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SANITARY, SOCIAL, AND METEOROLOGICAL ASPECTS AND NATURAL DISASTERS IN THE NORTHEASTERN REGION OF BRAZIL

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Abstract

This study aims to characterize the occurrence of natural disasters in the mesoregions situated in Brazil's Northeastern region from sociosanitary and meteorological aspects during the period from 1991 to 2013. The grade-of-membership (GoM) method, based on fuzzy sets theory, was applied in order to define a typology of groups with distinct features. In order to identify differences among medians of climatic, socio-sanitary and disaster variables, Kruskall Wallis and Nemenyi tests were applied. To illustrate spatio-temporal patterns, thematic maps were made through QGIS software. Typology showed three extreme profiles: predominant 1, characterized by mesoregions with moderate occurrence of drought and flood, favorable conditions for rainfall surplus, best sanitary conditions and more urbanization, standing out in the coastal region of the Northeast; predominant 2 which has high drought and flood records, favorable conditions for rainfall deficit, intermediary sanitary conditions and moderate urbanization, found predominantly in mesoregions located in Brazilian Semiarid area; and predominant profile 3 which shows high flood records, favorable conditions to rainfall surplus, but low sanitary conditions and less urbanization, located fairly close of Maranhão state and the southern part Bahia state.

Keywords: Natural disasters, mesoregions, GoM, Brazilian Northeast.

Resumo / Resumen

ASPECTOS METEOROLÓGICOS, SOCIAIS, SANITÁRIOS E DESASTRES NATURAIS NA REGIÃO NORDESTE DO BRASIL

Objetiva-se, neste estudo, caracterizar à ocorrência dos desastres naturais das mesorregiões do Nordeste do Brasil, a partir dos aspectos meteorológicos e sociosanitários, considerando o período de 1991 a 2013. A metodologia Grade of Membership, baseada na teoria de conjuntos nebulosos, foi aplicada com o intuito de definir uma tipologia de grupos com distintos atributos. Posteriormente, aplicou-se o teste não-paramétrico de Kruskall Wallis e Nemenyi, com o intuito de identificar diferenças significativas entre as medianas das variáveis climáticas, sociosanitárias e de desastres que caracterizam os perfis. Para ilustrar o comportamento espaço temporal, construiu-se mapas temáticos através do QGIS. A tipologia delineou três perfis extremos: o predominante 1 agregou mesorregiões com moderada ocorrência de seca e enxurrada, condições favoráveis ao excesso de precipitação, melhores condições sanitárias e maior urbanização, destacando-se na região litorânea do Nordeste; o predominante 2 tem como características elevados registros de secas e enxurradas, condições favoráveis ao déficit de precipitação, intermediárias condições sanitárias e moderada urbanização, predominando-se mesorregiões localizadas ao centro da região em estudo com destaque ao Semiárido Brasileiro; e o perfil predominante 3 apresentou mesorregiões com elevados registros de inundações, condições favoráveis ao excesso de precipitação, mais baixas condições sanitárias e menor urbanização, localizado nas mediações do estado do Maranhão e sul da Bahia.

Palavras-chave: Fenômenos Naturais, Mesorregiões, GoM, Nordeste Brasileiro.

ASPECTOS SANITARIOS, SOCIALES, METEOROLÓGICOS Y DESASTRES NATURALES EN LA REGIÓN NORESTE DE BRASIL

El objetivo de este estudio es caracterizar la ocurrencia de desastres naturales en las mesorregiones del Nordeste de Brasil, desde los aspectos meteorológicos y socio-sanitarios, considerando el período de 1991 a 2013. Se utilizó la metodología de Grade of Membership, basada en la teoría de conjuntos difusos, para crear una tipología de grupos com diferentes características. Para identificar diferencias entre las medianas de las variables climáticas, sociosanitarias y de desastres se aplicaron las pruebas de Kruskall Wallis y de Nemenyi. Por último, para ilustrar el comportamiento espacio-temporal, construyeron mapas temáticos usando el software QGIS. La tipología creada delineó tres perfiles extremos: perfil predominante 1 posee mesoregiones con ocurrencia moderada de sequía y torrentes, condiciones favorables para el exceso de precipitaciones, mejores condiciones sanitarias y mayor urbanización, localizada en la región costera del Nordeste; el perfil predominante 2 se caracteriza por altos registros de sequías y torrentes, condiciones favorables para el déficit de lluvias, condiciones sanitarias intermedias y urbanización moderada, mesorregiones ubicadas en el centro de la región en estudio, con énfasis en el Semiárido Brasileño; y el perfil predominante 3 presentó mesorregiones con altos registros de inundaciones, condiciones favorables para precipitaciones excesivas, menores condiciones sanitarias y menor urbanización, mesoregiones ubicadas entre los estados de Maranhão y el sur de Bahia. De las 42 mesorregiones estudiadas, el 28,6% se caracterizó como perfil mixto y sólo una mesorregión se classifico como Amorfa.

Palabras-clave: Desastres Naturales, Mesorregiones, GoM, Nordeste brasileño

INTRODUCTION

Disasters are characterized by the interruption of a community's normal functioning, causing human, material and/or environmental losses. These exceed the impacted society's ability to respond effectively and face the consequences of natural events, which interact with conditions of social vulnerability (FIELD et al., 2012; TRAJBER et al., 2017). Thus, establishing disaster risk conditions requires the consideration of a combination of physical, social, and political factors (NARVÁEZ et al., 2009; DE ALMEIDA et al., 2016).

In 2018, The Centre for Research on the Epidemiology of Disasters (EM-DAT) records showed that natural disasters' intensity and spatial extent increased over the period (BLOOM and KHANNA, 2007; LEISEROWITZ, 2012). The 2013 Intergovernmental Panel on Climate Change (IPCC) report warned that the frequency and intensity of natural disasters would tend to grow or intensify with global environmental and climate change.

In Brazil, in recent years, increasingly frequent natural disasters have been recorded. Important national study centers, such as the Center for Studies and Research in Engineering and Civil Defense – CEPED have evidenced this rise over historical data series in recent decades. The country has experienced an intensification of damage caused by extreme events causing scarce or excessive rainfall that is often linked to the absence of adequate urban planning (CEPED, 2013; UFSC, 2014).

Several studies point out that most disasters recorded in Brazil are caused by a precipitation deficit in a given period, causing aridity and droughts (SILVA et al., 2013). Furthermore, prolonged, or exceptional and concentrated rains cause flood events, flash floods, flooding, and landslides, causing deaths, health impacts, environmental damage, interrupted services, and social and economic disturbances (TOMINAGA, 2009; BRAZIL, 2012, MOURA et al., 2010).

Between 1990 and 2015, Brazil's climatological and hydrological events had the most significant share of disasters; floods accounted for 25% of the records (CEPED, 2012; BRASIL, 2016). They were responsible for 40.3% of the people affected, 44.8% of deaths, 63.5% of morbidity, and 67.5% of afflicted people, mainly displaced and homeless (FREITAS et al., 2014).

The Northeast of Brazil (NEB) is one of the regions with the highest occurrence of natural disasters, corresponding to 40% of the country's total records, of which 78% are drought-related, followed by floods with 21% (BRASIL, 2016). In 2013, 75% of the municipalities in the Northeast were affected by drought, the worst in the last 50 years (FREITAS et al., 2014). It was also observed that the coastal cities of the NEB had a higher frequency of hydrological disasters (SOUZA et al., 2012), with heavy rains above 60 mm/day and torrential rains above 100 mm/day, worsened by socio-environmental vulnerability, resulting in disasters with adverse effects on the population (OLÍMPIO et al., 2013).

The magnitude of these events' impact depends on the intensity of meteorological, climatic, and geological phenomena, the region's economic development, and public investment and articulation of policies regarding disaster prevention (KOUSKY, 2012). Thus, the occurrence of Natural Disaster (ND) events is directly associated with the terms danger, risk, and vulnerability (MARCELINO, 2005).

Concerning danger, any natural or human-induced process or event that potentially generates damages and losses to society should be considered (IWAMA, et al., 2016). These threats can be separated into human risks (conflicts, technical accidents) and natural hazards resulting from climatic, tectonic, or biological causes (floods, droughts, earthquakes, and epidemics, among others). These are classified as extreme events that can generate risks and potentially develop into disasters if they affect vulnerable groups (DAO and PEDUZZI, 2004).

The risk is related to the probability of an event's occurrence and the damage resulting from the natural threat and/or human action given the conditions of vulnerability present in society (UNISDR, 2009; IWAMA, et al., 2016). The interaction between danger and vulnerability results from the harmful consequences or anticipated loss of life and injuries, damage to the properties, and the affected economic and/or environmental activities. According to Marchenzini et al. (2017), disasters bring about losses and damage to populations and the environment, affecting health, water, food quality, and infrastructure (housing, hospitals, and transport) due to the impact of the hazard (TOMINAGA, 2009).

Vulnerability is a set of social, economic, political, cultural, technical, educational, and environmental conditions that make people or populations more exposed to danger (MARCHEZINI et al., 2017). It addresses individuals' characteristics in anticipating, dealing with, resisting, and recovering from a climate event (CUTTER, 1994).

Given the above, our objective is to characterize the occurrence of natural disasters in the mesoregions of Northeastern Brazil based on meteorological and socio-sanitary aspects from 1991 to 2013.

MATERIAL AND METHODS

STUDY AREA

The Northeast region of Brazil (NEB) is located between 1°N 18°S and 34.5°W 48.5°W, which are tropical latitudes, with a territorial extension of 1,558,196 km², representing approximately 18.2% of the Brazilian territory. The NEB's population is 27.6% of the Brazilian total; thus, it is the second-largest region by population, corresponding to 53,081,950 inhabitants (IBGE, 2010; 2016).

The region consists of 1,794 municipalities in nine federative units in which the study area refers to the geographical division of 42 administrative mesoregions, distributed in the states of Alagoas (3), Bahia (7), Ceará (7), Maranhão (5), Paraíba (4), Pernambuco (5), Piauí (4), Rio Grande do Norte (4) and Sergipe (3) (Figure 1).

The Brazilian Northeast has high climatic variability, ranging from semi-arid regions with an annual accumulated rainfall of less than 500 mm to humid regions with a high total annual rainfall, averaging 1,500 mm, in the coastal and northern areas of the region. Due to its considerable territorial extension, different meteorological systems operate in the NEB region, leading to high intra- and interannual precipitation variability (MOURA and SHUKLA, 1981; RAO et al., 2016; OLIVEIRA et al. 2017).

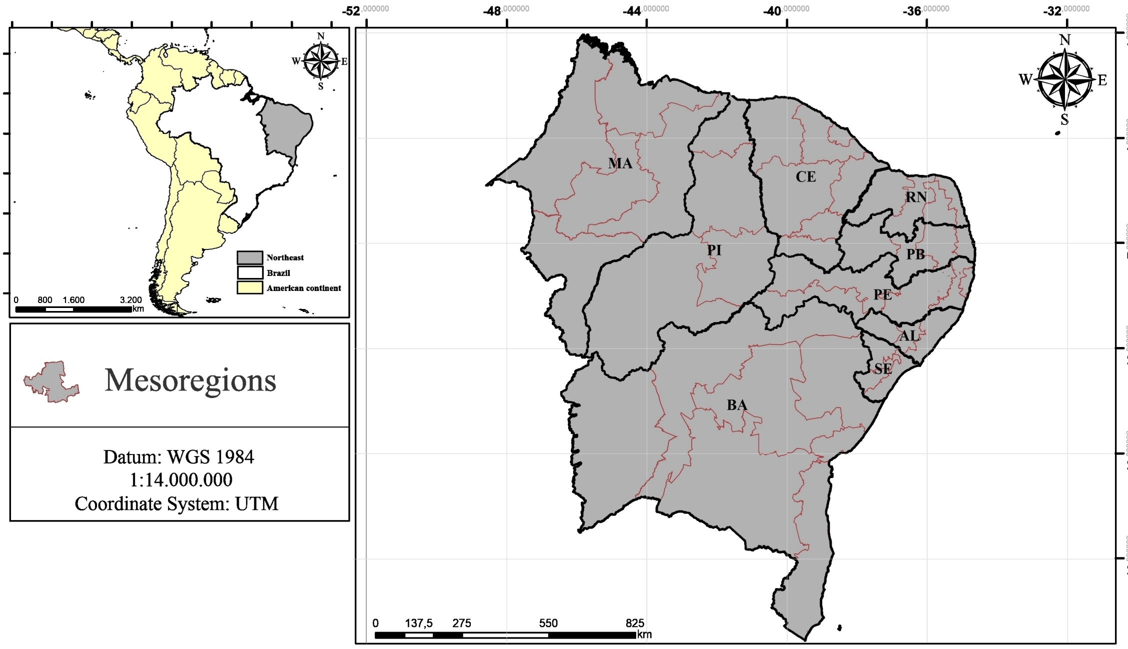

Figure 1- The Northeast Region of Brazil – NEB and its respective mesoregions.

DATA

The recorded data on the occurrences of natural disasters used in this work came from the Center for Study in Natural Disaster Research (CEPED) of the Federal University of Santa Catarina (UFSC), which makes the information available to the respective Units of the Federation. They were digitized at the municipal level and then grouped by NEB mesoregion, considering the disasters with the highest occurrence from 1991 to 2013, classified as Drought, Storms, and Floods.

The information on precipitation originated from the partnership between the University of Texas and the Federal University of Espirito Santo, using the methodology described by Xavier et al. (2016). The research on Brazil generated high resolution (0.25º×0.25º) information for different meteorological variables, namely: precipitation (mm), evapotranspiration (mm), maximum and minimum temperature (°C), solar radiation (W), relative humidity (%RH), and wind speed (m/s). The study data were collected from 3,625 rain gauges and 735 weather stations from 1980 to 2013, using different interpolation techniques, analyzed, and validated for the information under analysis. The data are freely accessible and are available at: https://utexas.box.com/Xavier-etal-IJOC-DATA.

Thus, for the present analysis, precipitation information about a grid point was collected for each municipality in the NEB region, and, subsequently, the averages for the points within the respective NEB mesoregions were calculated.

From the 27 available analytical variables, we used information from four indexes of climatic extremes (Table 1) selected for their more significant relationship with disasters. These data were obtained by Climdex, developed by Zhang and Yang (2004), and managed by researchers from the Center for Research on Climate Change (CCRC) of the University of New South Wales (UNSW) and other partners and collaborators. The data are in the public domain and available at: http://cccma.seos.uvic.ca/ETCCDMI/software.shtml.

To identify potential social factors that permeate each region's vulnerability to natural disasters, we used the population and socio-sanitary characteristics (Table 1) of the 2010 Brazilian Demographic Census, provided by the Brazilian Institute of Geography and Statistics (IBGE).

Variable	Description
Drought	Number of occurrences of drought
Floods	Number of occurrences of Floods
Flash Floods	Number of occurrences of flash floods
CDD	Maximum number of consecutive days with precipitation less than 1 mm
CWD	Maximum number of consecutive wet days greater than or equal to 1 mm
R95p	Annual rainfall exceeding 95th percentile (mm)
PRCPTOT	Total rainfall on wet days
Water supply	Percentage of households with inadequate water supply
Sewage Services	Percentage of households with inadequate sanitation
Garbage Collection	Percentage of households with inadequate garbage collection
Urban Residents	Percentage of the population residing in the urban area

Table 1 - Set and description of study variables comprising the types of disasters, climatological and socio-sanitary variables.

The separatrices (quartiles) methodology was used to categorize each parameter under analysis into four levels, attributing the highest scores to the worst indicators.

GRADE OF MEMBERSHIP (GOM)

The Grade of Membership (GoM) methodology was used to identify the profiles of vulnerability to natural disasters in the NEB, based on Zadeh's (1965) theory of nebulous sets and employed in the multidimensional modeling of discrete data (MANTON, 1994). This methodology's analytic structure is notable for considering that the individuals or events analyzed, in this case, the mesoregions, do not only belong to a single profile/group but to multiple sets with different attributes.

We used the maximum likelihood method, based on the variables of the mesoregions' individual characteristics, to define the extreme profiles and their respective degrees of belonging (MANTON et al., 1994, GUEDES et al., 2016). The following formula expresses the mathematical model:

$$L(x) = \prod_{i=1}^{I} \prod_{j=1}^{J} \prod_{l=1}^{Lj} \left(\sum_{k=1}^{K} g_{ik} * \lambda_{kjl} \right)^{y_{ijl}}$$

of which: I is the number of observations in the sample; J is the number of variables included;LJ is the number of categories of each of the J variables, and K is the number of extreme profiles.

The method estimates two types of parameters, the description, and classification of individuals in their respective profiles. The characteristics that define the profile descriptions are obtained from the comparison between the estimates of λKJL and the marginal frequencies of the results of a response category l to a variable j, providing the probability of each category of the respective variables j in each of the profiles k, thus defining the predominant particularities in the extreme profiles k. The disposition of the mesoregions was based on the degree of relevance gik. That is, for each mesoregion in the study, the degree of belonging to the k-th profile was estimated, which can vary between 0 and 1, where a

$$\sum_{k=1}^{K} g_{ik} = 1$$

for each i. Thus, the mesoregion will not only belong to a single set but partially to multiple sets/profiles with different degrees of relevance.

Different profile configurations were created based on the estimated results, establishing three distinct configurations to characterize the incidence of natural disasters for the mesoregions under study, according to climatic, socio-sanitary, and population attributes. The GoM's classification of the profiles is determined by comparing the reference values obtained from the ratio between the values of λKJL and the percentage frequencies of each of the categories of the variables. Thus, the ratio's estimated value must be greater than 1.4 for the category under analysis to be an integral characteristic of the respective profile. Subsequently, the microregions were placed in the group profiles using Guedes' (2010) methodology as a belonging criterion, in which: 1) pure type of the extreme profile k:

$$se\ g_{ik} \geq 0{,}75\ com\ k = 1, 2, 3;$$

2) mixed type:

$$se\ (0{,}50 \leq g_{ik} < 0{,}75) \cap (0{,}25 < g_{3} \leq 0{,}50) \cap (g_{¿} < 0{,}25)\ com\ k \neq m \neq n;$$

3) amorphous type: if

$$g_{ik} < 0{,}50\ com\ k = 1 \cup 2 \cup 3$$

KRUSKAL WALLIS TEST

Kruskal Wallis' (1952) non-parametric statistical test was applied to the continuous variables to verify whether statistically significant differences exist between the medians of the profiles created with the Grid of Membership (GoM) based on the ranks of the data in each of the groups analyzed.

Subsequently, to identify the statistically significant differences between the groups, Nemenyi's (1963) non-parametric multiple comparison test was used based on the sum of the ranks. The test makes pairwise comparisons to find groups that differ from each other.

RESULTS AND DISCUSSION

From 1992 to 2013, the Northeast region of Brazil (NEB) recorded 15,382 occurrences of various types of natural disasters. The most frequent natural disasters (ND) for the Region are classified as Drought, with more than 12,000 recorded events accounting for 78.5% of all cases, followed by Flash Floods and Flooding corresponding to a total of 1,769 (11.5%) and 1,197 (7.8%) notifications, respectively. Therefore, it is evident that these multiple classifications of higher frequency events are potentiated through rainfall, contemplating the deficit or excess of precipitation.

Alvalá et al. (2019) indicate that the region has the highest percentage of the population exposed to disaster risk areas and is characterized by significant socio-environmental vulnerability (FREITAS et al., 2014). Less frequent events are observed in the region, such as Flooding, Windstorms, Hail, Mass Movements, Erosion, and Forest Fires, totaling 336 events, corresponding to 2.2% of the total records.

During the 22 years considered in the study, there has been a rise in the quantities analyzed. Aridity and drought events recur in the entire analysis period, especially in the last ten years, since the occurrences intensified over the years, with the highest values observed in 1993, 2001, 2003, 2007, and 2012. Disasters caused by excessive precipitation showed very similar behaviors in their series. They are infrequent in the region, although 2004 was atypical, with high records of flash floods and floods, as were 2008 and 2009.

Marcelino (2006) showed the relationship between the increasing occurrence of disasters and the growing population. Due to urbanization, individuals began to occupy places in areas unfit for housing, putting them in vulnerable situations and enhancing the risk of disasters. However, it should be considered that information systems have been improving over time and have become more efficient and available; their knowledge and understanding expand day by day. This fact may also justify the increase in records in the historical series studied.

Considering the spatial distribution of the occurrences of natural disasters for the mesoregions of the Northeast region of Brazil from 1992 to 2013 (Figure 2), different patterns can be identified for each of the classifications under analysis. Figure 2 (a) shows a concentration of aridity and drought records in areas closer to the center of the NEB. Its pattern follows the characteristics and particularities corresponding to the drought polygon, better known as the Brazilian Semi-arid region. Studies by Moura and Shukla (1996) and Marengo et al. (2011 and 2017) show that this region is marked by a water deficit with reduced rainfall and an arid climate. According to Leite et al. (1993), anthropogenic actions also potentiate events through the inadequate use of water and soil resources, the destruction of native vegetation, and fires.

Figures 2 (b) and (c) reveal the spatial distribution of events caused by excessive precipitation. The occurrence of floods (Figure 2 - b) is most concentrated in the mesoregions in Bahia, Pernambuco, and Paraíba; the state of Ceará is the least affected by events of this nature. The visual inspection of the floods (Figure 2 - c) showed a concentration of events in the northern part of the Northeast region of Brazil, corresponding to the mesoregions of the states of Ceará, Rio Grande do Norte, Piauí, and Maranhão.

Events of this kind are highly destructive, depending on how they affect the population. Subject to their intensity, many people are affected; they may be displaced, homeless, or injured. Furthermore, deaths and major destructive impacts on the population may well result. According to CEPED (2013), from 1991 to 2012, the NEB registered 2,188,911 persons affected and 27,405 people displaced and made homeless by these events. There was also a rise at the national level, from an average of 227 events/year from 1991 to 2001 to 504 events/year between 2002 and 2012.

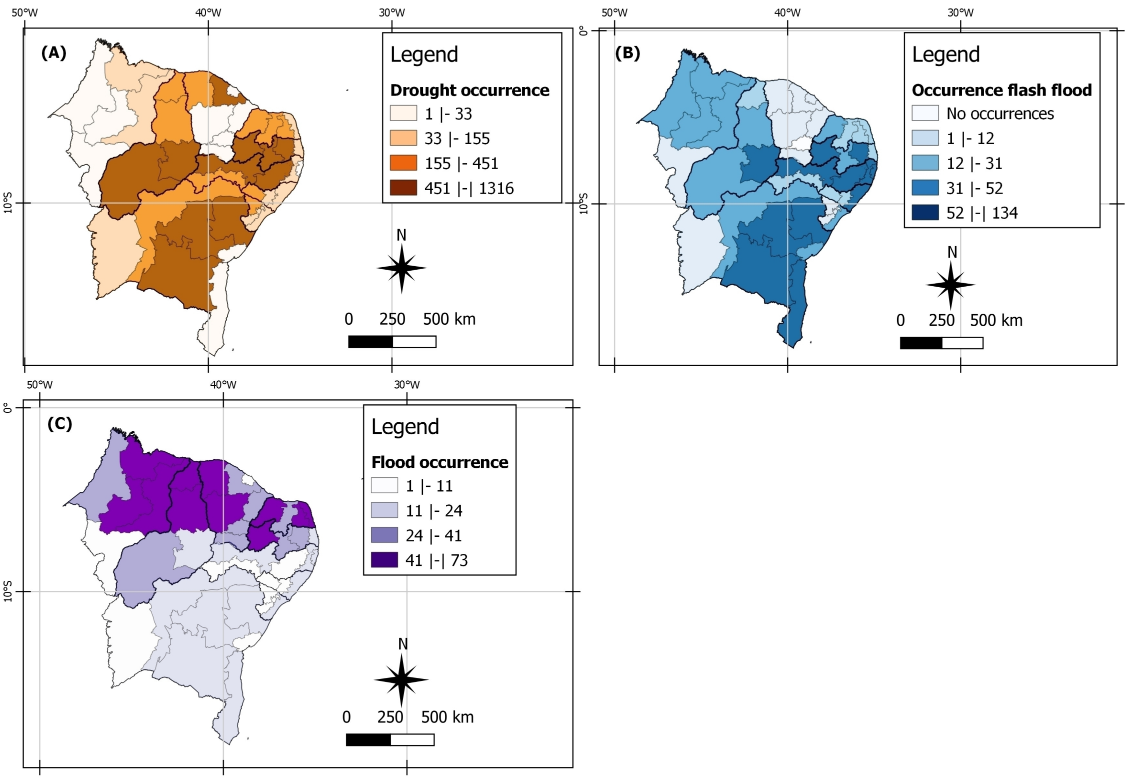

Figure 2 – Spatial distribution of occurrences of natural disasters for the Northeast region of Brazil, from 1992 to 2013.

Table 2 presents the statistics of minimum, maximum, and separatrices used to categorize the variables in the development of the GoM methodology. These are the NEB's meteorological and socio-sanitary parameters by the mesoregions under analysis. The results allowed us to conclude that there is a high variation in the region's climatic conditions, with a higher number of consecutive dry days (CDD) and a lower frequency of consecutive wet days (CWD). The annual accumulated rainfall ranges from 469.4 mm to 1,848.9 mm, with 50% of the units having values below 834.2 mm.

Sociosanitary indicators showed high variation between mesoregions. The percentage of households with an inadequate water supply range from 6.3% to 44.4%. Over 50% of households have inadequate sewage services above 15.5%, and garbage collection is the indicator with the highest percentages. In terms of the urban population, 25% of the mesoregions have urbanization values below 58.9%; the mesoregions have urbanization percentages of 47.3% (Table 2).

VARIABLES	MINIMUM	QUARTILES			MAXIMUM
		1st Q	2nd Q	3rd Q	
Drought	1.0	33.0	154.5	451.2	1,316
Flash Floods	0,0	11.8	31.0	52.3	134.0
Floods	1.0	11.3	24.0	41.3	73.0
CDD	12.5	28.4	46.6	68.3	118.9
CWD	11.3	15.8	19.9	28.1	87.6
R95p	119.0	164.5	192.9	273.0	438.9
PRECPTOT	469.4	731.6	834.2	1,197.4	1848.9
Water Supply	6.3	23.3	26.0	32.2	44.4
Sewage Services	2.6	9.6	15.5	22.3	36.6
Garbage Collection	4.6	22.7	32.7	40,2	55.9
Urban Population	47.3	58.9	62.9	74.4	97.1

Table 2 – Statistical description of disaster, climate, and socio-sanitary indicators for the mesoregions of the Northeast region of Brazil.

Table 3 (3.1 e 3.2) identifies the characteristics of the three profiles based on information on natural disasters and meteorological, social, and sanitary parameters.

Categories	Frequency		Lambdas			P/F (ratio of probabilities to marginal frequency)		
	n	%	λ_{1jl}	λ_{2jl}	λ_{3jl}	1	2	3
	PRECPTOT – Annual accumulated rainfall							
l1	11	26.2	0.000	0.522	0.000	0,0	**2.0**	0,0
l2	10	23.8	0.000	0.478	0.000	0,0	**2.0**	0,0
l3	10	23.8	0.319	0.000	0.502	1.3	0,0	**2.1**
l4	11	26.2	0.680	0.000	0.498	**2.6**	0,0	**1.9**
	R95p - Annual rainfall exceeding the 95th percentile							
l1	11	26.2	0.000	0.522	0.000	0,0	**2.0**	0,0
l2	10	23.8	0.000	0.478	0.000	0,0	**2.0**	0,0
l3	10	23.8	0.198	0.000	0.867	0.8	0,0	**3.6**
l4	11	26.2	0.802	0.000	0.133	**3.0**	0,0	0.5
	Inadequate water supply							
l1	11	26.2	0.512	0.260	0.000	**2.0**	0.9	0,0
l2	10	23.8	0.357	0.335	0.134	**1.5**	**1.4**	0.6
l3	10	23.8	0.131	0.256	0.384	0.6	1.1	**1.6**
l4	11	26.2	0.000	0.239	0.482	0,0	0.9	**1.8**
	Inadequate sewage services							
l1	11	26.2	0.828	0.159	0.000	**3.2**	0.6	0,0
l2	10	23.8	0.172	0.185	0.388	0.7	0.8	**1.6**
l3	10	23.8	0.000	0.501	0.000	0,0	**2.1**	0,0
l4	11	26.2	0.000	0.1534	0.6116	0,0	0.6	**2.4**
	Inadequate Garbage Collection							
l1	11	26.2	1.000	0.000	0.000	**3.8**	0,0	0,0
l2	10	23.8	0.000	0.558	0.000	0,0	**2.3**	0,0
l3	10	23.8	0.000	0.268	0.396	0,0	1.1	**1.7**
l4	11	26.2	0.000	0.175	0.604	0,0	0.7	**2.3**
	Urban Residents							
l1	11	26.2	0.000	0.314	0.408	0,0	1.2	**1.6**
l2	10	23.8	0.000	0.316	0.331	0,0	1.3	**1.4**
l3	10	23.8	0.000	0.370	0.261	0,0	**1.6**	1.1
l4	11	26.2	1.000	0.000	0.000	**3.8**	0,0	0,0

Table 3.1 – Absolute, relative, and estimated frequencies according to the vulnerability profiles generated by the GoM for the Northeast region of Brazil.

Categories	Frequency		Lambdas			P/F (ratio of probabilities to marginal frequency)		
	n	%	λ_{1jl}	λ_{2jl}	λ_{3jl}	1	2	3
	Occurrences of Aridity and Drought							
11	11	26.2	0.331	0.000	0.539	1.3	0,0	**2.1**
12	10	23.8	0.669	0.000	0.327	**2.8**	0,0	1.3
13	10	23.8	0.000	0.432	0,134	0,0	**1.8**	0.6
14	11	26.2	0.000	0.568	0.000	0,0	**2.2**	0,0
	Occurrences of Flash Floods							
11	11	26.2	0.000	0.000	0.584	0,0	0,0	**2.2**
12	20	47.6	0.659	0.568	0.416	**1.4**	1.2	0.9
13	11	26.2	0.341	0.432	0.000	1.3	**1.6**	0,0
	Occurrences of Flooding							
11	11	26.2	0.149	0.406	0.335	0.6	**1.5**	1.3
12	20	47.6	0.638	0.599	0.000	1.3	1.3	0,0
13	11	26.2	0.213	0.195	0,635	0.8	0.7	**2.4**
	CWD – Consecutive Wet Days							
11	11	26.2	0.000	0.606	0.000	0,0	**2.3**	0,0
12	10	23.8	0.298	0.394	0.000	1.3	**1.7**	0,0
13	10	23.8	0.393	0.000	0.351	**1.7**	0,0	**1.5**
14	11	26.2	0.309	0.000	0.649	1.2	0,0	**2.5**
	CDD – Consecutive Dry Days							
11	11	26.2	0.591	0.161	0.000	**2.3**	0.6	0,0
12	10	23.8	0.409	0.164	0.416	**1.7**	0.7	**1.8**
13	10	23.8	0.000	0.355	0.169	0,0	**1.5**	0.7
14	11	26.2	0.000	0.708	0.000	0,0	**2.7**	0,0

Table 3.2 – Absolute, relative, and estimated frequencies according to the vulnerability profiles generated by the GoM for the Northeast region of Brazil.

The extreme type 1 (P1) profile corresponds to the NEB mesoregions that have the following characteristics:

a) Disaster dimension: they are characterized by intermediate records of natural disasters classified as "drought" and "flash floods."

b) Meteorological dimension: the mesoregions in this profile have low levels of the indicator related to the number of consecutive dry days with daily rainfall below 1mm. The mesoregions have a greater weight in the intermediate levels of the indicator of the maximum number of consecutive wet days greater than or equal to 1 mm. They are also characterized by high annual rainfall values exceeding the 95th percentile (extremes of rainfall) and high annual rainfall.

c) Sociosanitary dimension: the mesoregions have the best sanitary infrastructure indicators, that is, low percentages of households with inadequate water supply, sewage services, and garbage collection services, resulting in a region with the best housing conditions. This profile brings together mesoregions with the highest urban population percentages.

Regarding the characteristics of the extreme type 2 profile (P2), the results in Table 3 allow the inference that the mesoregions that compose this profile have the following characteristics:

a) Disaster dimension: they are mesoregions with a high concentration of droughts, although there is also a high occurrence of floods.

b) Meteorological dimension: they aggregate mesoregions with high levels of consecutive dry days with daily rainfall below 1 mm and the lowest values of the number of consecutive wet days greater than or equal to 1 mm. They reveal low values of annual precipitation extremes exceeding the 95th percentile and low concentrations of annual accumulated precipitation.

c) Sociosanitary dimension: the mesoregions have intermediate access to sanitary infrastructure services. The mesoregions have moderate percentages of inadequate water supply, sewage services, and garbage collection services in this profile. Intermediate values of the variable "percentage of the population living in the urban area" were concentrated.

The mesoregions that make up the extreme profile 3 have the following characteristics (Table 3.1 e 3.2):

a) Disaster dimension: they are characterized by high occurrences of floods but low frequencies of droughts and floods.

b) Meteorological dimension: the mesoregions have high levels of the maximum number of consecutive wet days greater than or equal to 1 mm. There are areas with intermediate values for the indicators numbering consecutive dry days with daily rainfall below 1mm, annual rainfall that exceeded the 95th percentile, and annual rainfall.

d) Sociosanitary dimension: these are mesoregions with more significant limitations, with high concentrations of inadequate water supply, and sewage and garbage collection services. Furthermore, these are mesoregions with lower percentages of the population living in urban areas compared to the other profiles.

In addition to the three mainly pure profiles (P1, P2, and P3), four mixed profiles (PM1-3, PM2-3, PM3-2, and PM3-1) were identified in mesoregions where a given profile predominated with characteristics associated with one of the other extremes. Finally, there was an amorphous profile, which had no predominance in any of the pure profiles configured in the study.

The behavior of the averages of climatic, socio-sanitary, and population parameters and the respective significance of the tests applied found statistically significant differences between the profiles, whether pure or mixed (Table 4).

Variables	Profiles								P-value
	P1	P2	P3	PM 1-3	PM2-3	PM3-2	PM 3-1	Amorphous	
Drought	46.6**a**	501.9 **b**	72.2**a**	82.0**a**	214.2**b**	451.3**b**	14.0	363.0	0013
Flash Floods	55.9**a**	51.0**a**	23.7**b**	68.0**a**	9.3**b**	≤ 7 **b**	36.0	38.0	0099
Floods	13.9**a**	24.9**a**	34.2**a**	29.0**a**	27.8**a**	43**B**	36.0	66.0	0032
CDD	27.4**a**	54.8**b**	58.5**b**	36.9**a**	68.2**b**	80.1**b**	20.3	62.6	0223
CWD	23.2**a**	16.1**b**	48.1**a**	23.9**a**	19.7**b**	24.3**a**	87.6	34.6	0.0003*
R95p	310.0**a**	156.6**b**	266.7**a**	255.3**a**	194.0**ab**	167.4**ab**	326.6	241.8	<0.0001*
PRECPTOT	1,290.0**a**	692.2**b**	1,348.0**a**	1,068.5**a**	883.7**ab**	801.4**ab**	1,670	1,145	<0.0001*
Water Tabs	15.8**a**	30.2**b**	30.2**b**	25.7**ab**	22.6**ab**	33.9**b**	32.3	13.3	[0149]
ESG. Sanitary	9.5**a**	16.5**b**	27.9**c**	7.2**a**	16.8**b**	15.9**b**	23.9	16.1	0280
Garbage Collection	11.9**a**	32.6**b**	44.1**b**	9.9**a**	35.7**b**	40.3**b**	40.4	26.9	0.0006
Pop. Urban	89.2**a**	62.1**b**	61.6**b**	85.0**a**	59.7**b**	56.3**b**	64.1	78.1	0007

Table 4 – Averages of the variables under analysis according to the vulnerability profiles formed by the GoM and results of the statistical tests for comparison of groups

As mentioned above, flash flood events predominated in profile 1, with an average of 55.9 events, 46.6 droughts, and 13.9 floods. This predominance of flash floods may be facilitated by the region's extreme climatic conditions, as the annual rainfall was around 1,290 mm, 5% of rains exceeded 310 mm, and there were only 27.4 consecutive dry days on average. This profile had the best socio-sanitary conditions, with the lowest average percentages of inadequate households in the NEB, considering water supply (15.8%), sewage services (9.5%), and garbage collection (11.9%). On average, the profile has 89.2% of the urban population, thus concentrating the most extensive urban agglomerations: the metropolitan regions. This fact confers better social conditions and, thus, a greater adaptive capacity to adverse episodes.

Studies by Da Silva et al. (2019), analyzing indexes of climatic extremes for the NEB, detected positive trends of precipitation extremes; Salvador and Recife are the capitals with the highest number of residents living in risk areas in the region (CEMADEM, 2018). According to Ramos (1975), Moron (2007), and Santos et al. (2016), the principal systems causing intense precipitation in the region are the Intertropical Convergence Zone (ITCZ), the Easterly Wave Disturbances (EWD), cold fronts, and Upper

Tropospheric Cyclonic Vortexes (UTCV), often causing flash floods and floods.

The best sanitary conditions were also observed in the predominant profile 1, as most state capitals are in the study area. In addition to the largest population contingent, they have better socioeconomic conditions, with a higher concentration of households with access to the public water network, garbage collection, and sewage services. However, Tucci (2003) shows that urbanization potentiates the natural imbalances that favor flooding and the increase of waterborne diseases. The overcrowding of urban centers leads to the irregular occupation of spaces for housing, often in unsuitable locations in the surrounding areas, favoring the creation of peripheral regions with precarious social conditions.

In extreme profile 2, the most prevalent disaster was aridity/drought and flash floods, with an average of 501.9 and 51.0 events, respectively; there was a lower occurrence of floods (24.9 events). The climatic conditions favored a precipitation deficit, with averages of 54.8 consecutive dry days and 16.1 consecutive wet days. The average accumulated annual rainfall was 692.2 mm, the lowest value among the groups; it also accounted for the lowest extreme rainfall (156.6 mm). Thus, the precipitation deficit potentiated aridity and drought events, increasing the probability of this type of episode in these locations. The moderate socio-sanitary situation revealed that 30.2% of households had an inadequate water supply, 16.5% lacked sewage services, and 32.6% had no garbage collection. The percentage of the urban population is 62.1%, which classifies it as moderate urbanization.

The mesoregions corresponding to this profile are characterized by aridity and drought due to the low total rainfall, confirming the findings of Oliveira et al. (2017) and Da Silva et al. (2019) and lower accumulated annual rainfall (KOUSKY, 1979; ZHOU and LAU, 2001). According to Dias and Marengo (2007) and Nobre et al. (2006), aridity and drought are associated with the region's climatic characteristics and the variability of the Pacific and Tropical Atlantic Oceans. Although droughts predominate in the region, flash flood events were also observed, which may be associated with the occurrences of concentrated rainfall caused by the position of the ITCZ (SIQUEIRA et al., 2010) and the Convective Complexes (CALHEIROS et al., 2006).

Climate projections carried out by Marengo (2008) indicate a risk of intense droughts and rainfall reductions of up to 40% and temperature increases, as evidenced by Da Silva (2019). According to projection studies by the National Water Agency (NWA), it was estimated that by 2025 areas with more than 5,000 inhabitants may face a crisis in the water supply for human consumption. This factor would aggravate conditions in a region with a low Human Development Index and high infant mortality rates.

In extreme profile 3, on average, the records showed 72.2 occurrences of drought, 23.7 flash floods, and, notably, 34.2 flood events. These floods happen because the mesoregions have climatic conditions that favor excessive precipitation, with an average annual accumulation of 1,348 mm, with precipitation extremes exceeding 266.7 mm on average. There were 48.1 consecutive wet days, on average. However, despite indicators that favor precipitation, the region still has an average of 58.5 consecutive dry days. Sociosanitary conditions are comparatively more precarious as the profiles have the highest percentages of inadequate services: 31.2% with a substandard water supply, 27.9% with deficient sewage services, and 44.1% with inadequate garbage collection. Among the three profiles, it was the one with the lowest percentage of urbanization, at 61.6%.

Since floods are the main feature in profile 3, studies developed by Oliveira et al. (2013; 2014) showed an increase in precipitation extremes, which may potentiate disasters of this nature. However, the moderate number of consecutive dry days can be explained by the slight maritime influence in the regions located south of Maranhão and in the Far West of Bahia mesoregion. On the other hand, the heaviest rains in the north of the region are associated with their proximity to the Atlantic Ocean, which serves as a source of energy and humidity for the regional scale ITCZ, UTCV and Trade Winds active systems (DE SOUZA GUEDES et al., 2012). Furthermore, in the state of Maranhão, this region is inserted within the boundaries of the Legal Amazon, which provides favorable atmospheric characteristics for considerable volumes of rainfall.

The mesoregions of Profile 3 had the worst social and health indicators, with high percentages of households in inadequate conditions concerning water supply, sewage services, and garbage collection. This leads to precarious disaster prevention and post-disaster restructuring since the minimal conditions prevent the efficient recovery of affected areas. Razzolini and Günther (2008) stated that anthropogenic activities that alter the environment and are associated with absent or inadequate sanitation could lead to a rise in the incidence of diseases and a reduction in the expectation and quality of life of the human population. Mota et al. (2015) demonstrated that Maranhão's rural and riverside population live in precarious basic sanitation and housing conditions, with many hospitalizations, mainly of children, caused by waterborne diseases.

An analysis of the mixed profiles, that is, those with attributes pertinent to more than one profile, indicates that PM 1-3 had predominant characteristics of extreme 1 with particularities arising from extreme 3. Its similarity to P1 is due to the climatic conditions that favor rainfall, with an average annual accumulation of 1,068.5 mm, 5%of precipitation extremes exceeding 255.3 mm, and around 23.9 consecutive wet days. However, the mesoregions still have an average of 36.9 consecutive dry days. Sociosanitary conditions resemble their predominant group, with low inadequacy percentages: 25.7% for water supply, 7.2% for sewage services, and 9.9% for garbage collection. It is like profile 1 because of its larger urban population, with an average urbanization of 85.0%. However, unlike its predominant profile, this profile had more expressive values regarding the occurrence of floods, similar to profile 3, with an average of 29 floods.

The mixed profile PM 2-3 exhibited similar behavior to predominant profile 2 with characteristics of profile 3. There were multiple drought occurrences, with an average of 214.2 events, but with fewer floods, like profile 3. They are also like profile 3 for annual accumulated precipitation, around 883.7 mm, and with precipitation extremes of 194 mm. Sociosanitary conditions and the degree of urbanization do not differ from their predominant group, classified as moderate.

The mixed profile PM 3-1 was noteworthy for having profile 3 characteristics due to the high values for excessive precipitation events, which accounted for an average of 36 flash floods and 36 flood events, with few occurrences of aridity/drought (14 records). The climatic conditions favored excessive rain, registering 1,670 mm of accumulated precipitation; 5% of the records exceeded 326.6 mm. This profile was characterized by more consecutive wet days, with an average of 87.6 days and only 20.3 consecutive dry days. The percentages of households with inadequate conditions are high for the region, compared to the others, and had moderate urbanization, similar to the predominant profile 1.

There was a higher predominance of floods in the mixed profile PM 3-2, registering an average of 43 events followed by seven recorded floods. However, there were a high number of drought occurrences with 451.3 events. This profile stands out with the highest number of consecutive dry days (80.1) and 24.3 consecutive wet days. The annual rainfall was 801.4 mm, and on average, 5% of the values exceeded 167.4 mm. The data on households' essential services showed their inadequacy: 33.9% had a water supply, 15.9% had sewage services, and 40.3% had garbage collection. The lowest average percentage of urbanization was observed in this profile, at 56.3%.

The amorphous profile presented particular characteristics of the different pure profiles generated. There were higher occurrences of disasters, comprising 363, 38, and 66 aridity/drought events, floods, and floods, respectively. The climatic conditions are very distinct, with many consecutive dry days (62.6 days) and 34.6 successive wet days. On average, the annual rainfall was 1,145 mm, with extremes of 241.8 mm. Sociosanitary indicators show low percentages of inadequacy and a high percentage of urbanization (78.1%). It is worth mentioning that the metropolitan region of Teresina is in this mesoregion, which provides better conditions for the population.

An analysis of the occurrences of drought shows that the profiles P2, PM 2-3, and PM 3-2 are similar because they have the highest number of this type of disaster, with averages of 501.9, 214.2, and 451.3, respectively, differing statistically from the other groups. The episodes of flash floods showed similarities between the profiles P3, PM 2-3, and PM 3-2, with the lowest averages recorded. Considering the flood events, PM 3-2 had a statistically significant difference compared to the other profiles; together with the amorphous profile, it registered the highest number of these events.

Data on the climatic characteristics show that profiles P1 and PM 1-3 have the lowest averages of consecutive dry days, 27.4 and 36.9, respectively, significantly different from the other profiles. The groups with predominant attributes from the extreme 2, P2, and PM 2-3 were the driest regarding consecutive wet days. The P2 profile presented the lowest mean for extreme precipitation with 156.6 mm, differing significantly from groups P1, P3, and PM 1-3, which have the highest means. Similar behavior was verified for the annual accumulated average rainfall; P2 had the lowest amount, 692.2 mm.

However, it is notable that the highest annual and extreme accumulated precipitation averages were observed in PM 3-1.

There were significant differences in the socio-sanitary conditions between the profiles, with a predominance of extreme 1 (P1 and PM 1-3) compared to the other profiles. They have the lowest percentages of inadequate household services: water supply, sewage services, and garbage collection. The profiles where group one predominates had the best socio-sanitary conditions and were significantly more urbanized.

Subsequently, we identified the mesoregions in each of the three extreme profiles considered in the study through the degree of relevance () corresponding to each of the individuals under analysis. In the Northeast region of Brazil, 29 of the 42 mesoregions that cover the attributes herein were only equivalent to one extreme outline; that is, their degree of relevance was greater than 0.75 (gIK>0.75).

In the analysis of the mesoregions' distribution according to the profiles, it is observed that the regions with type "predominant 2" characteristics are 38.1% of the total; the mixed profiles with a predominance of type 2 contribute to 14.3%, totaling 52.4% of mesoregions with profile 2 characteristics.

The "predominant 3" profile was around 14.3% of the total of northeastern mesoregions, and the mixed profile with a predominance of profile 3 was 9.5%, totaling 23.8% for the profile of type. Approximately 16.7% of the mesoregions had predominant profile 1 characteristics. The mixed type with predominance of profile 1 is 4.7% of the mesoregions, presenting an overall preponderance of 21.4%. It is worth mentioning that only one mesoregion, the "Norte Piauiense," was classified as Amorphous since it has no expressive characteristics of any of the profiles considered in the analysis.

Figure 3 shows the spatial distribution of the result of the typology used in the study of the mesoregions considering the occurrence of natural disasters and associated with climatic and socio-sanitary characteristics. There is a distinct regional pattern to the results, markedly in the semi-arid portion of the Northeast region, where there is a broad concentration of natural disasters related to aridity and drought, corresponding to the extreme profile 2. In the coastal portion of the region, mesoregions belong to profile 1 with moderate occurrences of droughts and flash floods, favorable conditions for excessive rainfall, better sanitary conditions, and greater urbanization. Finally, the mesoregions characterized by high records of floods, favorable conditions for excessive precipitation, poor sanitary conditions, and less urbanization (profile 3) stand out and are located in the west of the NEB.

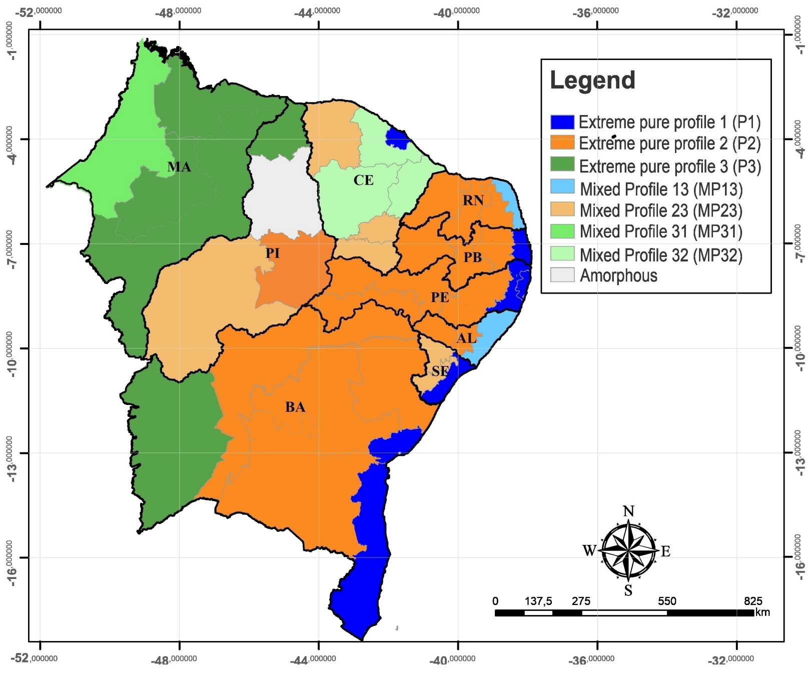

Figure 3 – Spatial distribution of the typology of the Northeast mesoregions.

CONCLUSION

This research permitted a multidisciplinary approach to the problem of natural disasters, identifying a high number of catastrophes in the Brazilian Northeast during the study period with significant increases over the years. Many people were directly or indirectly affected by these events, depending on social, environmental, climatic, and political factors. Furthermore, there has been a notable improvement in the quality of information recorded over the years.

Given the NEB's high climatic variability, the predominant events in the region are potentiated through the deficit or excess of precipitation, although these are not the primary factors for the intensification of an event. Droughts were the most frequent events in the Region and occurred with greater frequency throughout the series, followed by flash floods and floods that happened in specific years, with atypical high quantities throughout the period.

The climatic, socio-sanitary, and disaster indicators enabled the identification of the relationship between different factors, determining the construction of three profiles. In the Northeast region of Brazil, the profile of predominance 2 corresponded to the political and climatic delimitations of the Brazilian Semi-arid region. The profile was determined by the populations' exposure to the risk of aridity and drought arising from the high frequencies of consecutive dry days and low rainfall. The climate is dry and favors precipitation deficit. Intermediate sanitary conditions and moderate urbanization add to a lack of an adaptive capacity to cope with disasters.

The other profiles showed climatic characteristics favorable to excessive precipitation, with more consecutive wet days and greater rainfall extremes, boosting the occurrence of floods and inundations in their respective mesoregions. Profile 1 comprises the coastal region of the NEB, which has the most significant urban centers and the best adaptive capacity. On the other hand, the western part of the NEB, covering the state of Maranhão, concentrates the profile 3 mesoregions. There is less urbanization and precarious sanitary conditions, thus increasing exposure to natural disasters.

These results above can broaden the understanding of the nature and spatial distribution of natural disasters in Northeastern Brazil, therefore explaining to public managers and decision-makers how to prevent and mitigate the incidence of these events. Knowledge of the social, climatic, and population aspects related to disasters can encourage and subsidize effective and specific public policies aimed at each profile outlined to mitigate the impacts of disasters.

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