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Identification of Vulnerable Areas to Domestic Violence: A Multicriteria Decision-Making Approach

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Abstract This study proposes a multicriteria approach to classify municipalities based on to their vulnerability to Domestic and Family Violence Against Women (DFVAW). Using data from IBGE and violence records, the ELECTRE Tri-B method was applied based on socioeconomic criteria and the Assistance and Protection Index (IAP), which aggregates municipal indicators on specialized victim support services. Municipalities were grouped into four vulnerability levels, allowing the identification of regions with greater shortages of support and unfavorable socioeconomic conditions. The case study in the Metropolitan Region of Belém indicated that areas with better infrastructure recorded more reports, suggesting a relationship between access to services and violence reporting. Compared to the FCM-TOPSIS method, ELECTRE Tri-B demonstrated greater accuracy in differentiating vulnerabilities. The results highlight the usefulness of this approach as a tool to support public policies and optimize resource allocation in combating domestic violence.

Keywords: Violence against women, Multiple-criteria support methods, Metropolitan Region of Belém, ELECTRE Tri, Clustering

1 Introduction

Violence against women is one of the most persistent global challenges in the field of human rights, ranging from physical aggression to more subtle forms of control and oppression. This phenomenon, which crosses geographical and cultural boundaries, is widely recognized and condemned by the international community. An important milestone in this recognition is the Vienna Declaration and Programme of Action [ONU, 1993], adopted by the United Nations World Conference on Human Rights in 1993, which states that "the human rights of women and girls are an inalienable, integral and indivisible part of universal human rights".

In addition, the Inter-American Convention on the Prevention, Punishment and Eradication of Violence against Women, popularly known as the Belém do Pará Convention, held in 1994, represented a fundamental milestone in the fight against gender-based violence by recognizing that violence against women constitutes a violation of human rights and fundamental freedoms, which totally or partially limits the exercise of these rights and freedoms. The Convention defines this violence as any act or conduct based on gender that causes death, physical, sexual or psychological harm or suffering to women, whether in the public or private sphere [Brasil, 1996].

These documents reinforce the international commitment to upholding women's rights and are directly aligned with the Sustainable Development Goals (SDGs) of the 2030 Agenda, especially SDG 5 (Gender Equality), SDG 10 (Reducing Inequalities) and SDG 16 (Peace, Justice and Effective Institutions). In particular, target 5.2 aims to eliminate all forms of violence against women and girls in public and private spaces, recognizing this challenge as fundamental to sustainable human development and global health [ONU, 2015]. This highlights the urgency of implementing effective policies and measures to prevent and eradicate violence, protect rights and promote gender equity.

This urgency is even more evident in the Brazilian context, where violence against women remains a structural problem with a major social impact. Data from the Brazilian Public Security Forum indicate that, in 2023, one woman was a victim of femicide every six hours, highlighting the persistence of lethal gender violence [Bueno *et al*., 2024]. In addition, thousands of cases of physical, psychological, and sexual aggression are recorded every year, demonstrating the need for effective action to combat this reality. The Maria da Penha Law [Brasil, 2006] represented a milestone in the protection of women, providing advances in the fight against domestic and family violence. However, challenges remain in the implementation of protective measures.

According to the Brazilian Yearbook of Public Security [FBSP, 2023], published in March 2023, the breakdown of femicide rates (victims per 100,000 inhabitants) by region shows alarming data for the Northern Brazil. The highest

rates in 2021 and 2022 were in the states of Acre and Tocantins (2.9 victims per 100,000 inhabitants) and Rondônia (3.1 victims per 100,000 inhabitants), respectively; and the highest rate of attempted femicide was in Amapá (12 victims per 100,000 inhabitants). As for records of intentional bodily injury in the context of domestic violence for the year 2022, six of the seven states in the Northern Region had rates higher than the national average of 236.7 per 100,000 inhabitants: Acre (339.6), Amapá (307.7), Pará (249.9), Rondônia (499.4), Roraima (504.8) and Tocantins (278.5). Although the state of Amazonas had a lower rate (189.3), its variation was the highest in the country when compared to 2021, reflecting a worrying increase of 92%.

Considering the context of Domestic and Family Violence against Women (DFVAW), the approach proposed in this work aims to introduce and evaluate the ELECTRE Tri-B (ELimination Et Choix Traduisant la REalité — French for "ELimination and Choice Expressing REality") multi-criteria analysis methodology to classify municipalities in terms of vulnerability to this type of crime, using factors frequently associated with occurrences in the literature. In addition to socio-economic criteria, the methodology considered municipal data on the availability of victim care and protection services, taken from the Municipal Basic Information Survey (MUNIC, in Portuguese, Pesquisa de Informações Básicas Municipais), carried out by the Brazilian Institute of Geography and Statistics (IBGE, in Portuguese, Instituto Brasileiro de Geografia e Estatística).

The proposed methodology will be compared with the combination of the Fuzzy C-Means techniques, a clustering algorithm, and the multicriteria TOPSIS method (Technique for Order of Preference by Similarity to Ideal Solution), allowing an additional evaluation of the results obtained and an analysis of the suitability of the classifications in the context of the vulnerability criteria. In addition, the aim is to investigate the relationship between municipal indicators and records of bodily injuries classified as domestic violence, as reported by police reports. The case study will be applied to the eight municipalities of the Metropolitan Region of Belém[1]: Ananindeua, Barcarena, Belém, Benevides, Castanhal, Marituba, Santa Bárbara do Pará and Santa Izabel do Pará. With this in mind, this study aims to provide an analysis that has the potential to be used in drawing up and guiding public strategies aimed at locations that are more vulnerable to the occurrence of DFVAW.

1.1 Barriers to Reporting and the Need for Inclusive Public Policies

In one of the surveys carried out by the Visible and Invisible report [Bueno *et al*., 2023], women victims of violence were asked about their reaction to the most serious aggression suffered in the last 12 months. In all the years analyzed (2017-2023), the most common response was "did nothing". In 2017 and 2019, this percentage was 52%, indicating that the majority of victims remained silent. Among the reasons for not going to the police, 38% said they had solved it on their own, 21.3% didn't believe in the effectiveness of the police, 14.4% pointed to a lack of evidence and 13.2% said it wasn't important. The data shows a recurring pattern of silence, motivated by fear, lack of trust in institutions or the naturalization of violence.

Femicide in Brazil requires detailed studies on its causes and effects, as in [MPSP, 2018], which found that 97% of all victims did not have protective measures and 96% of fatal victims had not registered a police report, consolidating the hypothesis that femicides happen when the victim is not protected. Thus, it is understood that in order to avoid this last stage of worsening violence against women, it is essential to draw up public policies and make specialized services available for the protection and care of victims.

Based on the above, there is a need for tools to help allocate resources for preventive policies in high-risk areas, taking into account social and economic inequalities. Given the complexity of violence against women, a multicriteria approach is needed to integrate different factors in decision-making, allowing for the modeling of managers' preferences and the treatment of uncertainties in the data.

2 Related work

In order to select the related works, search criteria were considered that included regional classification approaches or spatial analysis applied to contexts of violence, not limited exclusively to gender-based violence. The papers presented include a previous version of this paper, already published, which adopted a similar methodology.

Studies in the literature have demonstrated the potential of computational techniques in analyzing data related to violence. One example is the work by [de Oliveira *et al*., 2019] which carried out a quantitative analysis of domestic violence against women in the municipality[2] of João Pessoa (Paraíba), based on 1,053 records reported in 2017. Using statistical methods and spatial representation using choropleth maps, in which geographic areas are shaded in proportion to the value of the variable being represented, the study identified patterns of distribution of violence in different regions of the city, showing clusters in both central and peripheral neighborhoods. The results reinforce the idea that domestic violence against women is not restricted to specific social classes, but is a widespread phenomenon that requires integrated attention from public policies.

The study [del Pilar Fuerte-Celis and de los Dolores Sánchez-Castañeda, 2021] presents a spatial analysis of homicide rates recorded in Mexican municipalities between 2000 and 2012, with the aim of identifying local variables associated with the occurrence of these crimes. Using geostatistical techniques such as Moran's Index and the Getis-Ord G*i tests, the authors identified spatial patterns of homicides and validated the groupings obtained using the Random Forest learning technique. The proposed classification considers the presence of organized crime, population density patterns and socioeconomic inequality as the main factors related to the spatial variations observed in the period analyzed.

[1] As established by State Complementary Law No. 164, of April 5, 2023, which amended State Complementary Law No. 27, of October 19, 1995

[2] The smallest administrative division in Brazil, encompassing urban and rural areas under a single local government

The work by [de Miranda Mota *et al*., 2021] proposes a model to identify areas vulnerable to homicide in a neighborhood of Recife, Pernambuco, using the multicriteria Dominance-based Rough Set Approach (DRSA) method, based on criteria such as income, education and demographic density. To refine the analysis, the K-means algorithm was applied to segment similar regions. In addition, spatial analysis techniques, such as the Local Moran index and hot spot analysis, were combined with a Geographic Information System (GIS), allowing critical areas to be mapped. The authors point out that the results can support public policies aimed at reducing violence.

The study presented in [da Silva Costa *et al*., 2022] proposes a decision support model for choosing the most suitable municipality for the implementation of the Casa da Mulher Brasileira in the Metropolitan Region of Belém, in the state of Pará. Using the Analytic Hierarchy Process (AHP) multicriteria decision method, three main criteria were considered: number of cases of violence, female population and accessibility to the region's municipalities. The model made it possible to technically evaluate these variables, both objectively and subjectively, and indicated Belém as the most appropriate municipality for the installation of the public facility, as it concentrated the best conditions among the criteria analyzed. The work highlights the potential of AHP in prioritizing public policies aimed at protecting women in situations of violence.

Ferrás *et al*. [2023] analyzed the spatial distribution of rates of violence against elderly women in the autonomous community of Galicia, Spain, with the aim of drawing up a Location Map to guide public policies. The research used statistical analysis and spatial autocorrelation, such as Moran's index, as well as investigating the relationship between violence and socioeconomic and territorial variables, such as low demographic density, ageing and dependency. The results indicate a higher prevalence in rural and low-density areas, suggesting the need for specific territorial planning for the provision of social and health services to this vulnerable group.

A previous version of this study was applied to the state of Paraíba [Medeiros *et al*., 2024], using the ELECTRE Tri-B method to classify municipalities in terms of vulnerability to DFVAW, based on data from the 2019 MUNIC survey, the SPI and records from Ligue 180. The results indicated that more than 80% of municipalities were highly prone to violence, reflecting a lack of services and strategies to protect women. However, the scope of the analysis - involving all 223 municipalities in the state - limited a more detailed assessment of the services offered in each location. In addition, the use of outdated criteria and a single source of data on violence (Ligue 180) represented important limitations, since the records may not fully reflect occurrences at municipal level.

This version of the study expands on the previous proposal, incorporating methodological improvements and a new geographical delimitation. The Belém Metropolitan Region was chosen because it brings together different socio-economic profiles, concentrates around a third of the state's population and allows for a more detailed analysis, given the small number of municipalities. The main updates include the addition of the "Average Monthly Salary" criterion, the updating of indicators with more recent data and the use of police reports as a database for violence. It was also possible to investigate more precisely the relationship between the supply of services and the volume of complaints. Finally, this version also proposed a comparison with an alternative method — FCM-TOPSIS (Fuzzy C-Means combined with the Technique for Order of Preference by Similarity to Ideal Solution), a hybrid approach that combines fuzzy clustering with multicriteria ranking — in order to validate the results obtained and assess the robustness of the approach.

Unlike the previously mentioned studies, which focus mainly on spatial analysis or descriptive statistics, both the previous and current versions use multicriteria decision support methods to classify municipalities in terms of vulnerability to violence against women. The main contribution lies in the application of these techniques to support the prioritization of public policies, simultaneously considering multiple socio-economic and structural criteria. The current version further advances by carrying out a comparative analysis between methods (ELECTRE Tri-B and FCM-TOPSIS), as well as offering a more detailed investigation of the relationship between available services and records of violence, which broadens understanding of the factors that influence reporting and the protection of victims.

3 Theoretical aspects

This section presents the theoretical foundations that underpin the methodology adopted in this study, with a focus on MultiCriteria Decision Making (MCDM) techniques. Initially, Subsection 2.1 explores MCDM concepts, with an emphasis on the ELECTRE family, an approach based on overclassification relationships that allows alternatives to be classified considering multiple criteria and uncertainties. Subsection 2.2 then looks at the combination of fuzzy C-Means and TOPSIS techniques, which integrate fuzzy logic into multi-criteria analysis to group and rank alternatives in a more flexible and precise way.

3.1 Multiple Criteria Decision Making - Electre

Multiple Criteria Decision Making is an approach used to help choose between alternatives in complex situations involving the evaluation of multiple criteria. This type of methodology is capable of dealing with complexity in the decision-making process as the amount of data and information increases, as well as adjusting parameters according to the specific context, offering a more structured and transparent analysis. Among the advantages of MCDM is the possibility of considering both quantitative and qualitative criteria, as well as incorporating decision-makers' preferences by assigning weights to the criteria, which allows their priorities to influence the final result [Moreira *et al*., 2019].

In the context of MCDM, "compensation", or trade-off, refers to the balance between advantages and disadvantages in different criteria: a disadvantage in one criterion can be compensated for by an advantage in another [Bouyssou, 1986]. Colson and De Bruyn [2014] classifies multicriteria methods into three main approaches: i) compensatory, where there is full flexibility for trade-offs; ii) non-compensatory, which

does not allow for any trade-offs; and iii) partially compensatory, which allows for limited trade-offs. Examples of MCDM methods include the AHP, which constructs a hierarchical analysis of the criteria, PROMETHEE (Preference Ranking Organization Method for Enrichment Evaluations), used for ordering, ranking and selecting alternatives, and the ELECTRE family, in which the degree of compensation can be adjusted and limited by defining the preference (p), indifference (q) and veto parameters [Bouyssou, 1986].

There are several multicriteria approach methods, each suitable for different types of decision problems and with specific characteristics and limitations that need to be assessed when choosing the most appropriate method. In this work, we opted for the ELECTRE Tri-B multicriteria method, a variant of the ELECTRE family, selected for its suitability for ordered classification problems. ELECTRE Tri-B compares alternatives with reference profiles that represent the boundaries of each previously established class.

3.2 Fuzzy C-Means and TOPSIS

The term "clustering" refers to the task of grouping data according to their similarities, forming clusters that contain elements similar to each other and distinct from other clusters. One of the best-known techniques for clustering is K-Means, characterized as a partitional algorithm which, given a set of input data, aims to find an optimal partition of the set into k disjoint clusters [Paulista and de Oliveira, 2018], with k being the main parameter to be defined.

Fuzzy C-Means, proposed by [Dunn, 1973] and [Bezdek *et al*., 1984] is an adaptation of K-Means, based on fuzzy logic. Unlike K-Means, which assigns each data point to a single cluster, FCM allows each point to belong to more than one group with different degrees of pertinence (probability of belonging). In a nutshell, its algorithm works by performing the following steps:

1. Random initialization of the centroids of each cluster, where the number of clusters c is restricted to $2 < c < n$, where n is the number of samples in the data set;
2. The pertinence of each data point to each cluster is calculated, using a function that takes into account the distance between the point and each centroid;
3. The new centroids weighted by the degrees of pertinence of the data points are calculated and the data points are repositioned to the nearest center;
4. The steps are repeated iteratively until the differences between the centroids of the current step and the previous one are minimal, indicating that the centroids have converged to a stable solution.

The TOPSIS method is a multicriteria decision analysis method proposed by [Hwang and Yoon, 2012] that is based on ranking alternatives in order of preference. The basic principle of TOPSIS is to evaluate an alternative so that it is as close as possible to the Positive Ideal Solution (PIS) and as far as possible from the Negative Ideal Solution (NIS) [Lima and Carpinetti, 2015] and [Chen *et al*., 2019]. The positive ideal solution is made up of the best achievable values of the criteria evaluated, while the negative ideal solution is made up of all the worst achievable values of the criteria [Bai and Sarkis, 2013].

4 Methodology

In terms of its nature, the research is classified as an applied study, since it aims to generate knowledge for practical application, aimed at solving a specific problem; in terms of the data analyzed, it is classified as qualitative-quantitative. The methodology for developing the work, illustrated in **Figure 1**, is based on a series of stages for delivering the results.

4.1 Data pre-processing

This section deals with data pre-processing, which is essential for applying the chosen methods. Subsection 4.1.1 deals with data acquisition and processing. The study used two sources of public information: the first was the IBGE[3], to collect the municipal structural and socio-economic information corresponding to the criteria, and the second was the Secretariat of Public Security and Social Defense[4], for records of domestic violence in the municipalities of Pará. Subsection 4.1.2 presents the description of the criteria and the correlation analysis with the violence data, a fundamental step in assigning weights using the AHP method.

4.1.1 Data acquisition and processing

The Belém Metropolitan Region (RMB, in Portuguese), the study's area of application, is made up of eight municipalities: the capital, Belém (1,303,403 inhabitants); Ananindeua (478,778); Marituba (111,785); Benevides (63,567); Santa Bárbara do Pará (21,087); Santa Izabel do Pará (73,019); Castanhal (192,256) and Barcarena (126,650)[5].

The choice of the Belém Metropolitan Region as the study area is justified mainly by the fact that it is made up of a relatively small number of municipalities, which allows for a more detailed and precise analysis of the results per municipality. Furthermore, although its composition is limited, the RMB concentrates approximately one third of the population of the state of Pará, which makes it representative and relevant for demographic, social and economic studies. This relevance is intensified by the alarming regional context in terms of violence against women, as highlighted above, which reinforces the relevance of the analysis focused on this area.

Some of the municipalities' data, such as the socio-economic indicators, Human Development Index (HDI) and Gross Domestic Product (GDP) per capita, as well as the Assistance and Protection Index (IAP, in Portuguese), were acquired through the IBGE data services API (Application Programming Interface)[6]. The HDI refers to the 2010 Census, while GDP per capita and IAP refer to 2021 and 2019, respectively. The use of data from the 2010 Census was necessary due to the unavailability of more recent data at the

[3]Available at: https://www.ibge.gov.br/

[4]Available at: https://codec.segup.pa.gov.br/

[5]Available at: https://www.ibge.gov.br/estatisticas/sociais/populacao/22827-censo-demografico-2022.html?

[6]Available at: https://servicodados.ibge.gov.br/api/docs

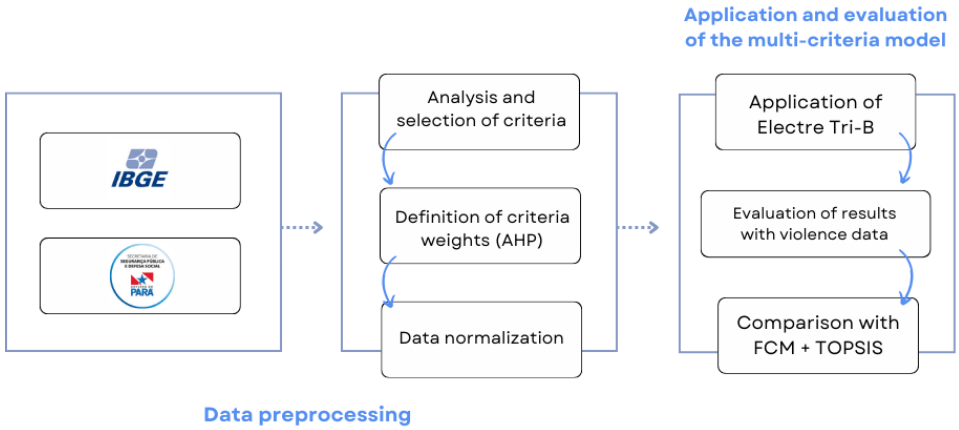

Figure 1. General Research Methodology.

time of the study. On the other hand, the Literacy Rate and Average Monthly Wage (AMW) criteria are based on the first results released from the 2022 Census and, as they are not yet available on the IBGE API, were collected manually on the website.

The database was structured with rows representing the municipalities and columns corresponding to the values of the criteria. Once consolidated, it was checked for possible inconsistencies, such as incorrect or missing data. The analysis to detect missing values did not identify any null records, eliminating the need for imputation or exclusion due to absence. Finally, the data was normalized on a scale of 0 to 1, using the Min-Max Scaler method, to ensure comparability between the criteria and enable the application of the ELECTRE Tri-B method.

The data on domestic violence by municipality was acquired through the Criminal Statistics Data Consultation[7], made available by the Secretariat of Public Security and Social Defense. The records are collected and qualified by the Deputy Secretariat for Intelligence and Criminal Analysis (SIAC, in Portuguese) from police reports and can be downloaded in spreadsheets in XLSX format (Excel Spreadsheet XML - eXtensible Markup Language). The data for the last two years, 2022 and 2023, was downloaded and then filtered to show only bodily injuries classified as domestic violence.

To make it possible to compare cases between municipalities with very different populations, the authors chose to use the measure Case Rate per 100,000 inhabitants, which corresponds to the total number of cases per municipality divided by its population and multiplied by 100,000 (comparable rate).

4.1.2 Analysis and selection of criteria

In terms of their content and representativeness, the criteria used can be divided into two groups. The first group, of care and protection service indicators, should numerically measure the availability of specialized services in the municipality, considering not only the quantity, but also the impact of the different types of services available. The second group, socioeconomic indicators, should assess how the municipality is situated in terms of human and economic development.

Indicators of care and protection services The IAP criterion is part of this group and is made up of the aggregation of indicators obtained by the 2019 Municipal Basic Information Survey[8] (MUNIC), referring to the availability of policies, services and actions specialized in the care and protection of women victims of domestic and family violence in each municipality. In short, the IAP is a weighted sum, in which each element (indicator) is multiplied by an associated weight and then the products are added together to obtain the final result. The weights were assigned based on the perception of the authors, so that indicators with a greater and immediate impact on the problem were given a weight of 1.5; 1.0 for medium impact and 0.5 for lesser and non-immediate impact. The MUNIC indicators used and their respective weights are described in **Table 1**.

Table 1. Indicators of care services

Code	Description	Weight
90201	It has specialized police stations	1.5
90358	It has specific legislation for gender-based violence	1.5
90640	It has policies or programs for the protection of elderly women who are victims	1.0
90626	Conduct conferences on the topic of women's rights or policies	0.5
90397	Constitution of reference and service centers for human rights	0.5
90272	Socio-educational initiatives on domestic and gender-based violence	0.5
90335	It implements specific programs and actions for women	0.5

The highest weight, 1.5, was given to the indicators of the presence of specialized police stations and specific municipal legislation on violence against women, due to their preventive nature aimed at protecting victims and enforcing the law. An average weight of 1.0 was given to the indicator of protection policies or programs for women victims, as it is a more

[7]Available at: https://codec.segup.pa.gov.br/

[8]Available at: https://www.ibge.gov.br/estatisticas/sociais/saude/10586-pesquisa-de-informacoes-basicas-municipais.html?=&t=destaques

specific indicator for tackling violence against older women. Although crucial, this indicator does not cover all victims of domestic violence and therefore has a more targeted and less comprehensive impact when compared to the municipal legislation indicator. Finally, a lower weight of 0.5 was given to the last three indicators due to their complementary nature, which tend to act in a more assistive and educational manner, with an impact that manifests itself over time through changes in behavior and raising awareness among the population. They were considered less important in immediate terms when compared to the direct and legal response provided by the indicators with higher weights.

The use of these indicators is justified by the importance of these services in the process of breaking the cycle of violence, since they contribute to women's empowerment [Fonseca *et al*., 2012] by providing a sense of security. The lack of protection, the precariousness of the institutions' infrastructure and human resources, and the disruption of the network are pointed out by [Arboit *et al*., 2019] as factors that negatively influence the process called the "critical route", defined by Sagot [2000] as the set of actions taken by the victim to break the cycle of violence in which she is inserted.

Socio-economic indicators The second group of indicators is made up of important regional socio-economic "thermometers". The importance of this group for the analysis is justified by studies that show that precarious income conditions, access to health and education can be triggers for violent acts in the most diverse dimensions [da Silva Alves, 2021]. Family composition and place of residence can also be influential factors in cases of violence, according to a study by Martins and Teixeira [2020]. The researcher [Dias, 2017], in turn, related poverty and social exclusion as factors that impact on domestic violence, listing unemployment, precarious work, low incomes, and inadequate social support and protection services, as characteristics present among the actors involved in cases of domestic violence. In addition, Leite *et al*. [2017] attribute socioeconomic issues, more specifically the Human Development Index (HDI), to the greater likelihood of victimization.

It should be noted that some of the factors mentioned above are covered by the HDI, whose value is based on health, education and income. It was therefore decided to use it as a criterion in this study's methodology. In addition, based on the aforementioned studies, the criteria Average Monthly Wage, Literacy Rate and Gross Domestic Product (GDP) - Per Capita, all obtained by the IBGE, were also considered. The criteria used and their respective descriptions are shown in **Table 2**.

The AHP method [Saaty, 1990] was used to define the weights of the criteria. Once the criteria have been defined, the judgment matrix must be constructed, an initial stage of the method necessary to measure the importance of the criteria. This process is done through pairwise comparisons, which are measured by values based on the Saaty scale, which assigns numerical values to the intensity of importance: 1 for equal importance, 3 for moderate, 5 for great, 7 for very great and 9 for absolute, with intermediate values of 2, 4, 6 and 8.

The pairwise evaluation (see **Table 3**) was stipulated by the authors and was based on [Martins and Teixeira, 2020], who consider the presence of public facilities in municipalities to be essential, since they contribute to increasing the feeling of safety for victims and, consequently, to the filing of complaints. Based on this hypothesis, IAP was given greater importance. Initially, all the other criteria were considered to be of equal importance. However, criterion C2 (HDI) was later re-evaluated, as its values are based on 2010 data and may not accurately reflect the current reality of the municipalities. Consequently, the importance of this criterion was reduced in the analysis.

To make the judgment matrix easier to understand, it is important to clarify the interpretation of some of its values. For example, the value assigned to the comparison between criteria C1 and C2, equal to 5, indicates that criterion C1 (IAP) was considered strongly more important than criterion C2 (HDI), according to the scale proposed by Saaty. Similarly, the value of 2 given to the comparison between C1 and C3, C4 and C5 indicates a moderate preference for C1 over the criteria mentioned. These values express the decision-makers' subjective judgments as to the relative importance of the criteria and are fundamental for calculating the respective weights in the multicriteria model.

To assess the consistency of the judgment matrix, the Consistency Ratio (CR) was calculated. Saaty [1980] defines that an acceptable CR value should be less than or equal to 0.10. For CR values CR > 0.10, a revision of the matrix is suggested. The RC calculated was 0.0, indicating perfect consistency between the judgments made - in other words, there are no logical contradictions in the comparisons, which reinforces the reliability of the matrix for multicriteria analysis purposes. The judgment matrix and the other calculations needed to achieve the AHP objective were applied using the Python library pyDecision[9], which facilitates the implementation of various multicriteria methods. As a result of the application, weight values were defined for each criterion. The weights were distributed to the criteria as follows: IAP (36.6), HDI (6.6), GDP (19.0), Literacy Rate (19.0) and Average Monthly Wage (19.0).

4.2 Application and evaluation of the multicriteria model

The ELECTRE Tri-B method was also applied using the pyDecision library mentioned above. In order for the method to carry out the overclassification process, i.e. the assignment of alternatives to previously defined classes, it is necessary to specify some essential parameters: B = Reference profile thresholds; P = Strong preference thresholds; Q = Indifference thresholds; V = Veto threshold and W = Criteria weights. The thresholds define a minimum degree of performance required in each criterion for an alternative to be considered viable for a given class.

For this work, the reference profile (B) thresholds for the classes were defined using a function created in Python to capture the quartile values for each criterion. Using these values makes it possible to divide the data distribution into four equal parts, based on the three quartile values. In other words, defining three thresholds results in the alternatives

[9] Available at: https://pypi.org/project/pyDecision/

Table 2. Selected criteria

Code	Criterion	Description
C1	IAP	Aggregation of variables from the Survey of Basic Municipal Information regarding the availability of services for assisting victims of DFVAW
C2	HDI	A statistical measure that assesses human development in countries based on three dimensions: health, education, and per capita income
C3	GDP Per Capita	An economic measure that represents the average economic output per inhabitant of a given country or region
C4	Literacy Rate	The rate is calculated by dividing the number of literate individuals aged 10 years or older by the corresponding age group population, multiplied by 100
C5	Average Monthly Wage	It is the average monthly salary of formal workers

Table 3. Criteria judgment matrix

	C1	**C2**	**C3**	**C4**	**C5**
C1	1	5	2	2	2
C2	1/5	1	1/3	1/3	1/3
C3	1/2	3	1	1	1
C4	1/2	3	1	1	1
C5	1/2	3	1	1	1

being grouped into four classes.

The indifference (Q), preference (P), and veto (V) thresholds indicate, respectively, the maximum indifference values, the minimum acceptable values for strong preference, and the maximum acceptable values for veto during the process of overclassifying alternatives. For their definitions, the condition $v_j \geq p_j \geq q_j$ must be followed. The values of these thresholds were defined empirically, based on successive tests. Initially, null values were adopted and then incremental adjustments were applied until the results obtained were consistent with the distribution of the data and the objectives of the analysis. The final values adopted were:

- q (indifference): 0.1
- p (preference): 0.2
- v (veto): 1.0

These values provided an adequate balance between the model's sensitivity to variation between the criteria and the robustness needed to classify the alternatives. The weights of the criteria (W) were previously determined using the AHP method, as described in the previous section. To better visualize the classification, the methodology used the Geopandas library and the IBGE's geographic mesh API to create a map of the region with the classes assigned to its municipalities.

In order to evaluate the classification, it was decided to use the data on reports of domestic violence made available by Pará State Security Department, as mentioned above. The use of this data for the evaluation is justified by the research by [Martins and Teixeira, 2020], which points out that the number of complaints is directly related to the availability of care and protection services, since this support gives women greater security to report their aggressor.

The study proposed applying an additional classification technique to the data for a comparative analysis of the results. Using the Fuzzy C-Means (FCM) technique, the municipalities were grouped according to their similarities, and the TOPSIS method was used to order the clusters formed, according to the weights defined by the AHP.

The FCM-TOPSIS approach offers a classification alternative by grouping data by similarity via Euclidean distance. Unlike ELECTRE Tri-B, which uses weights and thresholds for allocation, FCM segments data based on similarities. This comparison made it possible to assess the influence of the ELECTRE Tri-B parameters on classification and their relationship with FCM-TOPSIS clustering.

5 Results and discussions

This section analyzes and discusses the results of the classification of the municipalities in the Belém Metropolitan Region, comparing the approach based on ELECTRE Tri-B with the combination of the Fuzzy C-Means and TOPSIS techniques. In addition, the classifications obtained are compared with the records of domestic violence, assessing how the presence or absence of victim protection mechanisms influences these figures.

5.1 Application with the ELECTRE Tri-B

For a more detailed assessment, we decided to apply the methodology to a regional section with only a few municipalities, eight in this case. In addition to socio-economic data, the services provided by each municipality were analyzed. For a better understanding of the results, some descriptive statistics for the study region were generated and can be seen in Table 4.

Table 4. Descriptive statistics of the municipal data

Criterion	Minimum value	Maximum value	Mean
IAP	0.0	5	2.3
HDI	0.627	0.746	0.678
GDP	11027.6	71473.92	25831.0
Literacy Rate	91.8	97.2	94.6
AMW	1.6	3.6	2.1

For the ordered classification carried out by ELECTRE Tri-B, four classes of vulnerability to the occurrence of cases of DFVAW were defined: i) Low; ii) Medium; iii) High; and iv) Very High, so that the lower a city's scores on the criteria, the greater its vulnerability to this type of violence. It is important to mention that there is no official category of vulnerability to domestic violence; the categories were only defined in ordered levels of performance of the alternatives (cities) in the selected criteria.

The municipalities of Santa Izabel and Santa Bárbara do Pará, classified with "Very High" vulnerability and considered as priority regions for the analysis, registered the lowest IAP values in the region (0 and 0.5, respectively), indicating the absence of assistance services in Santa Izabel and the presence of only one indicator, "Executes specific programs and actions for women", in Santa Bárbara. In addition, both municipalities had unfavorable socio-economic indicators, with Santa Izabel registering the second lowest GDP per capita in the RMB (R$ 12,835.31), as well as low literacy rates and average monthly salary, while Santa Bárbara had the lowest values for all these criteria.

The municipalities of Benevides and Marituba, classified as highly vulnerable, had IAPs of 1.5 and 2, respectively. Marituba offered three services aimed at protecting women: "Carries out specific programs and actions for women", "Holds conferences on women's rights or policies" and "Has policies or protection programs for women victims", aimed at combating violence against older women, while Benevides only had the last two.

In addition to the IAP, both municipalities had an HDI below the regional average. Despite this, Benevides recorded a high GDP per capita (R$ 30,668.86), driven by the presence of large industries and logistics centers, although this figure does not necessarily reflect an equitable distribution of wealth among the inhabitants.

Of the eight municipalities analyzed, two were classified in the "Very High" vulnerability category, namely Santa Izabel do Pará and Santa Bárbara do Pará. Another two municipalities were assigned to the "High" class, corresponding to Benevides and Marituba. Detailed data on these municipalities, including the criteria assessed, can be found in Table 5.

The analysis of domestic violence records in the four municipalities indicates a directly proportional relationship between the availability of protection services and the number of reports, in line with the results observed by Martins and Teixeira [2020]. Santa Izabel and Santa Bárbara, which have the lowest rates of assistance to women, also registered the lowest rates of domestic violence in 2022 and 2023, suggesting possible underreporting, especially in Santa Izabel, which does not have any services from the Protection Attention Index.

In contrast, Marituba and Benevides had a higher number of complaints, reflecting the greater supply of support services. Despite the absence of Specialized Women's Police Stations (DEAM, in Portuguese), the proximity to Ananindeua, which has had a DEAM since 2018, enables indirect service to these cities, according to information from the Official News Agency of the Government of Pará[10].

The other municipalities in the region were distributed as follows: two in the "Low" class, the capital and headquarters of the RMB, Belém, and the municipality of Ananindeua; and two in the "Medium" class, Barcarena and Castanhal. Their data can be seen in Table 6.

Analyzing the local network of these municipalities, we identified important IAP services that partly justify their attributions in lower vulnerability classes. Some of the services are present in all four municipalities: "Has specialized police stations", "Has protection policies or programs for women victims" and "Holds conferences on women's rights or policies". Barcarena and Castanhal stand out in this criterion with the highest IAP values: 5 and 4, respectively.

Castanhal, for example, also has the indicators "Executes specific programs and actions for women" and "Socio-educational actions - Domestic and gender violence". Barcarena stands out for being the only municipality in the RMB, until the year of the survey, with the indicator "Has specific municipal legislation for violence against women". This is Municipal Law No. 2107[11], which establishes the Municipal Council for Women's Rights, its policy, the fund and other measures.

As far as performance in socio-economic indicators is concerned, Belém and Ananindeua have advantages: both cities had higher HDI values (0.746 and 0.718, respectively), Literacy (97.05% and 97.2%). For the same criteria, Castanhal and Barcarena had values below the average for the region. However, Barcarena had the highest GDP per capita, and the justification for this is similar to that observed in Benevides, as it is an important industrial center, as well as having the largest port in the state of Pará, the port of Vila do Conde, characteristics that contribute to the local and regional economy.

When we analyze the records of these cities, we immediately come across considerably higher rates, which reflect the great impact of the protection network combined with favorable socioeconomic development indices, the correlation of which has already been investigated in the studies by [da Silva Alves, 2021] and Leite *et al*. [2017]. For the years analyzed, Castanhal recorded the highest rate of complaints in 2022: 172.2 cases per 100,000 inhabitants. This high reporting rate, based on the approach used in the study, can be attributed to a number of factors, including awareness of the importance of reporting cases of domestic violence, which can be associated with the socio-educational actions on Domestic and Gender Violence promoted in the municipality, and the availability of the DEAM, which combined create an environment where victims are made aware and encouraged to seek help and report their aggressors.

It is important to note that this does not mean that there is no vulnerability to domestic violence in these municipalities. After all, case rates show figures that, from a certain perspective, can be alarming. However, when analyzing the incidence of cases of violence, regardless of the type, it is essential not to assess it in isolation. The social, economic and cultural context in which it occurs must be taken into account.

In the analysis of the map of the region with the classes obtained by applying the model, seen in **Figure 2**, where the darker areas represent regions with greater vulnerability to DFVAW and the lighter areas less vulnerability, it can be seen that, among the municipalities in the "High" and "Very High" classes, the further away from the municipality that is the seat of the Metropolitan Region (Belém), the greater their vulnerability. Castanhal, although it is the municipality furthest away geographically, was considered to be of

[10]Available at: https://www.agenciapara.com.br/noticia/15971/delegacia-de-atendimento-a-mulher-de ananindeua-completa-um-ano-de-atuacao

[11]Available at: https://barcarena.pa.gov.br/portal-da-transparencia/leis/

Table 5. Data of Municipalities Classified with High or Very High Vulnerability

Municipality	C1	C2	C3	C4	C5	Class	Case Rate for 2022	Case Rate for 2023
Benevides	1.5	0.665	30668.86	94.44	2.0	High	122.7	129
Marituba	2	0.676	18986.11	95.61	2.1	High	124.3	125.2
Santa Izabel do Pará	0	0.659	12835.31	92.91	1.7	Very High	93.1	76.7
Santa Bárbara do Pará	0.5	0.627	11027.66	91.84	1.6	Very High	94.8	104.3

Table 6. Data of Municipalities Classified with Low or Medium Vulnerability

Municipality	C1	C2	C3	C4	C5	Class	Case Rate for 2022	Case Rate for 2023
Belém	3	0.746	22216.33	97.05	3.6	Low	144	144.5
Ananindeua	3	0.718	16542.68	97.2	1.9	Low	134.9	126.6
Castanhal	4	0.673	22897.75	94.12	1.8	Medium	172.2	144.1
Barcarena	5	0.662	71473.92	93.85	2.7	Medium	141.3	147.7

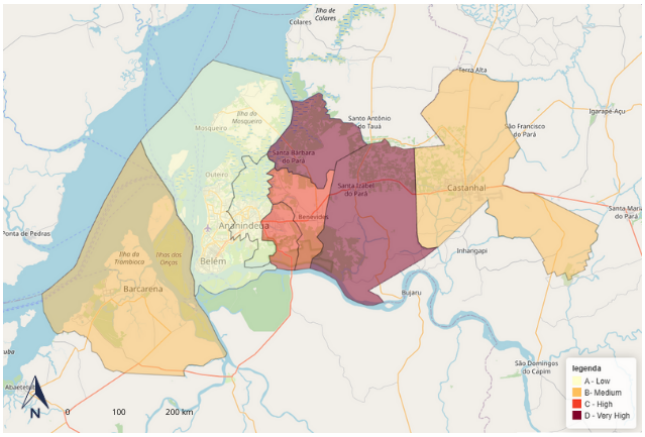

Figure 2. Map of the Classification Obtained Using ELECTRE Tri-B.

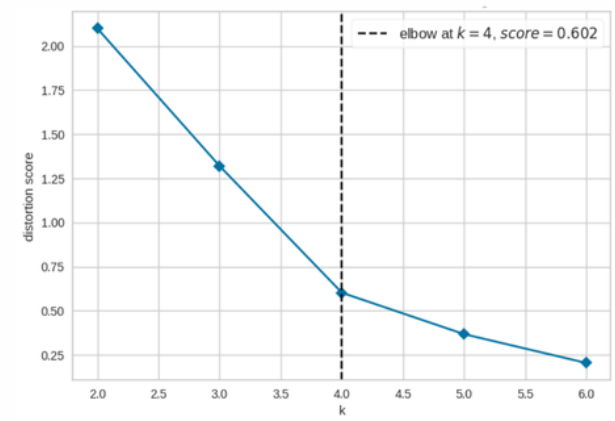

Figure 3. Plot of the Elbow Method.

medium vulnerability. The municipality has a specialized police station, as well as other services considered important for protecting victims, which may explain its high reporting rates in the years analyzed.

5.2 Application with FCM-TOPSIS

Considering that the metric used in FCM clustering can be influenced by outliers [Mekhmoukh and Mokrani, 2015], values that have a large difference from the average of the data in a column, as observed in Barcarena's GDP per capita, were normalized using the QuantileTransformer method. This method transforms the data to follow a uniform distribution, helping to reduce the impact of outliers.

The FCM was applied using Python's Scikit-Fuzzy library, which offers tools for implementing fuzzy logic algorithms, including Fuzzy C-Means. The optimum number of clusters, i.e. the number k of clusters that best group the data presented, was defined using the Elbow method. The graph generated can be seen in **Figure 3**.

The elbow method seeks to identify the point at which adding more clusters does not bring significant gains to the model. This point is chosen as the optimum number of clusters for the data set, which in the context of the application is 4. Both methods were executed on a dataset of 8 municipalities with negligible computational cost, with runtimes of less than 1 second for each algorithm. The other algorithm parameters were set following the standard recommendation: m = 2, error = 0.005 and maxiter = 1000. To obtain the hierarchical order of the clusters, the TOPSIS method was used with the same weights generated by the AHP. The clustering results can be seen in Table 7.

Table 7. Fuzzy C-Means Clustering of RMB Municipalities

PIS	Municipalities	Cluster
1°	Castanhal and Barcarena	Cluster 2
2°	Belém and Ananindeua	Cluster 1
3°	Benevides and Marituba	Cluster 3
4°	Santa Izabel and Santa Bárbara	Cluster 4

It can be seen that the resulting division was the same as that made by ELECTRE Tri-B. However, the clusters formed by FCM do not present a hierarchical order, providing only the best division for the four clusters considering the distance between the points. The order generated by TOPSIS represents the cluster's closest proximity to the Positive Ideal Solution (PIS), mentioned above.

The ELECTRE Tri-B method showed consistency in categorizing municipalities by similarity, validating its robustness in the analysis. Compared to TOPSIS, it presented a different order, classifying Belém and Ananindeua as closest to the ideal solution, while TOPSIS indicated Barcarena and Castanhal. This difference reflects the impact of the weights on the classification, since, despite not having the highest IAP, Belém and Ananindeua have better socio-economic indica-

tors, which influenced ELECTRE's decision.

The trade-off between the two methods reflects their different classification philosophies. ELECTRE Tri-B is more suitable for assessing vulnerability to DFVAW, as its partially compensatory approach prevents high performance in one criterion from compensating for critical deficiencies in others, ensuring a more balanced and interpretable view of intervention priorities. Furthermore, it explicitly incorporates decision-makers' preferences through the definition of weights and thresholds, making the classification process more transparent and adjustable to the problem context. FCM-TOPSIS, on the other hand, offers advantages in terms of ease of implementation and does not require prior threshold definition, relying instead on data-driven clustering via Euclidean distance. However, this also means it is less flexible in reflecting subjective preferences or asymmetric criteria importance. Despite these differences in approach, both methods converged on the same grouping of municipalities, with Santa Izabel and Santa Bárbara consistently identified as the most vulnerable, which reinforces the robustness of the findings.

6 Final considerations

The application of the ELECTRE Tri-B method proved efficient in classifying municipalities, reflecting the preferences of the decision-maker in a multi-criteria context. The method made it possible to identify locations with greater vulnerability to domestic violence by considering not only the availability of protection services, but also socio-economic factors. It was observed that municipalities with better socio-economic indicators and a greater protection network register more complaints, while those with low IAP values and unfavorable socio-economic conditions show possible signs of under-reporting.

Among the priority municipalities, there are unfavorable socio-economic indices, low IAP values and few or no registered cases, which may indicate underreporting, a phenomenon in which many cases of violence against women are not reported to the authorities or recorded in official statistics. The limited presence of protection services in these locations not only reduces the visibility of cases of domestic violence, but also makes victims more vulnerable and less likely to seek help.

The prioritization of intervention efforts can be adjusted based on an analysis of available resources and the specific needs of each municipality. This prioritization, guided by strategic implementation sites, can be even more valuable. Cities with better socio-economic indices and more robust support infrastructure can direct part of their resources to further strengthening their protection networks, extending this support to neighboring municipalities as well. While in isolated areas, with fewer resources and greater socio-economic challenges, reinforcements should be more intensive to ensure the necessary protection and support for victims, such as the implementation of specialized police stations and other support services.

The comparison with the FCM-TOPSIS method revealed differences in the ranking of municipalities, highlighting the impact of the weights on the classification. As the ELECTRE Tri-B is partially compensatory, it proved more suitable for the study by preventing good performance in one criterion from compensating for critical deficiencies in others. In this way, the method proved to be a robust tool to support decision-making, ensuring a more balanced assessment of the vulnerability of municipalities to domestic violence.

It is important to note that although one of the criteria used in this study comes from the 2010 Census, its influence on the analysis was reduced by updating the other indicators and weighting the weights assigned in the multicriteria method, which gave greater balance and consistency to the results. It is also recognized that the data from the MUNIC survey does not capture the full complexity of the network of services available in the municipalities, which may limit the representation of the real structure of protection for victims.

Future studies could therefore benefit from the inclusion of new indicators as they become available. In addition, it is recommended that criteria relating to individual characteristics of victims, such as number of children and race, be incorporated, with the aim of deepening understanding of the groups most vulnerable to violence and strengthening the formulation of more effective public policies. Furthermore, a limitation of the present study concerns the definition of the ELECTRE Tri-B thresholds (Q, P, V), which were determined empirically through successive adjustments. Future work could explore systematic sensitivity analyses varying these parameters to assess their influence on the classification results and further validate the robustness of the approach.

Declarations

Authors' Contributions

Alana Medeiros made significant contributions to the conception of this study, being responsible for the writing, development of the methodology and multicriteria models, and is the main contributor and author of this paper. João Júnior, Marisa Andrade and Saulo Costa contributed to the writing and methodological development. Fernando Costa contributed to the translation of the paper. Marcos Seruffo and Nelson Neto supervised and managed the project, in addition to conducting the review and editing of the manuscript.

Competing interests

We, the authors of this work, declare that there are no conflicts of interest in this study, whether financial, personal, institutional, academic, or of any other nature.

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Availability of data and materials

The source code for this work and the datasets are available on the authors' github repository in: https://github.com/AlanaMiranda/Classification-RMBPA.

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