote (state of Bahia) has up to 50.56% of its territory devoted to livestock production.

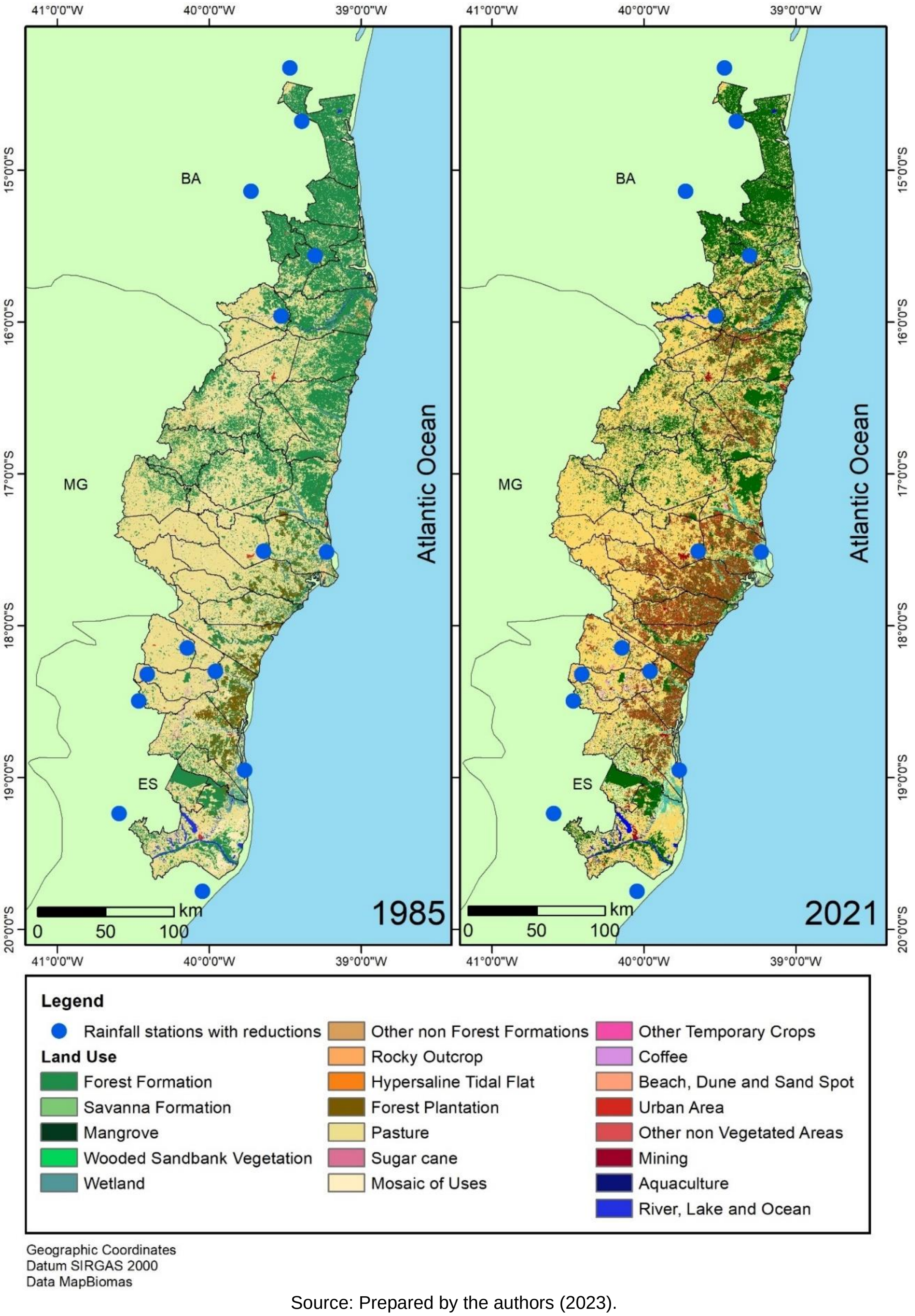
In the municipalities of Nova Venécia, Aracruz, and São Mateus, in the state of Espírito Santo, and Itapebi, in the state of Bahia, the predominant class of land use and occupation is pasture, with 52.0%, 22.5%, 31.9% and 65.0% of the territory, respectively (INCAPER, 2020e; INCAPER, 2020f; INCAPER, 2020g; PMMA, 2017b).

This paper discusses the hypothesis that the impacts of anthropogenic land use through monocultures cause changes in the rainfall regime. These transitions, from a natural environment to a predominantly altered one, have influenced the abiotic and biotic environment, and have consequently caused socio-economic problems, such as the loss of crops, rural exodus, and the weakening of the local economy; with farming and forestry being the main sources of income for the economy of the municipalities. In this regard, Neves et al. (2022) discuss the social problems in Southern Bahia that are affecting the region, such as climate change and loss of biodiversity in the area, findings that reinforce this hypothesis.

Data on land use from MapBiomas (Figure 4) shows that the central part of the Hileia Baiana suffered major landscape changes from 1985 to 2021. These data, combined with the results of reduced rainfall in the points that presented significant differences (Figure 3), reinforce the hypothesis of a direct cause-and-effect association between landscape change and the climate regime of a given region. Between 1984 and 2021, there was a reduction of 3,542.15 km^2 of Atlantic Forest, in contrast to an increase of 4,845.45 km^2 in silviculture areas, in the Hileia Baiana region (Table 4). There was a reduction in pasture areas, 1,534.14 km^2, and a mosaic of uses (agriculture plus pasture), 1,190.91 km^2. According to TORRESAN et al. (2020), the areas made up of natural formations and water bodies continued to decrease in the Hileia Baiana from 1985 to 2018. For the year 2018, natural formations and water bodies corresponded to 26.73 %, while these areas corresponded to 32.4 % in 1985.

In Figure 4, the points that showed a significant difference in rainfall were those located in the northern part of the Hileia, which are in an area that suffered significant transformations in the landscape during the period studied, reinforcing the hypothesis of a cause-and-effect correlation for the phenomenon of environmental change. There is a downward trend in rainfall at the two ends of the Hileia Baiana, to the north, from Pedrinhas to Itapebi (5 stations); to the south, from Fazenda Limoeiro to Riacho (7 stations); and the southwest, (2 stations) Fazenda Cascata and Alcobaça. In this study, all these stations showed a downward trend of rainfall. Silva et al. (2023) also reported reduced rainfall close to the north part of Hileia Baiana, in the Southwest Bahia Identity Territory.

Figure 4 - Land use and occupation in the years 1985 and 2021 in the Hileia Baiana area and stations with significant reductions in rainfall volumes



Source: Prepared by the authors (2023).

Table 4 - Changes in land use and occupation in the territorial area of the Hileia Baiana between 1985 and 2021

Land use	1985	2021	Alteration 1985 to 2021 (km²)	Alteration 1985 to 2021 (%)
Forest formation	16,585.96	13,043.81	-3,542.15	-21,36%
Savanna formation	2.39	22.75	20.36	853.02%
Mangrove	71.41	83.29	11.88	16.63%
Forest Plantation	1,413.43	6,258.88	4,845.45	342.81%
Wetland	888.34	1.326.83	438.49	49.36%
Other non-forest formations	194.98	129.96	-65.02	-33.35%
Pasture	23,068.98	21,534.84	-1,534.14	-6.65%
Sugar cane	0.01	13.55	13.54	-
Mosaic of uses	5,943.34	4,752.43	-1,190.91	-20.04%
Beach, Dune and Sand Spot	13.06	12.68	-0.38	-2.92%
Urban Area	94.81	232.00	137.20	144.71%
Other non-vegetated areas	33.69	35.08	1.39	4.11%
Rocky Outcrop	130.67	143.11	12.44	9.52%
Mining	0.01	3.23	3.22	-
Aquaculture	0.10	1.83	1.73	-
Salt flat	0.51	1.04	0.54	-
River, Lake, and Ocean	441.63	445.16	3.53	0.80%
Other temporary crops	17.54	114.83	97.29	554.66%
Coffee	141.18	517.09	375.92	266.27%
Other perennial crops	0.00	1.86	1.86	-
Wooded sandbank vegetation	127.03	75.67	-51.36	-40.43%
Herbaceous sandbank vegetation	0.00	409.52	409.52	-

Source: Prepared by the authors (2023).

CONCLUSIONS

Our data show that agricultural, livestock, and forestry activities in the Hileia Baiana are directly related to the climate dynamics of the Atlantic Rainforest and that major alterations in the natural environment can produce implications for the natural dynamics of the associated ecosystems.

In the Hileia Baiana, of the total of 45 rainfall stations studied, 14 showed a reduction in rainfall between 1943 and 2010. The locations that showed reduced rainfall both in the territory of the Hileia Baiana and in its area of influence were Alcobaça-BA, Aracruz-ES, Gongogi-BA, Itaju do Colônia-BA, Itajuípe-BA, Itapebi-BA, Lindenberg-ES, Mascote-BA, Montanha-ES, Nova Venécia-ES, Pedro Canário-ES, Pinheiros-ES, São Mateus-ES, and Teixeira de Freitas-BA.

Between 1984 and 2021, there was a reduction of 3,542.15 km² of Atlantic Forest, in contrast to an increase of 4,845.45 km² in silviculture areas, in the Hileia Baiana region. There was a reduction in pasture areas, 1,534.14 km², and a mosaic of uses (agriculture plus pasture), 1,190.91 km².

The economic activities in the Hilea region that have reduced biodiversity to monoculture deserts are directly related to maintaining stability in the rainfall regime. We would finally like to suggest further studies on the climatic behavior in the region, adding correlations with temperature, humidity, and wind intensity to the analyses, to reinforce the conclusive basis of this work.

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REFERENCES

ALMEIDA, P. F.; SILVA, J. B. L.; NEVES, F. M. Vulnerabilidade Ambiental do Município de Teixeira de Freitas – BA. **Revista Brasileira de Geografia Física**, v. 13, n. 04, p. 1587–1609, 2020. https://doi.org/10.26848/rbgf.v13.4.p1587-1609

ANDRADE LIMA, D. Vegetação. In: IBGE/Conselho Nacional de Geografia. **Atlas Nacional do Brasil**. Rio de Janeiro, 122 p. mapas color, 1966. Disponível em: <https://www.embrapa.br/busca-de-publicacoes/-/publicacao/1129405/dinamica-espaco-temporal-do-uso-e-cobertura-das-terras-na-hileia-baiana>. Acesso em: 15 fev. 2022.

ARAÚJO, A. C.; SILVA, L. M. R.; KHAN, A. S.; ARAÚJO, L. V. A Cultura do mamão em municípios selecionados do extremo sul da Bahia: análise do índice tecnológico da comercialização e do custo social das perdas. **Revista Econômica do Nordeste**, Fortaleza, v.41, n.4, p.699-714, 2010. https://doi.org/10.61673/ren.2010.327

ARAÚJO, L. V. **Análise econômica da cultura do maracujá no Estado da Bahia**, **1990 a 2005**. Monografia (Graduação em Ciências Econômicas) - Ilhéus: UESC, 2007. Disponível em: <https://drive.google.com/file/d/1eOfr2t7gu2TrAEbhH7oH42bGbEuNDbE1/view>. Acesso em: 15 fev. 2022.

BARBOSA, L. M.; SAKURAGUI, C. M. **Inventário Florístico de Espécies Arbóreas de um Fragmento Florestal da Hiléia Baiana no Extremo Sul da Bahia, Brasil**. Rio de Janeiro: UFRJ. 2019. Disponível em: <https://minerva.ufrj.br/F/?func=direct&doc_number=000886612&local_base=UFR01>. Acesso em: 15 fev. 2022.

CALIJURI, M. L.; CASTRO, J. D.; COSTA, L. S.; ASSEMANY, P. P.; ALVES, E. M. Impact of land use/land cover changes on water quality and hydrological behavior of an agricultural subwatershed. **Environmental Earth Sciences**, v. 74, p. 5373-5382, 2015. https://doi.org/10.1007/s12665-015-4550-0

CERB. **Estudo de impacto ambiental da barragem do rio colônia EIA/RIMA**. Volume IV - Relatório síntese do estudo de impacto ambiental, rev. – 02, 2011. Disponível em: <http://www.cerb.ba.gov.br/sites/www.cerb.ba.gov.br/files/sala_de_imprensa/publicacoes/EIARima_Barragem_do_Colonia.pdf>. Acesso em: 21 jul. 2022.

CORDEIRO, S. A.; SOUZA, C. C.; MENDOZA, Z. M. S. H. Florestas brasileiras e as mudanças climáticas. **Revista Científica Eletrônica de Engenharia Florestal**, n. 11, v. 1, p. 1-20, 2008. Disponível em: <https://faef.revista.inf.br/site/e/engenharia-florestal-11-edicao-12008.html#tab254>. Acesso em: 10 fev. 2022.

ESCOBAR, H. Drought triggers alarms in Brazil's biggest metropolis. **Science**, v. 347, n. 6224, p. 812–812, 2015. https://doi.org/10.1126/science.347.6224.812

FARIAS, E. S.; SILVA, G. M. F.; SILVA, J. B. L.; SILVA, D. P.; PIRES, L. C. Caracterização hidrológica das bacias hidrográficas dos rios Peruípe, Itanhém e Jucuruçu. **Scientia Plena**, v. 16, n. 8, p. 1-16, 2020. https://doi.org/10.14808/sci.plena.2020.081701

GPM. **Medição de Precipitação Global**, 2018. Disponível em: < https://gpm.nasa.gov/resources/faq/what-drought-and-what-causes-it#:~:text=Droughts%20are%20caused%20by%20low,factors%20that%20contribute%20to%20drough >. Acesso em: 31 jul. 2022.

INCAPER. Instituto Capixaba de Pesquisa, Assistência Técnica e Extensão Rural. **Pinheiros**: programa de assistência técnica e extensão rural 2020 – 2023, 2020. Disponível em: <https://incaper.es.gov.br/media/incaper/proater/municipios/Pinheiros.pdf>. Acesso em: 21 jul. 2022a.

INCAPER. Instituto Capixaba de Pesquisa, Assistência Técnica e Extensão Rural. **Pedro Canário**: programa de assistência técnica e extensão rural 2020 – 2023, 2020. Disponível em:

<https://incaper.es.gov.br/media/incaper/proater/municipios/Pedro_Canario.pdf>. Acesso em: 21 jul. 2022b.

INCAPER. Instituto Capixaba de Pesquisa, Assistência Técnica e Extensão Rural. **Governador Lindenberg**: programa de assistência técnica e extensão rural 2020 – 2023, 2020. Disponível em: <https://incaper.es.gov.br/media/incaper/proater/municipios/Governador_Lindenberg.pdf>. Acesso em: 22 jul. 2022c.

INCAPER. Instituto Capixaba de Pesquisa, Assistência Técnica e Extensão Rural. **Montanha**: programa de assistência técnica e extensão rural 2020 – 2023, 2020. Disponível em: <https://incaper.es.gov.br/media/incaper/proater/municipios/Montanha.pdf>. Acesso em: 22 jul. 2022d.

INCAPER. Instituto Capixaba de Pesquisa, Assistência Técnica e Extensão Rural. **Nova Venécia**: programa de assistência técnica e extensão rural 2020 – 2023, 2020. Disponível em: <https://incaper.es.gov.br/media/incaper/proater/municipios/Nova_Venecia.pdf>. Acesso em: 23 jul. 2022e.

INCAPER. Instituto Capixaba de Pesquisa, Assistência Técnica e Extensão Rural. **Aracruz**: programa de assistência técnica e extensão rural 2020 – 2023, 2020. Disponível em: <https://incaper.es.gov.br/media/incaper/proater/municipios/Aracruz.pdf>. Acesso em: 23 jul. 2022f.

INCAPER. Instituto Capixaba de Pesquisa, Assistência Técnica e Extensão Rural. **São Mateus**: programa de assistência técnica e extensão rural 2020 – 2023, 2020. Disponível em: <https://incaper.es.gov.br/media/incaper/proater/municipios/Sao_Mateus.pdf>. Acesso em: 23 jul. 2022g.

INPE. **SOS Mata Atlântica e INPE apresentam dados do Atlas dos Remanescentes Florestais da Mata Atlântica**. 2014. Disponível em: <http://www.inpe.br/noticias/noticia.php?Cod_Noticia=3610#:~:text=Atualmente%2C%20restam%20apenas%208%2C5,permitido%20mais%20precis%C3%A3o%20nos%20levantamentos>. Acesso em: 15 fev. 2022.

LAGOS, A. R.; MULLER, B. L. A. Hotspot Brasileiro - Mata Atlântica. **Saúde & Ambiente em Revista**, v. n. 2, p. 35–45, 1994.

SOUZA, C.M., JR.; Z. SHIMBO, J.; ROSA, M.R.; PARENTE, L.L.; A. ALENCAR, A.; RUDORFF, B.F.T.; HASENACK, H.; MATSUMOTO, M.; G. FERREIRA, L.; SOUZA-FILHO, P.W.M.; et al. Reconstructing Three Decades of Land Use and Land Cover Changes in Brazilian Biomes with Landsat Archive and Earth Engine. **Remote Sensing**, v. 12, n. 17, p. 1-27, 2020. https://doi.org/10.3390/rs12172735

MARENGO, J. A.; ALVES, L. M.; ALVALA, R. C. S.; CUNHA, A. P.; BRITO, S.; MORAES, O. L. L. Climatic characteristics of the 2010-2016 drought in the semiarid Northeast Brazil region. **Anais da Academia Brasileira de Ciências**, v. 90, n. 2, p. 1973-1985, 2018. https://doi.org/10.1590/0001-3765201720170206.

MARENGO, J. A. **Mudanças climáticas e eventos extremos no Brasil**. Rio de Janeiro: FBDS, 2009. Disponível em: <http://www.fbds.org.br/cop15/FBDS_MudancasClimaticas.pdf>. Acesso em: 11 fev. 2022.

IPCC. **Summary for Policymakers. In: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change.** Ed.: MASSON-DELMOTTE, V. P.; ZHAI, A.; PIRANI, S.L.; CONNORS, C.; PÉAN, S.; BERGER, N.; CAUD, Y.; CHEN, L.; GOLDFARB, M.I.; GOMIS, M.; HUANG, K.; LEITZELL, E.; LONNOY, J.B.R.; MATTHEWS, T.K.; MAYCOCK, T.; WATERFIELD, O.; YELEKÇI, R.; YU, B. ZHOU. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 3−32, 2021. https://doi.org/10.1017/9781009157896.001

PBMC – PAINEL BRASILEIRO DE MUDANÇAS CLIMÁTICAS. **Base científica das mudanças climáticas** - Grupo de Trabalho 1. In: AMBRIZZI, T.; ARAUJO, M. (Eds.) Primeiro Relatório da Avaliação Nacional sobre Mudanças Climáticas. Rio de Janeiro: COPPE, 2014, 464 pp. Disponível em: <http://www.pbmc.coppe.ufrj.br/index.php/pt/publicacoes/relatorios-pbmc/item/base-cientifica-das-mudancas-climaticas-volume-1-completo>. Acesso em: 14 fev 2022.

PINTO, L. P.; HIROTA, M. M. **30 anos de Conservação do Hotspot de Biodiversidade da Mata Atlântica: desafios, avanços e um olhar para o futuro**. São Paulo: Fundação SOS Mata Atlântica,

2022. Disponível em: <https://cms.sosma.org.br/wp-content/uploads/2022/05/Livro-30anos-SOS-mobile-1.pdf>. Acesso em: 18 abr 2024.

PMMA. **Plano municipal de conservação e recuperação da Mata Atlântica de Mascote**. São Paulo: Fundação SOS Mata Atlântica, 2017a. Disponível em: <https://www.gamba.org.br/wp-content/uploads/2017/05/PMMA_MASCOTE.pdf>. Acesso em: 19 jul. 2022.

PMMA. **Plano municipal de conservação e recuperação da mata atlântica de Itapebi**. São Paulo: Fundação SOS Mata Atlântica, 2017b. Disponível em: <https://www.gamba.org.br/wp-content/uploads/2017/05/PMMA_ITAPEBI.pdf>. Acesso em: 19 jul. 2022.

SALAZAR, L.F.; NOBRE, C.A.; OYAMA, M.D. Climate change consequences on the biome distribution in tropical South America. **Geophysical Research Letters**, v. 34, n. 9, 2007. https://doi.org/10.1029/2007GL029695.

NEVES, F. M.; ALVAREZ, G.; CORREA, F. F.; SILVA, J. B. L. Drivers of vulnerability to climate change in the southernmost region of Bahia (Brazil). **Sociedade & Natureza**, v. 34, p. 1-15, 2022. https://doi.org/10.14393/SN-v34-2022-62222

SANTOS, E. H. M.; GRIEBELER, N. P.; OLIVEIRA, L. F. C. **Relação entre uso do solo e comportamento hidrológico na Bacia Hidrográfica do Ribeirão João Leite**. Revista Brasileira de Engenharia Agrícola e Ambiental, v. 14, n. 8, p. 826-834, 20104. https://doi.org/10.1590/S1415-43662010000800006

SCHIAVETTI, A.; CAMARGO, A. F. M. **Conceitos de bacias hidrográficas**: teorias e aplicações. Ilhéus: Editus, 2002, 293p.

SILVA JUNIOR, J. M. **A Bahia que dá certo**. 2021. Disponível em: https://www.cnabrasil.org.br/artigos/a-bahia-que-d%C3%A1-certo. Acesso em: 17 de fev. 2022.

SILVA, T. L. F.; BRITO JUNIOR, B. S..; SILVA, J. B. L. Analysis of the Pluviometric Regime in the Southwest Bahia Identity Territory: Implications for Water Resources Management. **Revista de Geociências do Nordeste**, v. 9, n. 2, p. 144–155, 2023. https://doi.org/10.21680/2447-3359.2023v9n2ID33955.

SOUZA, F; MARTINS, H. T. Social Environmental Dilemmas and Governing the Commons: The Itanhém River Basin in Southern Bahia, Brazil. *In:* **The Cambridge handbook of Commons Research Innovations**. United Kingdom: Cambridge, p. 216- 225, 2022. https://doi.org/10.1017/9781108938617.025.

SPANGHERO, P. E. S.; OLIVEIRA, R. C. Mapeamento do uso e ocupação da terra do município de Alcobaça, Bahia (2015). In: **Os desafios da geografia física na fronteira do conhecimento**. Ed. PERZ FILHO, A.; AMORIM, R. R. Instituto de Geociências – Unicamp, Campinas – SP, 2017. https://doi.org/10.20396/sbgfa.v1i2017.1855.

TEIXEIRA, A. C. O. **Alterações no uso da terra das bacias do baixo Rio de Contas e Gongogi e regime hidrológico do Rio Gongogi – BA.** 2009. 119f. Dissertação (Mestrado em Desenvolvimento Regional e Meio Ambiente) - UNIVERSIDADE ESTADUAL DE SANTA CRUZ / PRODEMA, 2009. Disponível em: <http://www.biblioteca.uesc.br/biblioteca/bdtd/200760012D.pdf>. Acesso em: 15 fev. 2022.

TORRESAN, F. E.; ALBUQUERQUE, N. C. B.; ASSIS, A. C. C. **Dinâmica espaço temporal do uso e cobertura das terras na Hiléia Baiana**. Embrapa Tabuleiros Costeiros, Documentos n. 236, 2020, 38p. Disponível em: <https://www.infoteca.cnptia.embrapa.br/handle/doc/1129405>. Acesso em: 15 fev. 2022.

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