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ORIGINAL PAPER

Agricultural vulnerability to climate change in the Rio das Contas Basin, Brazil

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Abstract

Climate change threats agriculture, mainly in developing countries. Understanding the vulnerability of farmers is very important to counteract the negative impacts. Therefore, this paper aims to analyze the degree of vulnerability to climate change of farmers of the Rio das Contas Basin, Brazil, based on their degree of sensibility, exposure, and adaptive capacity. Variations in exposure and vulnerability indexes between regional biomes were calculated. The sensibility index was higher than 50% in all municipalities. The exposure index was over 60% in most municipalities. A value of the adaptive capacity index, sufficient to reduce vulnerability, was not observed in any municipality. The vulnerability index was higher than 66% in more than half of the municipalities. Exposure and vulnerability indexes varied with the biome. The vulnerability is the result of high exposure and sensibility combined with low adaptive capacity. This suggests the need for investment to minimize these effects and mitigation activities to counter the negative impacts of future climate variability.

Keywords Climate change · Vulnerability · Agriculture · Brazilian Northeast · Rio das Contas Basin

Introduction

Climate change and extreme events, due to both natural causes and human exploitation of environmental resources, have increased since the preindustrial era, constituting the main challenge of the world (Feulner 2017). These changes affect the social and economic life of most populations, especially in the agricultural sector, which depends on the ideal temperature and precipitation ranges (Huffman et al. 2018). This sector will be one of the most affected by climate change because environmental conditions are a crucial factor for agricultural productivity (Nelson et al. 2014; Nazareth et al. 2020).

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Anthropic greenhouse gas (GHG) emissions will increase the Earth's temperature by 1.5 °C by the end of the twenty-first century compared to the period between 1850 and 1900. Consequently, the vulnerability of the population will also increase (IPCC 2014a). Small agricultural farmers in developing countries such as Brazil are most vulnerable to the current and future impacts of climate change (Crist et al. 2017; De Matos Carlos et al. 2020). Climate variability can increase the poverty of individuals in more exposed rural areas with limited adaptive capacity (Bouroncle et al. 2017).

The vulnerability and adaptive capacity of farmers are associated with climate change and their socioeconomic conditions (Below et al. 2012). The vulnerability or adaptive capacity of different localities and, or, communities has been studied (Malone and Brenkert 2008; Iglesias et al. 2011), especially regarding the impact of climate change and the way people adapt to this (Below et al. 2012; Piedra-Bonilla et al. 2020).

Agribusiness represents over 21.3% of Brazil's Gross Domestic Product (CEPEA 2020). The Brazilian Northeast region, with approximately 18% of this percentage (IBGE 2017), or 3.82% of this GDP, has the majority of the rural population with low levels of agricultural productivity (Alves and Marra 2009). Farmers in this region work under continuous drought conditions and will suffer the most significant impact from an elevation of temperatures by up to 3.5° C to 4.4° C by the end of the twenty-first century, with decreasing rainfall and more extended droughts (PBMC 2013). In addition, these effects will magnify problems faced by more impoverished farmers, such as rural–urban migration and poor access to education (Machado Filho 2015).

More regionalized studies are needed, as the "averages of impacts" at the global and country levels are already known (IPCC 2014a). The impact of climate change should be studied in model localities of vulnerability and the results used in determining public policy (Smit and Wandel 2006; Below et al. 2012).

The main objective of this research was to estimate and analyze the sensibility, exposure, and adaptive capacity, as well as the degree of vulnerability to climate change, of farmers in the Rio das Contas Basin, Bahia, Brazil. In addition, this research has sought to demonstrate whether vulnerability and exposure indexes for climate change vary among biomes in this basin. This study considered farmers with properties in the Rio das Contas Basin, with approximately 55,000 km^2, equivalent to 10.2% of the territory of the state of Bahia, and was carried out from 2014 to 2015.

Materials and methods

Study area

The Rio das Contas Basin is part of the East Atlantic hydrographic region and is the largest contained in this state, with 92 municipalities (CBHRC 2013). The population of this basin is 2,148,031 inhabitants (15.3% of the people of the state of Bahia), with 35% in the rural area and 752,427 inhabitants (PNUD 2013) (Fig. 1).

The municipalities of the Rio das Contas Basin are small to medium-sized, with activities mainly in livestock and variable climate among their biomes, which include the Atlantic Forest, Caatinga and Cerrado. Small-scale agriculture for home consumption, cocoa cultivation in some regions, and extensive rearing of livestock are the main rural economic activities in this basin. This region has low human development rates (MHDI) (PNUD 2013).

The Rio das Contas Basin, with several different biomes, has high economic and sociocultural value and relevance for rural farmers (De Matos Carlos et al. 2020). The most critical aspects of agricultural activity should be studied to define public policies related to sustainable development and to improve the relationship between humans and the

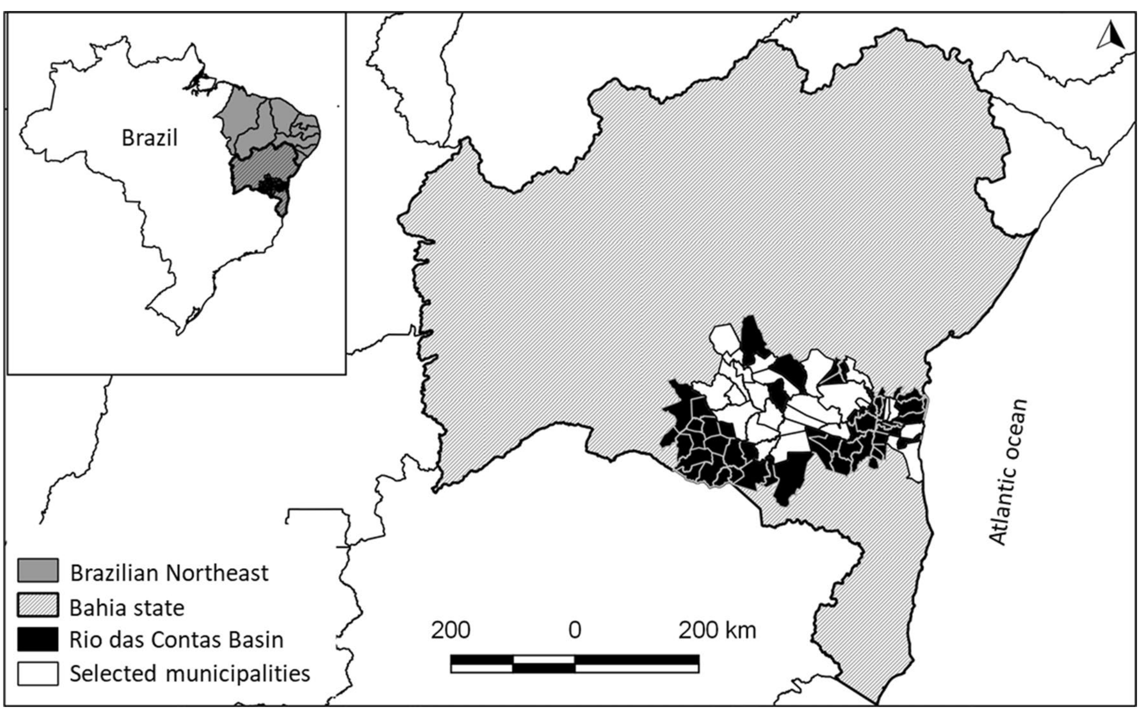

Fig. 1 Rio das Contas Basin in the state of Bahia, Brazil. Source: Author's elaboration based on data from the Brazilian Institute of Geography and Statistics (IBGE 2010)

Table 1 Factors determining sensibility (S), exposure (E) and adaptive capacity (AC) of farmers in the Rio das Contas Basin, Bahia, Brazil

Sensibility	Rainfed agriculture Has agricultural insurance Number of people who depend on income generated on property Dependence of the farmer on agricultural activity Pluriactivity Willingness to change management
Exposure	Difference between the monthly average value of precipitation in the year of the survey (2014) and the historical average from 1985 to 2014
Adaptive capacity	Land ownership Access to public irrigation projects Access to technical assistance / rural extension Farmer education level Participation in trade unions or trade associations Access to credit

Source: Adapted from Lindoso et al. (2014)

environment. Understanding climate change issues requires regional analyses of specific economic sectors, as the impacts vary locally and sectorally (Yohe and Tol 2002). The degree of vulnerability to climate change of rural farmers in the Rio das Contas Basin was evaluated to answer questions poorly explored at the regional level, such as: Which municipalities in the Rio das Contas Basin are most vulnerable to the effects of climate change? What are the determining factors of this vulnerability?

Indicators

The degree of vulnerability and the test of the hypothesis that climate change contributes to increasing the vulnerability of rural farmers in the Rio das Contas Basin were calculated using a synthetic indicator (vulnerability index—VI) in Eq. 1 (Lindoso et al. 2014). This indicator, which defines a system vulnerability, is comprised of the sensibility (S), exposure (E), and adaptive capacity (AC) indexes:

$$\mathrm{VI} = \frac{E + S + (1 - \mathrm{AC})}{3} \tag{1}$$

Sensibility refers to the susceptibility of a system to disturbance by inserting the farmer (decision maker) into local dynamics and results in the interface between local socioeconomic issues and climate events. Exposure is an external property of socioecological systems and is defined as the type, magnitude and frequency of weather events. Adaptive capacity is linked to that of farmers in dealing with exposure and reducing their sensibility, preventively, during and after climate change (Lindoso et al. 2014).

Sensibility (S), exposure (E), and adaptive capacity (AC) indexes were estimated using Eq. 2 (Filmer and Pritchett 2001):

$$I_j = \sum_k \left[f_k \left(a_{ki} - \bar{a}_k \right) / s_k \right], j = \{S, E, \mathrm{AC}\} \tag{2}$$

where I represents the index created, that is, I_S the sensibility; I_E the exposure; and I_{AC} the adaptive capacity. Each variable that makes up the index is indexed by k and each farmer by i. The value of variable k for farmer i is given by a_{ki}; $\bar{a}_k$ indicates the mean value and s_k the standard deviation of the variable k. The value f_k is the weight of each variable in the index.

The value of f_k was based on the factor analysis statistical method (Filmer and Pritchett 2001), which consists of synthesizing and describing the behavior of a set of interrelated variables into a smaller number of variables called "factors" (Fávero et al. 2009). This allows maximizing the explanatory power of all those studied (Thompson 2004; Yanai and Ichikawa 2007). Factors are interpreted as hidden characteristics, hardly observed, and common to the dataset (Härdle and Simar 2007).

The k variables used to construct the sensibility (S), exposure (E) and adaptive capacity (AC) indexes were defined by the vulnerability (Lindoso et al. 2014) (Table 1).

The k variable values were assigned according to the effect on the indexes, with higher sensibility expected with the absence of agricultural insurance and/or other activities. Dependence on farm income and/or a number of dependents is positively related to sensibility. Rainfed farming was used as a proxy for the lack of irrigation, that is, farmers without irrigation mechanisms were classified as rainfed. The willingness to change management techniques decreases the farmer sensibility index.

The exposure index was calculated considering the last 30 years before the survey and the need for a long-term climate change pattern (Budathoki 2017). Monthly values allow for more accurate analysis as rainy and dry seasons vary throughout the year. Comparing rainfall in 2014 with the historical average made it possible to verify whether farmers were experiencing rainfall deficits during the survey period.

Farmers with adaptive capacity index characteristics are much better adapted, and the lower the education level, the lower the adaptability.

The vulnerability index considered the three indexes described in Eq. 1 and allowed for tracing the vulnerability levels of farmers in the Rio das Contas Basin, Bahia, Brazil.

Database

The database was divided into two groups: secondary (exposure index calculation) and primary (sensibility and adaptive indexes calculation) data.

Secondary data were obtained from the Terrestrial Hydrology Research Group (THRG) database (Sheffield et al. 2006).

The primary database was elaborated by De Matos Carlos et al. (2020) using a semi-structured questionnaire comprising questions related to i) socioeconomic information of farmers and their properties; ii) farmer perception of climate change; and iii) willingness to take climate change adaptation activities. Farmers were selected by simple random sampling (Hartter 2009), and the sample size was calculated with the equation (Triola 2008):

$$n = \frac{N \times p \times q \times \left(Z_{\frac{\alpha}{2}}\right)^2}{p \times q \times \left(Z\frac{\alpha}{2}\right)^2 + (N-1) \times E^2} \tag{3}$$

where n is the sample size for a finite population; N, that of the total farm population, that is, the total number of agricultural establishments in the state of Bahia; p, the proportion of the phenomenon, that is, percentage of rural farmers in the Rio das Contas Basin; q, the complementary proportion $(1 - p)$; $Z_{\alpha/2}$, the desired degree of confidence (95%); and E, the maximum estimation error indicating the maximum difference between the sample proportion and the true proportion of the population.

A sample of 289 rural properties was selected from the universe of 145,647 agricultural establishments in the 92 municipalities that make up the basin (IBGE 2006) using Eq. 3.

The sample was designed to obtain a random distribution of farms across a large number of climatic zones in the Rio das Contas Basin (representing an east–west gradient across the region). Twenty-six municipalities out of the 92 that make up the basin were selected by a *buffer zone* encompassing those located no more than 50 km from the Rio das Contas Basin along with its extension (De Matos Carlos et al. 2020).

Levels of vulnerability and exposure to climate change may vary between the biomes of the Rio das Contas Basin. Therefore, these indexes were studied using the geographic information system (GIS), linking the database of selected municipal boundaries with that of biomes, which were provided by the Ministry of the Environment (MMA) and the IBGE. These bases were joined by intersecting features. The municipalities with the area in two biomes were classified as

Table 2 Values (%) for sensitivity (SI), exposure (EI), adaptive capacity (AC) and vulnerability (VI) for the selected municipalities in the Rio das Contas Basin, Bahia, Brazil

Munic	SI	EI	AC	VI	Munic	SI	EI	AC	VI
Abaíra	72.85	91.57	36.39	76.01	Ituaçu	62.97	85.70	41.05	69.21
Anagé	64.66	67.96	39.13	64.50	Jaguaquara	67.92	51.48	33.62	61.93
Aracatu	65.27	81.39	26.78	73.29	Jequié	65.82	52.31	37.12	60.34
Barra da Estiva	68.11	81.91	32.97	72.35	Jitaúna	70.30	39.17	34.38	58.36
Boa Nova	72.90	47.55	35.96	61.50	Jussiape	63.39	90.57	35.77	72.73
Brumado	69.12	87.13	45.70	70.18	Livramento	74.96	92.91	39.13	76.25
Caetanos	74.97	70.85	47.30	66.17	Manoel Vitorino	68.67	64.37	36.61	65.48
Caraíbas	59.44	77.17	43.27	64.45	Maracás	71.26	71.52	42.70	66.69
Dom Basílio	69.50	89.45	40.30	72.88	Mirante	58.65	68.31	39.66	62.43
Ibicoara	68.41	87.04	41.27	71.39	Piatã	73.06	90.94	43.05	73.65
Ibirapitanga	72.17	20.27	39.42	51.01	Rio de Contas	70.64	91.95	37.56	75.01
Ilhéus	70.94	0.00	39.09	43.95	Tanhaçu	68.68	78.94	34.39	71.08
Itacaré	61.89	14.80	39.04	45.88	Ubatã	67.66	22.38	39.98	50.02

transitional Atlantic Forest-Caatinga, and those in only one biome were considered to be either Atlantic Forest biome or Caatinga. None of the municipalities selected had an area in the Cerrado biome. Farmers were classified using this procedure. Analyses were performed using QGIS 2.18.0 free software (Quantum GIS Development Team 2017).

Statistics

Vulnerability indexes and exposure to climate change were subjected to Kruskal–Wallis rank sum (KW) nonparametric variance analysis and the multiple comparisons test to verify differences between biomes. These analyses were performed with R 3.4.1 free software (R Development Core Team 2017).

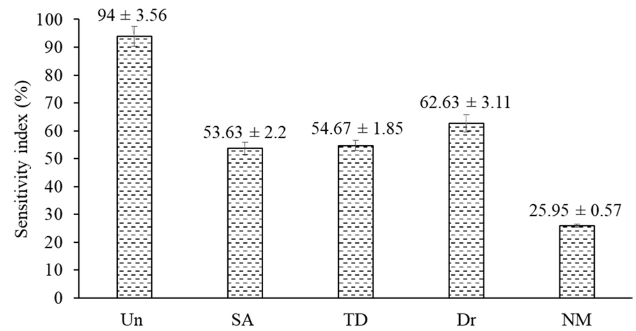

Fig. 2 Percentage values observed in the sample per variable in the sensibility index—SI (Un = unsafe, SA = single activity, TD = total dependency, Dr = dryland and NM = do not change management)

Results and discussion

The results were discussed, and the index sensibility (SI), exposure (EI), adaptive capacity (AC) and vulnerability (VI) values presented mean and standard errors of 66.06 ± 27.11, 68.24 ± 4.42, 38.52 ± 4.31 and 65.26 ± 9.20, respectively (Table 2). The results were obtained from participating farmers and, for ease of understanding and discussion, municipal averages for the 26 sampled municipalities.

The sensibility index of all the municipalities was higher than 50%, with Caetanos (74.97%) being the most sensitive. This rate was high, even for less vulnerable municipalities, such as Mirante, with the lowest value (58.65%).

Sensibility indexes in most municipalities were higher than those in Northern Sudan (Mohmmed et al. 2018), where drought sensibility was generated by more than ten years of extreme famine (Nkunzimana et al. 2016; WFP 2016; FAO 2017). This reinforces the fact that climate change is a significant cause of food insecurity (FAO 2018; Onyutha 2019), influencing food production, availability and distribution (IPCC 2014b). Monitoring climate change and its relationship to socioeconomic issues can identify the most affected and vulnerable groups (Wood and Mendelsohn 2015). Agriculture in developing countries such as Brazil is essential for the domestic economy and the international market for agricultural commodities (Assunção and Chein 2016). In addition, a large part of the rural population in northeastern Brazil lives below the poverty line (Bastos et al. 2018), making access to food and essential products difficult. Characteristics such as deficient roads for production transport, seasonal famine and scarce services increase the sensibility of the rural population to climate change (Bastos et al. 2018).

Of the 289 farmers interviewed, 94% do not have agricultural insurance; 62.63% have rainfed agriculture, that is, they do not have irrigation mechanisms; 53.63% have no economic activity other than that practiced on their farm; 54.67% have total dependence on income generated through agriculture; and 25.95% are unwilling to change their forms of land management (Fig. 2).

Dependence of more than half on agricultural production and the income generated increases farmers' sensibility, and the lack of insurance reduces protection against adverse weather conditions (IBGE 2010; Cremades 2018), which is aggravated by the high cost of agricultural insurance (Hoeppe 2016). The survey data indicate that most farmers who have agricultural insurance, in general, are more experienced, have land tenure, and the average size of their property (54 hectares) is greater than the sample average (34 hectares). Those who do not have insurance, in turn, are small or family farmers and do not have access to public credit or government support. According to Ozaki (2007) and Buainain et al. (2014), the insurance market in Brazil presents many difficulties. Among the main limitations, the following can be highlighted: the market has limited regional coverage; lack of information and low "culture" of insurance; high premium rate; occurrence of catastrophic risk; and lack of government incentive and support. These factors increase farmers' sensibility to climate change.

Rainfed practice in more than half of the municipalities is due to the absence of irrigation mechanisms, increasing the negative impacts of temperature and/or changes in precipitation (Kukal and Irmak 2018). The high costs of irrigation (Cunha et al. 2013) justify the dependence on rainfall. Nevertheless, alternative strategies such as water harvesting, policies with efficient irrigation systems, water management

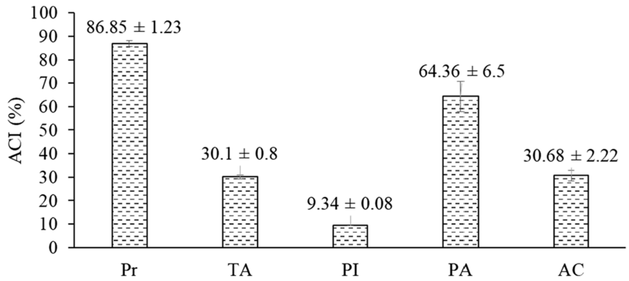

Fig. 3 Percentage values observed in the sample per variable in the adaptive capacity index—ACI (Pr = property, TA = technical assistance, PI = public irrigation, PA = participation in associations, AC = access to credit)

and rainfall retention have helped to overcome water scarcity (Prasanna 2017).

Exposure indexes were higher than 60% in most municipalities with rainfall lower than the historical values. The EI in our study area were higher than those of family farmers in the semiarid region of Ceará, Brazil, where only 14% of them have an exposure index above 70% (Lindoso et al. 2014). Precipitation in the Rio das Contas Basin, lower than the historical standard, indicates high exposure to climate change (De Matos Carlos et al. 2020). The lower exposure index of the municipality of Ilhéus is due to well-distributed rainfall being more elevated than the region's historical average, similar to those of municipalities in areas near the coast (Silva et al. 2010; Cardoso et al. 2018). Rising temperatures and reduced rainfall can cause the replacement of semiarid vegetation by arid land, decreasing agricultural and livestock productivity and, consequently, increasing the exposure index (Assunção and Chein 2016). Increasing climate variability with lower rainfall and higher temperatures will reduce production, especially in more vulnerable areas such as tropical and semitropical latitudes (IPCC 2014c).

The adaptive capacity index of farmers (Table 2) was lower than 50% in all municipalities, with Caetanos having the highest value (AC = 47.3%). This low adaptive capacity of the farmers is similar to that reported in the western US (Gardezi 2017). However, adaptive capacity is not just about technical, financial, or institutional resources but also refers to sociocognitive factors, including farmers' choices and perceptions of climate change (Grothmann and Patt 2005; Eakin et al. 2016; Seara et al. 2016). The vulnerability would be lower if exposure and sensibility were minimized by mitigation activities with minimal impact on the environment. Adaptation strategies can enable farmers to anticipate and mitigate the adverse effects of climate change (FAO 2002; Menezes 2011). In addition, the creation and use of mitigation activities, combined with adaptation strategies, improve performance and reduce greenhouse gas emissions (GHGs) and, consequently, the impacts of climate change (IPCC 2014c).

A total of 86.85% of the farmers own the land they plant, and 64.36% participate in rural associations. Nevertheless, access to local technical assistance, public irrigation projects, and agricultural credit are low in 30.1%, 9.34%, and 30.68% of the municipalities, respectively (Fig. 3).

Land tenure increases access to loans and participation in associations (Cunha et al. 2015), as well as the possibilities of diversifying their production and acquiring efficient irrigation mechanisms to meet water scarcity. However, poor access to technical assistance, public irrigation, and rural credit reduce this process (Eiró and Lindoso 2014; Pires et al. 2014). This reduces adaptive capacity, which depends on resource ownership and willingness and ability to convert it into practical action (Brown and Westaway 2011; Coulthard 2012; Cinner et al. 2018; De Matos Carlos et al. 2020). The values attributed to the adaptive capacity variables of the Rio das Contas Basin were lower than those of municipalities in the Brazilian state of Amazonas (Menezes et al. 2018). In Amazonas, sociopolitical institutions and organizations and socioeconomic issues have made adaptive capacity higher than exposure and sensibility to climate change.

In Fig. 4 we show the spatial distribution of vulnerability to climate change in Rio das Contas Basin. We produced in QGIS 3.10.8 a choropleth map in which the average value of the vulnerability index for each municipality was presented. The vulnerability indicator was categorized into five classes, from "minor" to "major," using the classification of equal intervals. The classification follows the approach adopted by Parker et al. (2019). The VI of 17 municipalities was high/highest, five were classified as medium, and four were classified as low/lowest.

The average vulnerability of the municipalities studied was higher than those of the state of Amazonas, Brazil, with an average of 40.6% (Menezes et al. 2018), and is due to the reduced exposure to which they are subjected. High vulnerability indexes are due to high exposure and sensibility values and low adaptive capacity (Baca et al. 2014). The high sensibility, extreme exposure and low degrees of adaptive capacity ranked the municipality of Livramento de Nossa Senhora in the Rio das Contas Basin as the most vulnerable.

The indexes of exposure and vulnerability to climate change varied among farmers with areas in the Caatinga and Atlantic Forest biomes in the Rio das Contas Basin, with 177 in the first, 54 in the second and 58 in the "Caatinga Atlantic Forest Transition" area. Exposure (KW = 213.31; gl = 2; $p < 0.01$) and vulnerability (KW = 145.89; gl = 2; $p < 0.01$) indexes decreased from the Caatinga to the Atlantic Forest, which was confirmed by the posttest multiple comparisons for all biomes ($p < 0.05$). Fourteen municipalities are in the Caatinga biome, six in the Atlantic Forest and six in the "Caatinga-Atlantic Forest Transition" area, with exposure (KW = 19.635; gl = 2; $p < 0.01$) and vulnerability (KW) (KW = 18,374; gl = 2; $p < 0.01$) indexes higher in

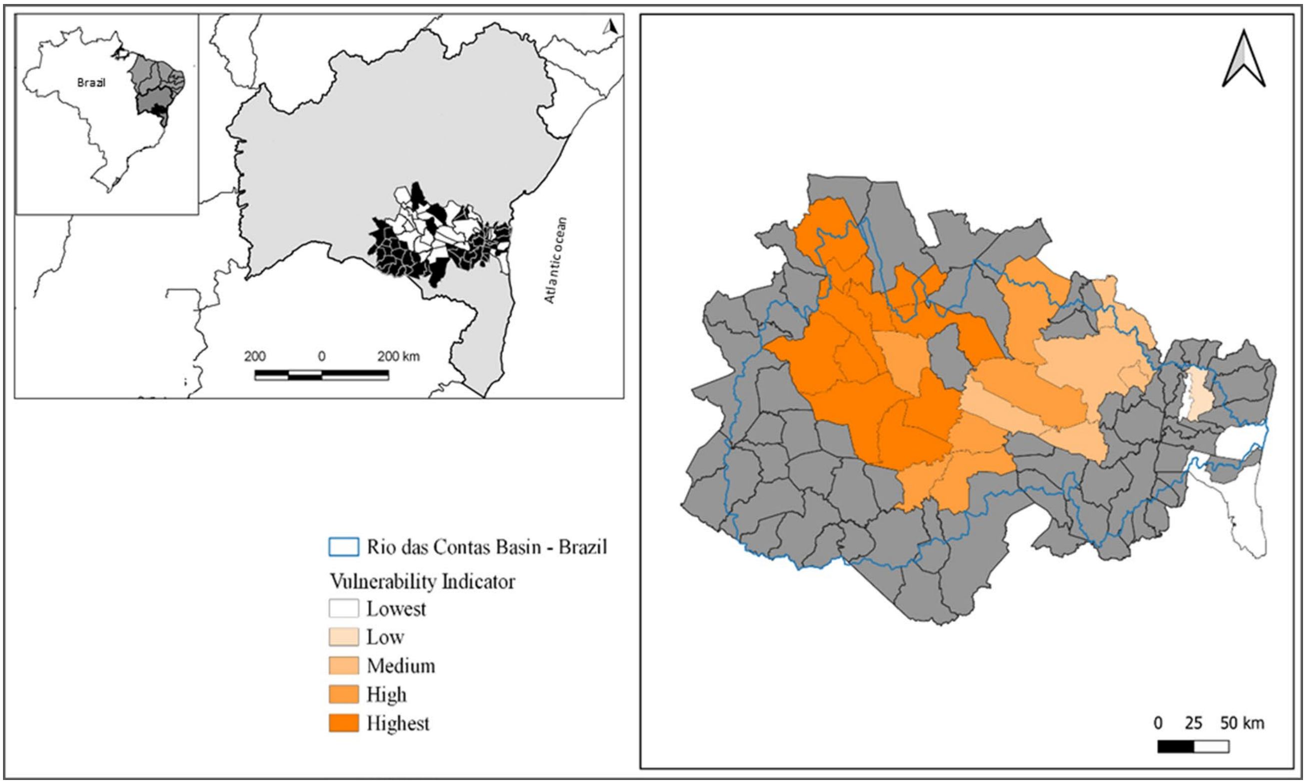

Fig. 4 Vulnerability index in the Rio das Contas Basin, Bahia, Brazil

the Caatinga and lower in the Transition area and Atlantic Forest. The reduction at the municipal level of the exposure index values was confirmed by the posttest of multiple comparisons ($p < 0.05$) except between the Atlantic Forest and Transition biomes. The significance of the posttest for vulnerability index values was found only between the Caatinga biome and Atlantic Forest (Fig. 5). The least and most exposed and vulnerable municipalities are those of the Atlantic Forest and Caatinga biomes, respectively, except for Jequié and Jaguaquara, with conflicting results.

The location of the most vulnerable municipalities in the Caatinga biome is due to their more significant degradation due to anthropic actions and the high diversity that increases the vulnerability of animal and plant species, plants with twisted branches and deep roots and stony soils with low fertility (MMA 2018). Precipitation in this biome is low and irregular, with a high evaporation index, a semiarid climate with dry, thorny vegetation such as bromeliads, herbaceous plants and cactus. This biome has lost approximately 45% of its original native vegetation (MMA 2018), and one-third of its area is desertified land due to low rainfall and burning (EMBRAPA 2015). The edaphoclimatic conditions also increase the environmental vulnerability of the municipalities of the Caatinga biome, with a dry climate desertified by both natural actions and artificial burning practices. This increases the exposure of food farmers with the least ability to adapt and hence their vulnerability. The moderate level of vulnerability of the municipality of Jequié, even though it is located within the Transition biome, may be due to its high MHDI (Supplementary Material 1—S1), the second largest in the sample area.

On the other hand, the value of the VI medium of the municipality of Jaguaquara, while located in a less vulnerable biome, can be explained by its low MHDI value and the third lowest adaptive capacity. The characteristics of the Atlantic Forest biome include high diversity of animal and plant species, medium and large plants with higher humidity and shade, a predominantly humid tropical climate, and a high tropical and humid subtropical climate with regular and well-distributed rainfall (MMA 2018). However, Atlantic Forest has been exploited since the beginning of European colonization through the extraction of Brazil wood and continuous deforestation, having a total of 29,075 hectares only in 2015 and 2016, with the highest area in Bahia state, 12,288 hectares (INPE 2018). Fire prevention and control, combined with adaptation mechanisms, would alter future pessimistic scenarios, minimizing negative impacts on farmers. Awareness of the population regarding the collateral effects of deforestation is essential.

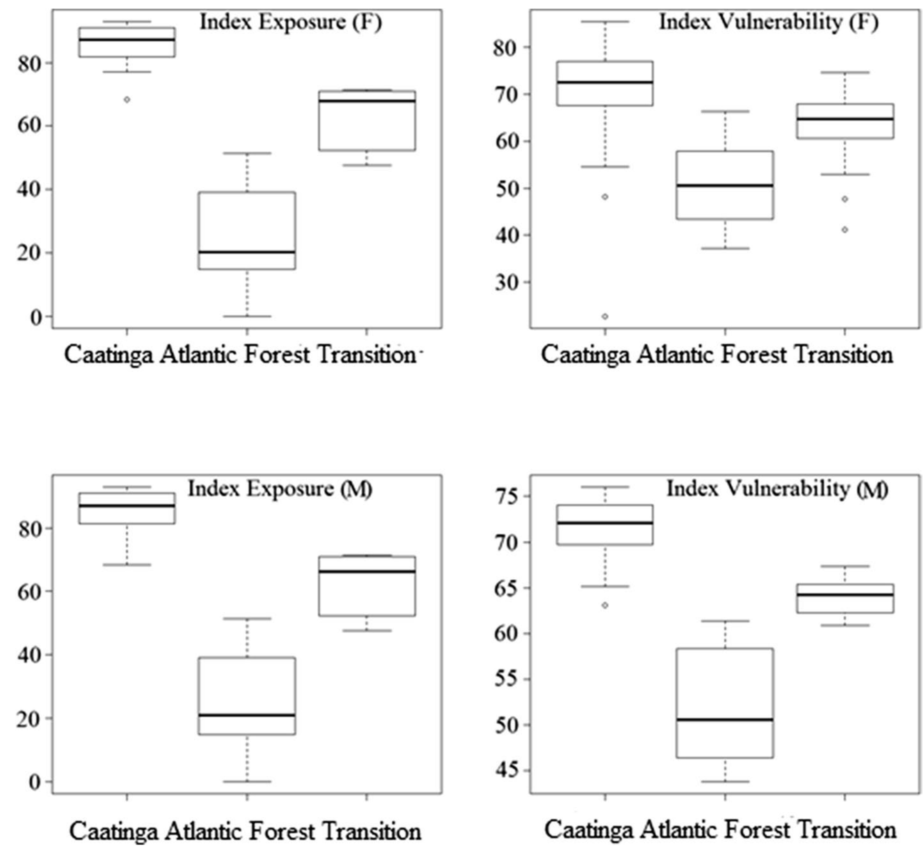

Fig. 5 Box-plot representation of exposure and vulnerability index values for climate change at farm (F) and municipality (M) levels between biomes. The box length is defined by the 25th–75th percentiles, and the bold line is the median value. The vertical rods extend to the most extreme value of the data, less than 1.5 times the box interquartile range. The open points, which exceed 1.5 times the interquartile range, correspond to the outliers

Although elevation and altitude variables have not been included in the vulnerability index, it is important to highlight their importance for analyzing vulnerability to climate change. In our sample, municipalities located or close to the coast (and therefore of lower altitude and elevation) were less vulnerable (Ilhéus, Itacaré, Ubatã and Ibirapitanga). This occurred because the precipitation in these municipalities decreased less than the historical average, benefiting rainfed agriculture.

Finally, considering the future climate is fundamental in long-term planning, but climate variability concerns and justifies efforts at adaptation (Adger 2005). The high exposure and sensibility index in most of the 26 municipalities, combined with low adaptive capacity, constitute a scenario of high vulnerability. The MHDI of most of these municipalities is low (PNUD 2013) and, being in the Caatinga biome, is alarming because 159 of 289 farm farmers depend 100% on the income generated in the agricultural sector. These specificities demonstrate the high degree of vulnerability of farmers in the Rio das Contas Basin and the need for active adaptation activities to improve this situation.

Conclusion

The sensibility of rural farmers of the Rio das Contas Basin, Bahia, Brazil, to climate change was higher than 50% in all municipalities. The municipalities of Livramento de Nossa Senhora and Ilhéus had the highest and lowest exposure indexes, respectively. Adaptive capacity, sufficient to reduce vulnerability to climate change, was not observed in any of these municipalities. The vulnerability of more than 65% of the municipalities was high/highest, with Livramento de Nossa Senhora being the most vulnerable. Exposure and vulnerability indexes varied with the biome, with the Caatinga municipalities being the most exposed and vulnerable. The high levels of vulnerability of farmers in the Rio das Contas Basin are due to current climate changes. They are the results of high exposure and sensibility combined with low adaptive capacity. This suggests the need for investment to minimize these effects and mitigation activities to counter the negative impacts of future climate variability.

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Author contributions E.A.S. wrote the draft of this manuscript. D.A.C. designed the study. E.A.S., D.A.C. and J.B.S. proposed the idea, supervised the whole work and contributed to the manuscript preparation. E.A.S. and D.A.C. performed a statistical analysis. J.C.Z. and J.B.S. discussed the results and contributed to the manuscript final preparation. All authors reviewed the final manuscript.

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Compliance with ethical standards

Conflict of interest The authors declare no conflicts of interest.

Ethical approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee [Research Ethics Committee in Research with Human Beings of the Federal University of Viçosa, under Opinion Nº.713.698 (CAAE: 30752814.2.0000.5153)].

References

Adger WN, Brooks N, Bentham G, Agnew M, Eriksen S (2005) New indicators of vulnerability and adaptive capacity. Tyndall Centre for Climate Change Research Norwich. http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.112.2300&rep=rep1&type=pdf. Accessed 20 June 2019

Alves E, Marra R (2009) A persistente migração rural-urbana. Revista de Política Agrícola 18(4):5–17

Assunção J, Chein F (2016) Climate change and agricultural productivity in Brazil: future perspectives. Environ Dev Econ 21(5):581–602. https://doi.org/10.1017/S1355770X1600005X

Baca M, Läderach P, Haggar J, Schroth G, Ovalle O (2014) An integrated framework for assessing vulnerability to climate change and developing adaptation strategies for coffee growing families in Mesoamerica. PLoS ONE. https://doi.org/10.1371/journal.pone.0088463

Bastos PMA, Mattos LB, Santos GC (2018) Determinantes da pobreza no meio rural brasileiro. Revista de Estudos Sociais 20(41):4–30. https://doi.org/10.19093/res6163

Below TB, Mutabazi KD, Kirschke D, Franke C, Sieber S, Siebert R, Tscherning K (2012) Can farmers' adaptation to climate change be explained by socio-economic household-level variables? Glob Environ Change 22(1):223–235. https://doi.org/10.1016/j.gloenvcha.2011.11.012

Bouroncle C, Imbach P, Rodríguez-Sánchez B, Medellín C, Martinez-Valle A, Läderach P (2017) Mapping climate change adaptive capacity and vulnerability of smallholder agricultural livelihoods in Central America: ranking and descriptive approaches to support adaptation strategies. Clim Change 141(1):123–137. https://doi.org/10.1007/s10584-016-1792-0

Brown K, Westaway E (2011) Agency, capacity, and resilience to environmental change: lessons from human development, well-being, and disasters. Annu Rev Environ Resour 36(1):321–342. https://doi.org/10.1146/annurev-environ-052610-092905

Buainain AM, Vieira PA, Cury WJM (2014) Gestão do Risco e Seguro na agricultura brasileira. FUNENSEG, Rio de Janeiro

Budathoki N (2017) Climate change: perceptions, reality and agricultural practice: evidence from Nepal. https://doi.org/10.13140/RG.2.2.33569.04961

Cardoso YS, Lopes MR, Assis Silva S, Alves DI, Souza Lima JS (2018) Distribuição e incerteza da precipitação pluviométrica e do potencial erosivo das chuvas para o estado da Bahia, Brasil. Revista Engenharia na Agricultura 26(2):149–159. https://doi.org/10.13083/reveng.v26i2.835

CBHRC - COMITÊ DA BACIA HIDROGRÁFICA DO RIO DAS CONTAS (2013) Regimento interno do Comitê da Bacia Hidrográfica do Rio das Contas. Jequié

CEPEA - CENTRO DE ESTUDOS AVANÇADOS EM ECONOMIA APLICADA E CONFEDERAÇÃO NACIONAL DA AGRICULTURA E PECUÁRIA (CNA) (2020) PIB do agronegócio brasileiro de 1996 a 2018. https://www.cepea.esalq.usp.br/br/pib-do-agronegocio-brasileiro.aspx. Accessed 04 Set. 2020

Cinner JE, Adger WN, Allison EH, Barnes ML, Brown K, Cohen PJ, Gelcich S, Hicks CC, Hughes TP, Lau J, Marshall NA, Morrison TH (2018) Building adaptive capacity to climate change in tropical coastal communities. Nature Clim Change 8(2):117–123. https://doi.org/10.1038/s41558-017-0065-x

Coulthard S (2012) Can we be both resilient and well, and what choices do people have? Incorporating agency into the resilience debate from a fisheries perspective. Ecol Soc 17(1):4. https://doi.org/10.5751/ES-04483-170104

Cremades R, Surminski S, Costa MM, Hudson P, Shrivastava P, Gascoigne J (2018) Using the adaptive cycle in climate-risk insurance to design resilient futures. Nature Clim Change 8(1):4–7. https://doi.org/10.1038/s41558-017-0044-2

Crist E, Mora C, Engelman R (2017) The interaction of human population, food production, and biodiversity protection. Science 356(6335):260–264. https://doi.org/10.1126/science.aal2011

Cunha DA, Coelho AB, Féres JG, Braga MJ, Souza EC (2013) Irrigação como estratégia de adaptação de pequenos agricultores às mudanças climáticas: aspectos econômicos. Revista de Economia e Sociologia Rural 51(2):369–386. https://doi.org/10.1590/S0103-20032013000200009

Cunha DA, Coelho AB, Féres JG (2015) Irrigation as an adaptive strategy to climate change: an economic perspective on Brazilian agriculture. Environ Dev Econ 20(1):57–79. https://doi.org/10.1017/S1355770X14000102

De Matos Carlos S, Cunha DA, Pires MV, Couto-Santos FR (2020) Understanding farmers' perceptions and adaptation to climate change: the case of Rio das Contas basin, Brazil. GeoJournal 85:805–821. https://doi.org/10.1007/s10708-019-09993-1

Eakin H, York A, Aggarwal R, Waters S, Welch J, Rubiños C, Heisters SS, Bausch C, Anderies JM (2016) Cognitive and institutional influences on farmers' adaptive capacity: insights into barriers and opportunities for transformative change in central Arizona. Reg Environ Change 16(3):801–814. https://doi.org/10.1007/s10113-015-0789-y

Eiró F, Lindoso DP (2014) Mudança climática, percepção de risco e inação no semiárido brasileiro: como produtores rurais familiares percebem a variabilidade climática no Sertão do São Francisco-Bahia. Revista Econômica do Nordeste 45(4):135–148

EMBRAPA - EMPRESA BRASILEIRA DE PESQUISA AGROPECUÁRIA. PORTAL NOTÍCIAS (2015). https://www.embrapa.br/busca-de-noticias/-/noticia/3240771/desertificacao-atinge-grandes-areas-do-semiarido>/ Accessed 16 Oct 2018

FAO - FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS (2002) FAO'S WORK ON CLIMATE CHANGE. https://www.nature.com/articles/s41598-018-21848-2.pdf. Accessed 10 Oct 2018

FAO - FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS (2017) Final evaluation of Sudan Food Security Policy and Strategy Capacity Building programme. Retrieved from Rome, Italy: Project evaluation series. http://www.fao.org/3/a-bd658e.pdf. Accessed 15 July 2019

FAO - FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS (2018) Climate Change and Food Security: A Framework Document. http://www.fao.org/3/k2595e/k2595e00.pdf. Accessed 10 Oct 2018

Fávero LPL, Belfiore P, Silva FL, Chan BL (2009) Análise de dados: modelagem multivariada para tomada de decisões. Rio de Janeiro

Feulner G (2017) Global challenges: climate change . Glob Challeng 1(1):5–6. https://doi.org/10.1002/gch2.1003

Filmer D, Pritchett LH (2001) Estimating wealth effects without expenditure data—or tears: an application to educational enrollments in states of India. Demography 38(1):115–132

Gardezi SM (2017) Rethinking adaptive capacity: a study of Midwestern US corn farmers. Dissertation, Iowa State University. https://lib.dr.iastate.edu/etd/15519. Accessed 20 July 2020

Grothmann T, Patt A (2005) Adaptive capacity and human cognition: the process of individual adaptation to climate change. Glob Environ Change 15(3):199–213. https://doi.org/10.1016/j.gloenvcha.2005.01.002

Hartter J (2009) Attitudes of rural communities toward wetlands and forest fragments around Kibale National Park, Uganda. Human Dimens Wildl 14(6):433–447. https://doi.org/10.1080/10871200902911834

Härdle W, Simar L (2007) Applied multivariate statistical analysis. Springer, New York

Hoeppe P (2016) Trends in weather related disasters–consequences for insurers and society. Wea Clim Extremes 11(1):70–79. https://doi.org/10.1016/j.wace.2015.10.002

Huffman WE, Jin Y, Xu Z (2018) The economic impacts of technology and climate change: new evidence from US corn yields. Agric Econ 49(4):463–479. https://doi.org/10.1111/agec.12429

IBGE – INSTITUTO BRASILEIRO DE GEOGRAFIA E ESTATÍSTICA, (2006) Censo Agropecuário 2006: Brasil. Grandes Regiões e Unidades da Federação, Rio de Janeiro

IBGE – INSTITUTO BRASILEIRO DE GEOGRAFIA E ESTATÍSTICA, (2010) Censo 2010: Brasil. Grandes Regiões e Unidades da Federação, Rio de Janeiro

IBGE – INSTITUTO BRASILEIRO DE GEOGRAFIA E ESTATÍSTICA (2017) Sistema IBGE de Recuperação Automática – SIDRA. https://sidra.ibge.gov.br/tabela/5938. Accessed 04 Sept 2020

Iglesias A, Quiroga S, Diz A (2011) Looking into the future of agriculture in a changing climate. Eur Rev Agric Econ 38(3):427–447. https://doi.org/10.1093/erae/jbr037

INPE - INSTITUTO NACIONAL DE PESQUISAS ESPACIAIS (2018) Programa de Queimadas. Monitoramento por Satélite. http://www.inpe.br/ queimadas/. Accessed Oct 2018

IPCC – INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE (2014a) climate change: impacts, adaptation, and vulnerability—Part A: global and sectoral aspects. In: Field CB, Barros VR (eds.) Cambridge University Press. https://www.ipcc.ch/report/ar5/wg2/. Accessed 20 July 2019

IPCC - INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE (2014b) Climate change: impacts, adaptation, and vulnerability—Part A: global and sectoral 2014. https://www.ipcc.ch/report/ar5/wg2/full-report-global-aspects/. Accessed 20 July 2019

IPCC - INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE (2014c) Climate Change: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. https://www.ipcc.ch/report/ar5/syr/. Accessed 30 July 2019

Kukal MS, Irmak S (2018) Climate-driven crop yield and yield variability and climate change impacts on the US great plains agricultural production. Nature Sci Rep 8:3450. https://doi.org/10.1038/s41598-018-21848-2

Lindoso DP, Rocha JD, Debortoli N, Parente II, Eiró F, Bursztyn M, Filho SR (2014) Integrated assessment of smallholder farming's vulnerability to drought in the Brazilian Semi-arid: a case study in Ceará. Climatic Change 127(1):93–105. https://doi.org/10.1007/s10584-014-1116-1

Machado Filho H (2015) Climate Change and its Impacts on Family Farming in the North/Northeast Regions of Brazil: Policy Research Brief 52, International Policy Centre for Inclusive Growth. https://ideas.repec.org/p/ipc/pbrief/52.html. Accessed 20 Aug 2019

Malone EL, Brenkert AL (2008) Uncertainty in resilience to climate change in India and Indian states. Clim Change 91(3–4):451–476. https://doi.org/10.1007/s10584-008-9472-3

Menezes L, Oliveira B, El-Deir SG (2011) Percepção ambiental sobre mudanças climáticas: estudo de caso no Semiárido Pernambucano. II Congresso Brasileiro de Gestão Ambiental, IBEAS Londrina. https://www.ibeas.org.br/congresso/Trabalhos2011/I-036.pdf. Accessed 01 Aug 2019

Menezes JÁ, Confalonieri U, Madureira AP, Brito Duval I, Santos RB, Margonari C (2018) Mapping human vulnerability to climate change in the Brazilian Amazon: the construction of a municipal vulnerability index. PLoS ONE. https://doi.org/10.1371/journal.pone.0190808

MMA - MINISTÉRIO DO MEIO AMBIENTE (2018) Desmatamento na Caatinga. http://www.mma.gov.br/informma/item/6122-desmatamento-na-caatinga-ja-destruiu-metade -da-vegetacao-original. Accessed 15 Oct 2018

Mohmmed A, Zhang K, Kabenge M, Keesstra S, Cerdà A, Reuben M, Elbashier MMA, Dalson T, AliA AS (2018) Analysis of drought and vulnerability in the North Darfur region of Sudan. Land DegradDevelop 29(12):4424–4438. https://doi.org/10.1002/ldr.3180

Nazareth MS, Gurgel AC, Cunha DA (2020) Economic effects of projected decrease in Brazilian agricultural productivity under climate change. GeoJournal. https://doi.org/10.1007/s10708-020-10286-1

Nelson GN, Valin H, Sands RD, Havlík P, Ahammad H, Deryng D, Elliott J, Fujimori S, Hasegawa T, Heyhoe E, Kyle P, Lampe MV, Campen HL, Croz DM, Meij HV, Mensbrugghe DV, Müller C, Popp A, Robertson R, Robinson S, Schmid E, Schmitz C, Tabeau A, Willenbocke D (2014) Climate change effects on agriculture: Economic responses to biophysical shocks. Proc Natl Acad Sci 111(9):3274–3279. https://doi.org/10.1073/pnas.1222465110

Nkunzimana T, Custodio Cerezales E, Thomas A, Uregia NT, Perez Hoyos A, Kayitakire F (2016) Global analysis of food and nutrition security situation in food crisis hotspots. Report by the European Commision Joint Research Center in colloboratoin with the FAO and the WFP. https://ec.europa.eu/jrc/en/publication/eur-scientific-and-technical-research-reports/global-analysis-food-and-nutrition-security-situation-food-crisis-hotspots. Accessed 20 July 2019

Onyutha C (2019) African food insecurity in a changing climate: The roles of science and policy. Food Energy Secur. https://doi.org/10.1002/fes3.160

Ozaki VA (2007) O papel do seguro na gestão do risco agrícola e os empecilhos para o seu desenvolvimento. Revista Brasileira de Risco e Seguro 2(4):75–92

Parker L, Bourgoin C, Martinez-Valle A, Läderach P (2019) Vulnerability of the agricultural sector to climate change: the development of a pan-tropical Climate Risk Vulnerability Assessment to inform sub-national decision making. PLoS ONE. https://doi.org/10.1371/journal.pone.0213641

PBMC - PAINEL BRASILEIRO DE MUDANÇAS CLIMÁTICAS (2013) Sumário Executivo do Volume I – Base Científica das Mudanças Climáticas. Contribuição do Grupo de Trabalho 1 para o 1º Relatório de Avaliação Nacional do Painel Brasileiro de Mudanças Climáticas. Rio de Janeiro. http://www.pbmc.coppe.ufrj.br/documentos/MCTI_PBMC_Sumario%20Executivo%204_Finalizado.pdf. Accessed 16 June 2019

Piedra-Bonilla EB, Cunha DA, Braga MJ (2020) Climate variability and crop diversification in Brazil: an ordered probit analysis. J Clean Prod. https://doi.org/10.1016/j.jclepro.2020.120252

Pires MV, Cunha DA, Reis DI, Coelho AC (2014) Percepção de produtores rurais em relação às mudanças climáticas e estratégias de adaptação no estado de Minas Gerais, Brasil. Revista de Ciências Agrárias 37(4):431–440

PNUD - PROGRAMA DAS NAÇÕES UNIDAS PARA O DESENVOLVIMENTO (2013) . Atlas do Desenvolvimento Humano no Brasil.

Prasanna TL (2017) Analysis of Vulnerability Indices in Various Agro-Climatic Zones of Andhra Pradesh. Acharya NG Ranga Agricultural University

QUANTUM GIS DEVELOPMENT TEAM (2017) Quantum GIS geographic information system. Open Source Geospatial Foundation Project. http://qgis.osgeo.org. Accessed Oct 2017

R DEVELOPMENT CORE TEAM (2017) R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. https://www.R-project.org/. Accessed Oct 2017

Seara T, Clay PM, Colburn LL (2016) Perceived adaptive capacity and natural disasters: a fisheries case study. Glob Environ Change 38:49–57. https://doi.org/10.1016/j.gloenvcha.2016.01.006

Sheffield J, Goteti G, Wood EF (2006) Development of a 50-year high-resolution global dataset of meteorological forcings for land surface modeling. J Clim 19(13):3088–3111. https://doi.org/10.1175/JCLI3790.1

Silva PCG, Moura MSB, Kiill LHP, Brito LL, Pereira LA, Sá I B, Correia RC, Teixeira AHC, Cunha TGF, Guimarães Filho C (2010) Caracterização do Semiárido brasileiro: fatores naturais e humanos. Embrapa http://www.alice.cnptia.embrapa.br/alice/handle/doc/861906

Smit B, Wandel J (2006) Adaptation, adaptive capacity and vulnerability. Glob Environ Change 16(3):282–292. https://doi.org/10.1016/j.gloenvcha.2006.03.008

Thompson B (2004) Exploratory and confirmatory factor analysis: understanding concepts and applications. Am Psychol Assoc. https://doi.org/10.1037/10694-000

Triola MF (2008) Introdução à estatística. LTC

WFP – WORLD FOOD PROGRAMME (2016) North Darfur: Food Security Monitoring, Rome, Italy: World Food Programme. https://www.wfp.org/publications/sudan-food-security-monitoring. Accessed 10 Oct 2019

Wood SA, Mendelsohn RO (2015) The impact of climate change on agricultural net revenue: a case study in the Fouta Djallon,

West Africa. Environ Develop Econ 20(1):20–36. https://doi.org/10.1017/S1355770X14000084
Yanai H, Ichikawa M (2007) Factor analysis. Handb Stat Psychom 26:257–296. https://doi.org/10.1016/S0169-7161(06)26009-7
Yohe G, Tol RSJ (2002) Indicators for social and economic coping capacity—moving toward a working definition of adaptive capacity. Glob Environm Change 12(1):25–40. https://doi.org/10.1016/S0959-3780(01)00026-7