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# Efficiency of the Municipalities of the Cariri Ceará Region in the COVID-19 Pandemic: a Critique Using Data Envelopment Analysis (DEA)

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# Efficiency of the Municipalities of the Cariri Ceará Region in the COVID-19 Pandemic: a Critique Using Data Envelopment Analysis (DEA)

Eficiência dos Municípios da Região do Cariri Cearense na Pandemia de COVID-19: uma Crítica Usando a Análise de Envoltória de Dados (DEA)

Eficiencia de los municipios de la región de Cariri Ceará en la pandemia de COVID-19: una crítica a través del análisis envolvente de datos (DEA)

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## Abstract

**Research objective:** To analyze the management efficiency of public resources by municipal administrations in the Cariri region of Ceará in coping with the COVID-19 pandemic.
**Theoretical framework:** Aroeira, Vilela and Ferreira (2020) evaluated the clinical and managerial efficiency of hospitals under SUS (Unified Health System) in the treatment of COVID-19 in Brazilian municipalities from the date of the first case of the disease in the country until the date of death number 100,000 and, later, until number 600,000, finding that the municipalities analyzed have, on average, better clinical efficiency indexes than managerial.
**Methodology:** Data Envelopment Analysis (DEA) was used to calculate the efficiency of the 26 municipalities, using the BCC (Banker-Charnes-Cooper) model, with an output orientation.
**Results:** The results indicate that 8 of the municipalities analyzed reached an efficiency rate of 100%. In addition, the highest efficiency levels were not necessarily found in those with the highest per capita spending on health. The number of notifications was the variable with the greatest potential for improvement, requiring more attention from managers.
**Originality:** The evaluation of efficiency in the context of the COVID-19 pandemic in municipalities in a region that recorded the highest rate of infection and contagion, in addition to using the Municipal Management Effectiveness Index - Health Dimension (IEGM_Saúde), which can be replicated for studies in different regions of Brazil and the world.
**Theoretical and practical contributions:** The model presented with the inverse proposal for certain variables can be adopted by researchers and managers of public entities for the formulation of public policies and decision-making in different parts of the world.
**Keywords:** COVID-19. Efficiency. Data Envelopment Analysis (DEA). Local Government

## Resumo:

**Objetivo da pesquisa:** Analisar o desempenho dos municípios da região do Cariri Cearense na pandemia do Coronavírus.
**Enquadramento teórico:** O Brasil tem sido severamente impactado pela pandemia de COVID-19, os graves problemas socioeconômicos que o país enfrenta desde antes da detecção do primeiro caso da doença e a distribuição populacional, com padrões e realidades locais bastante heterogêneas, ocasionaram comportamento distintos de proteção, notadamente no âmbito dos governos locais.

**Metodologia:** Para o cálculo da eficiência dos 26 municípios, utilizou-se a Análise Envoltória de Dados (DEA), por meio do Modelo BCC (Banker-Charnes-Cooper), com orientação para *outputs*.
**Resultados:** Os resultados indicam que 8 municípios analisados atingiram o índice de eficiência de 100%. Além disso, o melhor nível de eficiência não necessariamente ocorre naqueles que tiveram maiores gastos per capita com saúde. O número de notificados foi a variável que apresentou o maior potencial de melhoria, requerendo mais atenção dos gestores.
**Originalidade:** A avaliação da eficiência no contexto da pandemia da covid-19 em municípios de uma região que possuía a maior taxa de índice e contágio, além de utilizar o Índice de Efetividade da Gestão Municipal –Dimensão Saúde (IEGM_Saúde), do Tribunal de Contas do Estado do Ceará, como *output,* esse último, ainda não explorado nos estudos analisados.
**Contribuições teóricas e práticas:** O modelo apresentado com a proposta inversa para determinadas variáveis, pode ser utilizado por pesquisadores e órgãos públicos as secretarias municipais para a formulação de políticas públicas e tomadas de decisões.
**Palavras-chave:** COVID-19. Eficiência. Análise Envoltória de Dados (DEA).

## Resumen:

**Objetivo de la investigación:** analizar el desempeño de los municipios de la región Cariri Cearense en la pandemia de Coronavirus.
**Antecedentes teóricos:** Brasil se ha visto gravemente afectado por la pandemia COVID-19, los graves problemas socioeconómicos que el país ha enfrentado desde antes de la detección del primer caso de la enfermedad y la distribución de la población, con patrones y realidades locales bastante heterogéneas, han generado un comportamiento de protección diferente, especialmente en el marco de los gobiernos locales.
**Metodología:** Para el cálculo de la eficiencia de los 26 municipios, se utilizó el Análisis de la Evolución de Datos (DEA), por medio del Modelo BCC (Banker-Charnes-Cooper), con una orientación hacia los productos.
**Resultados:** Los resultados indican que 8 municipios analizados alcanzaron una tasa de eficiencia del 100%. Además, el mejor nivel de eficiencia no se da necesariamente en quienes han tenido el mayor gasto en salud per cápita. El número de temas de los que se informó era la variable que tenía más posibilidades de mejorar, y que requería más atención por parte de los directores.
**Originalidad:** La evaluación de la eficiencia en el contexto de la pandemia del covid-19 en municipios de una región con mayor índice y contagio, además de utilizar el Índice de Eficacia de la Gestión de la Dimensión de Salud Municipal (IEGM_Saúde), del Tribunal de Cuentas del Estado de Ceará, como producto, este último, aún no explorado en los estudios analizados.
**Aportaciones teóricas y prácticas:** El modelo presentado con la propuesta inversa para determinadas variables puede ser utilizado por investigadores y organismos públicos en las secretarías municipales para la formulación de políticas públicas y para la toma de decisiones.
**Palabras clave:** COVID-19. Eficiencia. Análisis Envolvente de Datos (DEA).

## 1 Introduction

Performance in the use of public resources is key to the exercising of social control, as well as to the achievement of efficiency by public administration. Government spending aims to meet the citizens' needs by providing quality services and goods. When it comes to health spending, it has a direct impact on the quality of life and well-being of society (Gadelha, 2017).

Health-related spending in Brazil in 2019 totaled R$ 711.4 billion, or 9.6% of the Gross Domestic Product (GDP), the highest proportion in the historical series by the Brazilian Institute of Geography and Statistics (IBGE), through the satellite accounts, which are an extension of the System of National Accounts (SCN) and aim to expand the analysis capacity of the National Accounts in certain areas, such as health (Instituto Brasileiro de Geografia e Estatística [IBGE], 2022).

The COVID-19 pandemic has directly affected health spending worldwide since 2020. Over 670,000 people have already died in Brazil by June 2022 (Covid-health, 2022). In the region of Cariri Cearense, made up of 29 municipalities, the imbalance of Ceará's urban network and socio-spatial inequalities regarding access to health services constitute a barrier to actions aimed at tackling the pandemic (Fernandes, Da Silva, & Muniz, 2021).

Some international studies have demonstrated the importance of studying efficiency using the DEA methodology. Zou et al (2021) applied the DEA methodology to measure the technical efficiency (TE), pure technical efficiency (PTE) and scale efficiency (SE) of public

security in 31 provincial-level administrative divisions (regions) in China from 2014 to 2018, and to analyze the effectiveness of public security in each year. Andrews, Beynon, and McDermott (2019) evaluated, using DEA, the technical efficiency, unit costs, and utilization rates of Cambodia's public health services to quantify the extent to which current health financing can accommodate the expansion of social health protection coverage.

Su et al (2022) evaluated the equity and efficiency of health resource allocation of public hospitals in Guangdong province, collecting data from the Guangdong Health Statistical Yearbook 2016-2020 and the Guangdong Statistical Yearbook 2017-2021. Nurcahyo, Kristiningrum and Sumaedi (2020) measured the efficiency of 30 ISO 9001-certified district public health centers in Jakarta, Indonesia, and, using DEA, showed that there is a variation in the efficiency values of the ISO 9001-certified public health centers studied in the research.

This research is relevant because, according to Morais et al. (2021), in the period from January 2020 to February 2021, the municipality of Juazeiro do Norte, followed by Crato and Farias Brito, concentrated the highest incidence and number of confirmed cases of COVID-19, affecting mostly brown, female people aged between 30 and 34 years. Gouveia et al. (2020) found that in the state of Ceará, from March to May 2020, the peak incidence of COVID-19 was reached on April 30, with a downward trend after this period. In terms of lethality, the Cariri region recorded the highest figures (8%).

Given the above, it should be made clear that in times of crisis, public leaders, particularly those in the health sector, seek to increase the efficiency of resources and obtain efficiency gains in the management of the SUS (Cruz, 2016). As municipalities have limited resources and, mostly, depend on transfers from the federal and state governments, the need to be more efficient is even more urgent (Moutinho, 2016). In order to assess efficiency, De Witte et al. (2020) state that DEA is one of the most widely adopted techniques in the literature.

In this sense, the following research question is posed: what is the level of efficiency of the municipalities of Cariri, Ceará, in 2020, in the face of the COVID-19 pandemic? This article aims to analyze the level of efficiency and performance of municipalities in the Cariri region of Ceará in the Coronavirus pandemic, by using Data Envelopment Analysis (DEA). DEA is a methodology for analyzing efficiency in the application of public resources, and is mainly employed for data on education and health (Silva et al., 2021).

The studies by Aroeira, Vilela and Ferreira (2020) and by the same authors in 2021 are closer to this research. However, this study innovates by evaluating efficiency in the context of the COVID-19 pandemic in municipalities in a region where the highest rate of infection was found, as well as using the Municipal Management Effectiveness Index - Health Dimension (IEGM_Saúde), from the State Audit Court of Ceará, as an output, which has not yet been explored in the analyzed studies.

Finally, it is worth noting that the model presented with the inverse proposal for certain variables can be used by researchers and public entities, such as municipal secretariats, to formulate public policies and decision-making.

## 2 Theoretical Framework

### 2.1 Public Spending, Data Envelopment Analysis (DEA) and COVID-19

The “corona-crisis” that has already surpassed even the Great Depression, as stated by some authors, including Cardoso (2020), has shown that inequality in the distribution of epidemiological patterns has occurred due to the unequal distribution of socioeconomic conditions and the means of preventing and treating diseases (Lima, Buss, & Paes-Sousa, 2020).

Thinking about the resources allocated to public health actions, specifically within the scenario of the pandemic brought on by the Sars COV-2 virus, popularly known as COVID-

19, means giving public resources the tangent line that not only carries out the required actions to control and prevent the disease, but rather works to save lives.

Cutting down on the spread of new cases of contagion as well as the number of deaths requires the state to act incisively within its health system to implement effective social distancing policies, alongside mass testing and tracking of the infected (Leite et al., 2022).

The actions of the Federal Government in response to the measures to tackle the pandemic resulted in an outlay of R$39.5 billion for the public budget in 2020 (1.63% of total expenditure) and R$33.4 billion in 2021 (1.45% of total expenditure) (Portal da Transparência, 2022).

Brazil's state financial intervention on the front line against COVID-19 has impacted directly on the budgets of the Union, states and municipalities. The years 2020 and 2021 were particularly challenging for managers, especially for public coffers. Government has focused its actions not only on the sanitary sector, but also, as it is directly affected, the social sector (unilateral income transfers) as well as the economic sector (tourism, energy, credit, etc.).

The Federal Government's Monitoring of Spending to Combat COVID-19 is detailed on the Transparent National Treasury website. It shows the total amount of funds spent by the federal government on the pandemic, totaling 524 billion spent on COVID-19 in 2020 and 121 billion in 2021.

The DEA (Data Envelopment Analysis) method, presented by Charnes, Cooper and Rhodes (1978), consists of a non-linear (non-convex) programming model, which provides a new meaning about efficiency in order to use it to analyze the actions of non-profit entities, which are linked to public programs.

Gomes and Mangabeira (2004) pointed out that the Data Envelopment Analysis (DEA) approach, which uses linear programming to weight the efficient frontier (piecewise linear), is capable of incorporating various inputs (resources, inputs or factors of production) and outputs (outputs or products) to determine the efficiency of decision making units (DMU's).

According to Peña (2008), the DEA method has been successfully used to analyze the efficiency of public administration and non-profit institutions. In this sense, DEA can be a very useful system for analyzing efficiency in the public sector, given that public administrators are concerned with the ranking of study units according to a certain grouping of inputs / outputs, rather than examining the determinants of this ranking (Delgado and Machado, 2008).

## 2.2 Related Studies

The review of national and international literature found studies that used DEA to analyze the effectiveness of public spending on health. A search of the Web of Science database up to May 2022 revealed 38 articles on the subject. While Hunt and Link (2020) focus on economics to analyze the efficiency of public spending, others such as Bostian et al. (2020) and Ozbugday et al. (2020) adopt a managerial perspective. Authors such as Gao and Wang (2021) also address this specific issue related to health. In addition to these, others such as (Gao and Wang, 2021) deal with this issue, focused on health.

Zakowska and Godycki-Cwirko (2020) conducted a systematic review of data envelopment analysis applications in primary health care, focusing on studies from 2017 to 2019. The study covered articles published up to March 25, 2019 and adopted the approach of the Institute of Health Science in Oxford. The analysis revealed a gradual increase in publications concerning the use of the DEA method, highlighting its predominance in evaluating the efficiency of Primary Health Care (PHC) institutions.

The analysis of the articles revealed a gradual increase in the number of publications regarding the use of the DEA method, demonstrating that it is the most widely used method

for examining the efficiency of Primary Health Care (PHC) institutions.

Leite et al. (2022) analyzed research on public spending on health, based on publications from 2020 on the Web of Science. Through a bibliometric analysis, the authors examined 121 articles and pointed out the scarcity of Brazilian productions on the issue. In addition, it was found that many studies address public, environmental and occupational health, and that they refer to health systems, public perceptions and government structuring in countries in the face of the COVID-19 pandemic.

To analyze the proportions of public spending on COVID-19 hospitalizations by SUS in Brazil, Santos et al. (2021) showed that spending varied between regions. The Brazilian Southeast had the highest number and total amount spent on hospitalizations, as well as the highest average duration of stay and the highest case-fatality rate.

Aroeira, Vilela, and Ferreira (2020) evaluated the clinical and managerial efficiency of SUS hospitals in treating COVID-19 in Brazilian municipalities from the date of the first case in the country until the date of the 100,000th death. They found that the analyzed municipalities have, on average, better clinical efficiency (0.76) than managerial efficiency (0.65).

Aroeira, Vilela and Ferreira (2020) evaluated the clinical and managerial efficiency of SUS hospitals in the treatment of COVID-19 in Brazilian municipalities from the date of the first case of the disease in the country until the date of death of 100,000 and found that the municipalities analyzed have, on average, better clinical efficiency indexes (0.76) than managerial (0.65).

In 2021, the aforementioned authors examined the clinical and administrative efficiency of SUS hospitals in treating COVID-19 in Brazilian cities from the first reported case in the country until the 600,000th death, also considering the number of vaccinated people as a variable. On average, the cities evaluated had higher administrative efficiency rates (0.86) than clinical efficiency (0.67). On average, the analyzed municipalities show better indexes of managerial efficiency (0.86) than clinical efficiency (0.67).

This study differs from previous ones by using IEGM_Saúde (IEGM_Health) as an important output when analyzing the Cariri region of Ceará, due to the higher incidence rates at the time, as well as by using the variables inversely, since the lower the contagion, incidence and deaths, the more efficient the municipality.

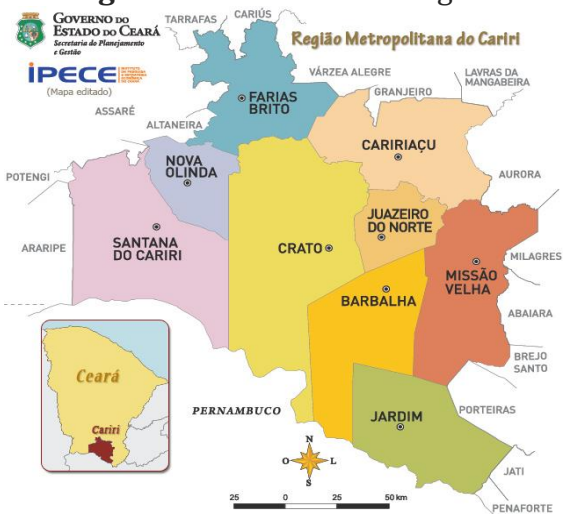
## 3 Methodology

### 3.1 The Cariri region of Ceará

The sample considered 26 municipalities in the Cariri region of Ceará, as the other three lacked data. A commonly used strategy is to only analyze subjects with complete data on the variables (Nunes, 2007).

The Cariri region of Ceará is made up of the following municipalities: Abaiara, Altaneira, Antonina do Norte, Araripe, Assaré, Aurora, Barbalha, Brejo Santo, Campos Sales, Caririaçu, Crato, Farias Brito, Granjeiro, Jardim , Jati, Juazeiro do Norte, Lavras da Mangabeira, Mauriti, Milagres, Missão Velha, Nova Olinda, Penaforte, Porteiras, Salitre, Santana do Cariri and Várzea Alegre. The Cariri region of Ceará is located in the south of the state. It is famous for being home to the Chapada do Araripe National Park, which boasts great biodiversity, as well as important archaeological sites.

**Figure 1** - Ceará's Cariri region




Source: Ceará State Government (2024)

The Cariri Metropolitan Region (RM), covering a total area of 5,456.01 km$^2$, is the second most significant urban region in the state. It became a metropolitan region due to the conurbation formed by the municipalities of Crato, Juazeiro do Norte, and Barbalha, collectively known as CRAJUBAR.

Regarding COVID-19, its distribution is not uniform across the country. While the initial cases were identified in Brazilian capitals, new cases gradually emerged in more distant regions due to community transmission. Notably, the Cariri region in the state of Ceará exhibited a rising trend in COVID-19 cases, emphasizing the need to address its specific characteristics.

### 3.2 Methodological Framework and Data Collection

Regarding the methodological framework, this study adopts a quantitative approach. In terms of objectives, it falls into the descriptive category, utilizing documentary analysis for data collection from official municipal websites, social media platforms, Integrasus, and information requests via e-Sic.

The study relies on commonly used variables to report pandemic response efforts. The Chart 1 provides details on the variables (inputs and outputs) used in the Data Envelopment Analysis (DEA), including data sources and references.

Data collection occurred between January and June 2022, using complete and available data from the transparency reports of the municipalities for the year 2020. Notably, the Cariri metropolitan region exhibited higher incidences and confirmed cases.

These variables informed the efficiency calculation for COVID-19 response among Cariri municipalities, facilitated by Frontier Analyst 4 software.

**Chart 1 - Variables used in the study**

| Inputs | Description | Source of collection | Reference |
|---|---|---|---|
| GasPubPC | Public spending per capita on health | IBGE e TCE/CE | Nunes and Souza (2019), Teles (2018), Oliveira, Mota and Vasconcelos (2022) |
| **Outputs** | **Description** | **Source of collection** | **Reference** |
| INObt | Inverse of the obtained number | DATASUS and municipalities' websites | Shirouyehzad et al. (2020), Ghasemi et al. (2020), Aroeira, |

| | | | |
|---|---|---|---|
| | | | Vilela and Ferreira (2021) |
| NRec1 | Number of recoveries | DATASUS and municipalities' websites | Shirouyehzad et al. (2020); Aroeira, Vilela and Ferreira (2020). |
| INNot | Inverse of the number of notified cases | DATASUS and municipalities' websites | Breitenbach et al (2020). |
| INCasCon | Inverse of the number of confirmed cases | DATASUS and municipalities' websites | Aroeira, Vilela and Ferreira (2020); Ghasemi et al. (2020); Shirouyehzad et al. (2020) |
| IEGM_Saúde | Municipal Management Effectiveness Index - Health Indicator | TCE/CE | Oliveira, Mota and Vasconcelos (2022) |

Source: Adapted by the authors, 2022.

Some variables are inversely related to efficiency, i.e. the lower the number of deaths, notified cases and confirmed cases, the more efficient the management. The indicators are similar to the inverse infant mortality rate, which was used as an output in the studies by Politelo, Rigo and Hein (2015) and Oliveira, Mota and Vasconcelos (2022).

### 3.3 DEA models and data analysis

Debreu's analysis of productivity (1951) gave rise to studies on the Economic Theory of Efficiency. Farrel (1957) explored the subject in greater depth and came up with the assertion that an organization's efficiency consists of generating the maximum possible number of products (outputs) with a given set of inputs.

Farrell's (1957) pioneering work on efficiency analysis began with his seminal research at the Royal Statistical Society, when he proposed a method for measuring the technical efficiency of firms and industries. This pioneering work became the basis for the development of data envelopment analysis by Charnes, Cooper and Rhodes (1978), who developed the first mathematical model for the DEA methodology called CCR (Ferreira and Silva, 2015).

The CCR develops a non-parametric piecewise linear surface involving the data. The model devised by Charnes, Cooper and Rhodes (1978) considers a technology with constant returns to scale to be valid, specified by a series of restrictions that allow for flexibility in the weights assigned to inputs and outputs. Thus, the model assigns the efficiency level of each Decision-Making Unit (DMU) by optimizing the ratio between the weighted sum of the level of outputs and the weighted sum of the inputs used, whose solution implies obtaining the values of v1 and ur, which represent the weights or relative importance of each input and product. In view of the above, the CCR captures the combination of supplies and products that obtains the best productive alternative for the DMU evaluated. The efficiency of the i-th DMU has the following form:

$$Max\ Eff_0 = \sum_{j=1}^{s} u_j y_{j0} \Big/ \sum_{i=1}^{r} v_i x_{i0} \qquad (1)$$

Fractional programming is an obvious problem for the conditions presented, which must be solved for each DMU, but the solution is in linearized form:

$$Max_{\phi\lambda} = \phi$$

$$x_{i0} - \sum_{j=1}^{n} \lambda_j x_{ij} \geq 0$$

$$\sum_{j=1}^{n} \lambda_j y_{rj} - y_{r0} \geq 0$$

$$\lambda_j = 0 \qquad (2)$$

Where $\phi$ represents the efficiency measure of the ith DMU. Therefore, if the value of $\phi$ is equal to one, the DMU will be efficient; if the DMU is inefficient, the value of $\phi$ will be less than one. The parameter $\lambda_j$ represents the vector of weights used in the linear combination of efficient DMUs.

Banker, Charnes and Cooper (1984) then idealized the CCR model, presenting the hypothesis of variable returns to scale. For Mello et al. (2005), models with variable returns to scale correspond to an extension of the model with constant returns to scale (CCR). The approach introduces the convexity constraint to the CCR model to replace the axiom of proportionality between inputs and outputs, so that the production possibility frontier becomes convex. The BCC model can be represented by means of a linear programming solution:

$$Max_{\phi\lambda} = \phi$$

$$x_{i0} - \sum_{j=1}^{n} \lambda_j x_{ij} \geq 0$$

$$\sum_{j=1}^{n} \lambda_j y_{rj} - \phi y_{r0} \geq 0$$

$$\sum_{j=1}^{n} \lambda_j = 1;\ \lambda_j \geq 0 \qquad (3)$$

Where $\sum_{j=1}^{n} \lambda_j = 1$ of order (Nx1) corresponds to the convexity constraint imposed on the CCR model.

In the BCC, the efficiency frontier forms a convex surface through the intersection of points, which is more compact than the surface formed by the constant returns model. Thus, the efficiencies achieved by the variable returns to scale model are superior to the scores obtained by the constant returns approach.

DEA has been adopted to analyze the performance of DMUs that use the same types of supplies (*inputs*) to produce the same goods and/or services (*outputs*). Municipalities can therefore be included in the DMU concept, as demonstrated by Oliveira, Mota and Vasconcelos (2022).

According to Mello et al. (2005), applying DEA requires three stages. The first consists of selecting and defining the DMUs, in this case the municipalities in the Cariri region of Ceará. The second stage involves selecting the variables used in the DEA. The selection of the variables adopted in the research took into account their adoption in previous studies in the area (Table 2), with the data referring to 2020. The third stage is the selection and application of the model. In this research it was chosen to use the DEA-BCC model, oriented

towards outputs, by Banker et al (1984), which considers variable returns to scale.

In the processing of DEA, the DEA-BCC model with an output orientation was adopted, aiming to achieve the best results based on the same input levels (Oliveira, Mota, & Vasconcelos, 2022).

In order to group the DMUs by level of efficiency, a cluster analysis was subsequently performed, which constitutes an empirical and objective method to carry out one of the most natural tasks of humans - classification (HAIR et al,. 2009). Thus, through this technique, an attempt was made to promote the grouping of municipalities in the Cariri region of Ceará, based on the efficiency level calculated through DEA, leading to the formation of four groups (Mota, Oliveira, & Vasconcelos, 2021).

Finally, for the data analysis using the DEA method, Frontier Analyst software, version 4, was utilized. For the statistical analyses, Jamovi 2.2.5 was used, and for the cluster analysis, IBM SPSS Statistics 20 was employed.

## 4 Results

Initially, a descriptive analysis of the variables was conducted. This type of approach allows for a better understanding of the data behavior, identifying trends, variability, and outlier values (Fávero et al., 2009). Table 1 describes the descriptive statistics of each variable used in the study.

**Table 1** - Descriptive statistics of the study variables

| Variable | Minimum | Maximum | Average | Standard deviation |
|---|---|---|---|---|
| GasPubPC | 522.52 | 2655.31 | 907.23 | 411.72 |
| INObt | 0.00 | 0.500 | 0.114 | 0.135 |
| Nrec | 29 | 16075 | 1659 | 3370.2 |
| INNot | 0.0007 | 0.003 | 0.00002 | 0.0008 |
| INCasCon | 0.0001 | 0.0132 | 0.0028 | 0.0033 |
| IEGM_Saúde | 24 | 81 | 65.0 | 12.7 |

Legend: GasPubPC: Per capita public health expenditure; INObt100: Inverse of the number of deaths; NRec: Number of recoveries; INNotPC: Inverse of the number of notifications; INCasCon: Inverse of the number of confirmed COVID-19 cases; IEGM_Health: Municipal Management Effectiveness Index - Health Indicator.

Source: Prepared by the authors, 2022.

The total per capita health expenditure in 2020 varied from R$ 2,655.31 (Barbalha) to R$ 522.52 (Mauriti). The maximum and minimum values of municipal expenditures highlight the heterogeneity of the data used in the DEA, which is also evidenced by the contrast between the extreme values of the other variables.

Additionally, the average of R$ 907.23 reflects the increase in *per capita* health expenditure, notably due to the COVID-19 pandemic. According to a study by Oliveira, Mota, and Vasconcelos (2022), the average per capita spending of the 36 most populous municipalities in Ceará was R$ 235.34 in the period of 2015 and 2016, and R$ 237.68 in 2017 to 2018. The COVID-19 pandemic was a significant factor in the increase, however, even with the urgency it demanded, there was a lack of speed in the release and execution of the new funds approved by the National Congress (Servo et al., 2021).

The variable number of deaths shows considerable discrepancies. While the DMU Jati reported no deaths in 2020, the municipalities of Farias Brito (134), Juazeiro do Norte (120), Barbalha (105), and Milagres (102) reported the highest numbers per 100,000 inhabitants. These findings differ from those of Morais et al. (2021), who, when analyzing the epidemiological data of COVID-19 cases in the Cariri Cearense metropolitan region, found an average fatality rate of 1.8%. The extended study period from January 1, 2020, to February 24, 2021, and the small number of municipalities, only 9, may justify the higher rate.

Regarding the importance of using this variable, Pinho and Carvalho (2021) argue that due to discrepancies in the availability of tests, not only at the beginning of the pandemic, case-based indicators are fundamentally incomparable. Thus, while death indicators have their own issues, they provide a more secure basis for comparative analyses.

In relation to the variable number of recoveries, it was found that while Jati recorded 29 recoveries, the municipality of Juazeiro do Norte recorded the highest number, with 16,075. It is important to note that a higher number of recoveries does not necessarily indicate success in combating the pandemic, as it fails to take into account that the number of recoveries has simply increased due to a very high number of infections (Caponi, 2021). Additionally, individuals with COVID-19 may develop various long-term effects. It is crucial to consider the pressing issues in response to the pandemic and its impact on future expenditures (Servo et al., 2021).

The number of confirmed cases shows discrepancies, with Antonina do Norte reporting 10.3, while the municipality of Farias Brito reported 70.35 per 1000 inhabitants. The latter also presented a higher fatality rate during the period, indicating that the higher the number of confirmed cases, the greater the number of deaths (Cavalcante et al., 2020).

When comparing with recent data, notably between May 17th and June 17th, 2022, the findings of this study differ from an article by Cesário (2022), as the author found that Barbalha led in the incidence of COVID-19 cases in the Cariri region. According to data from the IntegraSUS platform of the Health Department of Ceará (Sesa), it registered an incidence rate of 164 cases per 100,000 inhabitants. Table 2 presents the results of the efficiency calculation of each DMU, carried out through DEA, and their respective rankings of efficiency.

**Table 2 -** Efficiency of the municipalities in the sample

| Ranking | DMU | Efficiency level | Ranking | DMU | Efficiency level |
|---|---|---|---|---|---|
| 1st | Antonina do Norte | 100.0 | 14th | Salitre | 92.0 |
| 1st | Crato | 100.0 | 15th | Nova Olinda | 91.8 |
| 1st | Farias Brito | 100.0 | 16th | Várzea Alegre | 90.6 |
| 1st | Jati | 100.0 | 17th | Lavras da Mangabeira | 87.0 |
| 1st | Juazeiro do Norte | 100.0 | 18th | Jardim | 85.3 |
| 1st | Milagres | 100.0 | 19th | Barbalha | 85.2 |
| 1st | Mauriti | 100.0 | 20th | Araripe | 81.6 |
| 1st | Penaforte | 100.0 | 21st | Brejo Santo | 80.7 |
| 9th | Missão Velha | 98.0 | 22nd | Campos Sales | 79.3 |
| 10th | Aurora | 96.7 | 23rd | Santana do Cariri | 77.6 |
| 11th | Porteiras | 96.4 | 24th | Caririaçu | 75.0 |
| 12th | Granjeiro | 93.8 | 25th | Abaiara | 74.4 |
| 13th | Assaré | 92.0 | 26th | Altaneira | 57.3 |

Source: Prepared by the authors, 2022.

According to Table 2, the calculation pointed out that 8 municipalities reached the efficiency frontier. Among the efficient DMUs, the two largest cities in the region, Juazeiro do Norte and Crato, are present. The positioning of the municipalities occurred mainly due to the high IEGM_Health and the number of recoveries.

The IEGM indicator is obtained through the application of a questionnaire to the municipalities and aims to assess the effectiveness of municipal management. The organized data are subsequently confirmed by technicians from the state audit court (Oliveira, Mota, & Vasconcelos, 2022).

It allows for performance comparison, identification of best practices, and consequently, contributes to improving municipal efficiency (Araújo et al., 2015). Lastly, it is ensured that the Municipal Management Effectiveness Index (IEGM) is an effective performance indicator for this evaluation (Ramos et al., 2021), notably in the context of the COVID-19 pandemic.

Furthermore, three of the smallest municipalities in the region, Antonina do Norte, Jati, and Penaforte, also reached the efficiency frontier, primarily due to the low number of deaths, which were 2, 1, and 4, respectively. The results differ from those of Campos et al. (2021), as the authors, when assessing the vulnerability of the 853 municipalities in the state of Minas Gerais (MG), found that small municipalities are the most vulnerable. However, it is worth noting that the authors consider demographic, social, economic, health infrastructure, at-risk population, and epidemiological characteristics.

The results of Barbalha are noteworthy, as in a pre-pandemic study by Oliveira, Mota, and Vasconcelos (2022), the municipality ranked first, even though it was not the highest spender on healthcare. However, it must be clarified that in the context of COVID-19, pole cities that attract the largest number of hospitals and professionals tend to receive more residents from smaller areas seeking employment, education, and even medical treatment, thus creating a possible route for the virus to enter these areas (Bacchiegga and Vasconcellos, 2021).

On average, the efficiency level was 89.8, which differs from the results of Aroeira, Vilela, and Ferreira (2020), as the clinical efficiency index was 0.76 and the managerial efficiency was 0.65. Moreover, the same authors, when assessing the clinical and managerial efficiency of SUS hospitals in treating COVID-19 in municipalities in 2021, found improvements in the managerial (0.86) and clinical (0.67) efficiency indices.

**Table 3** - Improvement potential of DMUs

| Variável | Potencial de melhoria (%) |
|---|---|
| GasPubPC (I) | -3.48 |
| INObt (O) | 8.85 |
| NRec (O) | 14.05 |
| 1NNot (O) | 40.97 |
| IEGM (O) | 5.98 |
| NCasCon1000 (O) | 26.67 |

Source: Prepared by the authors, 2022.

As seen in Table 3, in the inefficient DMUs, the number of notified cases is the variable that deserves the most attention, with a reduction of 49.97% being needed for the whole group to become efficient. The number of confirmed and recovered cases needs to be reduced by 26.67% and 14.05% respectively. The results indicate that efficiency is related to the need to reduce contagion and, consequently, deaths by 8.85%.

The variable *spending per capita* on health showed a waste of 3.48%. In this sense, concerning waste at the federal level, Souza (2021) assures that when it comes to the acquisition of chloroquine and hydroxychloroquine, the allocative priority of managers

seems contradictory, for even with the distribution of medicines, the pandemic was spreading, with a continuous increase in cases and deaths. In addition, the author believes that the use of funds for the wrong priorities could have an impact on the underfunding of the SUS, as they will have to pay the bill for the waste.

Next, the municipalities were grouped according to the efficiency calculated using DEA (Table 2). To this end, and based on the clusters analysis, it was possible to identify four groups with different efficiency ranges. Table 4 shows the distribution of the DMUs.

**Table 4 -** Groups of DMUs by efficiency level

| Efficiency Range | DMU | Number of DMUs | Proportion (%) |
|---|---|---|---|
| 0 ≤ x ≤ 57,30 | Altaneira | 1 | 3.8 |
| 57,31 < x ≤ 81,60 | Araripe, Brejo Santo, Abaiara, Campos Sales, Caririaçu e Santana do Cariri | 6 | 23.1 |
| 81,61 < x ≤ 93,80 | Granjeiro, Assaré, Salitre, Nova Olinda, Várzea Alegre, Lavras da Mangabeira, Jardim e Barbalha | 8 | 30.8 |
| 93,81 < x ≤ 100 | Antonina do Norte, Crato, Farias Brito, Jati, Juazeiro do Norte, Milagres, Mauriti, Penaforte, Missão Velha, Aurora e Porteiras | 11 | 42.3 |

Source: Prepared by the authors, 2022

The distribution of DMUs by efficiency level (Table 4) shows a greater concentration of municipalities in the last group (11), followed by the second group (8) and the third (6). Only Altaneira was classified in the last group. The main causes are the number of deaths, notifications and confirmations, as well as the IEGM_Saúde variable, which had an index of only 41 points.

The best level of efficiency does not necessarily occur in the municipalities that spent the most *per capita* on health, since Barbalha and Granjeiro are in 1st and 2nd place among those that spent the most, however, they have medium-high and medium-low indexes of efficiency, with scores of 85.20 and 93.80, respectively. On the other hand, Juazeiro do Norte and Mauriti were the 5th and 6th to spend the least, but had the highest level of efficiency.

The results are similar to those of Oliveira, Mota and Vasconcelos (2022), who found in their study that Caucaia, Quixadá and Russas, for example, were not among those that spent the most resources, but had the best scores.

Queiroz *et al.* (2013) made a similar finding, as the most inefficient DMU was the one that made the largest expenditures, indicating that inefficiency is correlated with the quality of resource management. According to Tasca *et al.* (2022), the lack of planning and orderly response mechanisms to deal with the pandemic, especially by the federal government, has increased the management difficulties of municipalities and states, limiting the coordination of health managers with other sectors involved.

## Conclusions

Considering the relevance of municipalities in the context of Brazilian public health,

especially during the COVID-19 pandemic, not only because of their mission to coordinate and plan the SUS at the municipal level, in compliance with federal regulations, but also because of their relevant role in providing health care to the population affected by the disease. This study analyzed the performance of 26 municipalities in the Cariri region of Ceará against the COVID-19 outbreak through data envelopment analysis (DEA).

The results revealed that 8 of the 26 municipalities analyzed reached the 100% efficiency index. It was also found that the municipality of Barbalha, which stood out in research before the pandemic, such as that by Oliveira, Mota and Vasconcelos (2022), fell short in this study. The research revealed that, among the municipalities that reached the efficiency frontier, there is no predominance of a specific size, as is the case with the municipalities with the lowest efficiency levels.

When comparing the list of municipalities rated as efficient in other studies, it was found that the best level of efficiency is not necessarily found in those with the highest expenditure per capita on health, a similar result was found in the studies by Queiroz et al. (2013).

It is worth noting that, with regard to the improvements to be implemented in the group of municipalities in order to reach the efficiency frontier, it was found that the number of notifications is the variable that deserves the most attention, with a 49.97% reduction needed for the entire sample group to become efficient.

The number of confirmed and recovered cases needs to be significantly reduced. The results indicate that efficiency is related to the need to reduce contagion and, consequently, deaths from COVID-19. This last point reinforces the argument of Pinho and Carvalho (2021), since the authors assure the importance of indicators based on the number of deaths for the effectiveness of studies trying to assess the impacts of the pandemic.

Once the findings of the research have been observed at a regional level in Brazil, the methodology and comparative analysis can be replicated elsewhere at an international level, in order to see how managers perform in the allocation of public resources, considering the variables analyzed. It will be possible to carry out comparative studies, taking into account the characteristics of each country.

One of the limitations of the research is that at the time of collection, complete data was not available for all 29 municipalities in the Cariri region, limiting it to just 26. Another point worth noting is that the efficiency calculated using DEA did not take into account the rates of social isolation, transparency of information on spending and the fight against the pandemic. In addition, the number of ICU beds available could not be taken into account as this information is not available in active transparency.

As a suggestion for future research, it would be advisable to add new management and clinical indicators to the model, as well as other municipalities in the region. A further suggestion is to try to find out the link between the level of efficiency, information transparency related to COVID-19, immunization levels and social isolation, which have not been investigated in this research. Finally, we suggest including new variables such as the number of health professionals in each municipality.

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