ISSN: 2447-3359

REVISTA DE GEOCIÊNCIAS DO NORDESTE

Northeast Geosciences Journal

v. 11, nº 2 (2025)

https://doi.org/10.21680/2447-3359.2025v11n2ID41384

Efficiency of monitoring the bathing quality of the Fortaleza coast: analysis of the period from 2019 to 2021

Eficiência do monitoramento da balneabilidade da costa marítima de Fortaleza: análise do período de 2019 a 2021

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Abstract: The suitability of the coast for bathing is of great importance to society in several dimensions. There are many challenges in balancing the various conflicting interests in this environmental area. The State Environmental Superintendence of Ceará develops the Beach Suitability Monitoring Program, with the main objective of monitoring the quality of beach waters for primary use; with a greater scope of monitoring points on the coast of Fortaleza. The objective of this study was to analyze the efficiency of monitoring the coast of Fortaleza, and used the Data Envelopment Analysis (DEA) technique as an instrument for analyzing relative efficiency. DEA uses decision-making units (DMU) to analyze their performance in using their inputs to produce outputs. Five different analysis scenarios were used, taking as DMUs the three years of management of the Bathing Suitability Program (2019 to 2021). The results showed that the lowest efficiency result in all scenarios was 82.30% (most efficiencies were 100%) and that therefore the monitoring of the bathing suitability of the Fortaleza coast can be considered efficient given the chosen sample, but there is room for improvements to be implemented.

Keywords: monitoring; sea coast; water quality.

Resumo: A balneabilidade da costa marítima tem grande importância para a sociedade em várias dimensões. Muitos são os desafios para equilibrar os diversos interesses conflitantes nesta área ambiental. A Superintendência Estadual do Meio Ambiente do Ceará, desenvolve o Programa de Monitoramento Balneabilidade das Praias, com objetivo principal de monitorar a qualidade das águas das praias para o uso primário; com abrangência maior de pontos de monitoramento na orla de Fortaleza. O objetivo deste estudo foi analisar a eficiência do monitoramento da orla marítima de Fortaleza, e utilizou a técnica de Análise Envoltória de Dados (DEA) como instrumento de análise de eficiência relativa. A DEA utiliza unidades de decisão (DMU) analisando o desempenho destas na utilização de suas entradas (inputs) para produzir as saídas (outputs). Foram utilizados 5 cenários diferentes de análise, tomando como DMUs os três anos de gestão do Programa de Balneabilidade (2019 a 2021). Os resultados mostraram que o menor resultado de eficiência em todos os cenários foi de 82,30% (a maioria das eficiências foi de 100%) e que portanto o monitoramento da balneabilidade da costa marítima de Fortaleza pode ser considerado eficiente diante da amostra escolhida, mas há espaço para melhorias serem implementadas.

Palavras-chave: monitoramento; costa marítima; balneabilidade.

Recebido: 06/09/2025; Aceito: 03/12/2025; Publicado: 14/12/2025.

1. Introduction

The Brazilian coastal zone has strategic importance evident in several aspects. Conflicting interests over its use allow scientific debates that can support decisions capable of improving the scenario caused by anthropogenic actions. The proper use of beach water in a given coastal zone is determined by its bathing suitability. However, this suitability may be affected by anthropogenic actions or urban expansion along the coastline (MARQUES *et al*., 2024).

The National Environmental Council (CONAMA), through Resolutions No. 274/2000 and No. 374/2005, establishes criteria for bathing suitability and provides guidance on the monitoring foundations for beach water quality in Brazil (BRASIL, 2000; 2005). The state of Ceará, through the Ceará State Environmental Superintendence (SEMACE), implements the Beach Bathing Monitoring Program, whose main objective is to monitor beach water quality in the state (SEMACE, 2019).

By 2021, 32 sampling points had been established exclusively for beaches in the capital and 34 points for the remaining beaches across the state of Ceará (SEMACE, 2022). The National Environmental Council (CONAMA), in Resolution No. 1/1986, considers environmental impact to be essentially linked to human activities that cause any alteration in the physical, chemical, or biological properties of the environment (BRASIL, 1986). Coelho (2004) defines environmental impact as a process of social and ecological changes caused by disturbances in the environment.

Unplanned urbanization in coastal zones brings negative impacts to the environment, including factors related to sanitary safety and tourism economics (MOURA, 2009). According to Kobiyama and Mota (2008), water resources are understood as sources of essential economic value for the development of living beings. However, the analysis of anthropogenic activities and their impacts on coastal water resources must consider the entire environmental context and the forms in which these actions occur, whether punctual or not (RIBEIRO *et al*., 2007). Ceará is one of the Brazilian states with the highest occupation of coastal areas, with a high level of commercial exploitation linked to tourism (CAMPOS *et al*., 2003; MARQUES *et al*., 2024). Analyses of issues related to anthropogenic actions are fundamental for the sustainable maintenance of bathing suitability in coastal regions (GRAND *et al*., 2017).

Ruckelshaus *et al*. (2020) conducted studies in Switzerland and China and observed this issue of anthropogenic actions in coastal regions. Zheng *et al*. (2020) developed studies on innovations in coastal zone monitoring using data technologies to support public management decisions. Thus, it becomes important to discuss the efficiency of the monitoring conducted by the Ceará Beach Bathing Monitoring Program.

This leads to the research question: Can the monitoring of bathing suitability along the maritime coast of Fortaleza between 2019 and 2021 be considered efficient? The analysis period is justified by the transition between the pre-pandemic and pandemic phases caused by the COVID-19 virus.

The general objective of this study is to analyze the efficiency of bathing suitability monitoring on the beaches of Fortaleza, Ceará. The specific objectives are: (i) to analyze the Beach Bathing Monitoring Program from 2019 to 2021, focusing on information about Fortaleza; (ii) to conduct a quantitative analysis of the sample data for the period, applying Data Envelopment Analysis (DEA) to obtain new information regarding the efficiency of bathing suitability monitoring on Fortaleza's beaches from 2019 to 2021; and (iii) to conduct a qualitative analysis of the information gathered regarding the efficiency of bathing suitability monitoring on Fortaleza's beaches from 2019 to 2021.

From a methodological perspective, this research is exploratory and allows the development of a descriptive investigation (PRODANOV; FREITAS, 2013). The study incorporates both quantitative and qualitative methods. Mathematical and interpretative treatment of the results was performed with respect to applicable legislation. Efficiency calculations were conducted using the technique known as Data Envelopment Analysis (DEA), applying different observation scenarios and data treatment for the sample.

1.1 Coastal Zone and Bathing Suitability

According to Dias and Oliveira (2013, p. 372), the scenario of abundant environmental wealth that characterizes the coastal zone is also described as follows: "Ecosystems that alternate among mangroves, beaches, dune fields, estuaries, and other environments, thus constituting an area of significant natural richness."

The coastal zone contains areas that are particularly sensitive and fragile from an ecosystem perspective, comprising a series of environments restricted to this system of interaction among water, land, and air (AMBIENTE, 2020). According to Brazilian Presidential Decree No. 5,300 of December 7, 2004, the Brazilian coastal zone is delimited by a maritime strip and a terrestrial strip (BRASIL, 2004).

Several studies have shown the influence of human activities on the alteration of the natural landscape of the Coastal Zone, with notable contributions from Kawakubo *et al*. (2003), Silva *et al*. (2008), Meireles (2008), Paula *et al*. (2013), Dias and Oliveira (2013), Lima and Amaral (2013), and Silva and Farias Filho (2015). It is important to advance the discussion on good management and protection practices for this ecosystem environment. Kobiyama and Mota (2008) highlight the need for effective management of water resources in all natural environments, emphasizing coastal zones in their analyses. A review of ScienceDirect–Elsevier data revealed few studies that address the evaluation of data mining methods in Environmental Data Science or the use of mathematical models related to the application of Data Envelopment Analysis, which could be applied to coastal zone studies. Such applications would represent innovative approaches to this topic (GIBERT *et al*., 2018).

In Brazil, one of the states with the highest coastal zone occupation is Ceará, which currently reaches an occupation rate of 49.22%, resulting in one of the highest population densities in the country (CAMPOS *et al*., 2003). As in the rest of the world, this high level of occupation imposes strong environmental stress related to the use of this geographic region (GRUBER; BARBOZA; NICOLODI, 2003). Within this context, the accelerated urbanization of the Fortaleza coastline, the capital of Ceará, becomes evident (RODRIGUES, 2016).

Regarding the rational planning and management of land use and occupation in the coastal zone, the existence of constant monitoring of these spaces becomes important and necessary (SILVA, 2019). Urbanization along Fortaleza's seafront is the oldest in the state and was therefore disorganized. Its coastal real estate configuration was transformed by the impact of tourism-related economic activities, especially in the second half of the twentieth century (QUEIROZ, 2017).

The bathing suitability of a coastal zone has a direct impact on human health and well-being (BRASIL, 2000). According to Berg, Guercio, and Ulbricht (2013, p. 8), bathing suitability is defined as follows:

> Bathing suitability is the capacity of a location to allow bathing and sports activities in its waters; in other words, it is the quality of waters intended for primary-contact recreation. Bathing suitability is determined by the concentration of coliform bacteria present in the water. The analysis quantifies total and fecal coliforms, Escherichia coli, and/or Enterococci. (BERG; GUERCIO; ULBRICHT, 2013, p. 8).

This definition shows that bathing suitability in beach regions is directly linked to primary contact. This fact underscores the need for careful attention to coastal water quality. The World Health Organization states that, among all diseases affecting developing countries, approximately 80% are related to poor water quality (ARRUDA *et al*., 2016).

Anthropogenic actions combined with the lack of coastal resource management in certain regions of Brazil generate negative impacts on beach bathing suitability results (MARTINS *et al*., 2017). Valiela (1991), in his classic work, also demonstrates that population accumulation places significant pressure on coastal resources. Moreover, the problem of coastal eutrophication is associated with any activity in which the natural conditions of the watershed are altered due to urban expansion (MOURA; BOAVENTURA; PINELLI, 2010).

Therefore, the coastal zone is the area with the greatest accumulation of synergistic negative impacts caused by human activity, with tourism being one of the main contributors. Although it is not the only activity exerting pressure on ecosystems and social systems, tourism has received special attention due to its accelerated expansion, consuming increasingly larger spaces (MARQUES *et al*., 2024). Improper anthropogenic actions may lead to social, environmental, and economic impacts, contributing to the unsustainability of tourist destinations (RIOS, 2006).

According to Lemos *et al*. (2002), in the late 1990s most beach huts at Praia do Futuro, on the Fortaleza shoreline, did not have legal sewage connections. This scenario has changed over the years through systematic public interventions, but challenges remain. According to Ferreira, Andrade, and Costa (2013), in Fortaleza the stormwater drainage system is separate from the sewage system. In this case, stormwater is discharged directly into the sea, revealing the irregularity of the sewage system in this important coastal region (PAIVA *et al*., 2025). In some cases, stormwater mixes with polluting elements found in stormwater galleries, rendering an area of high social and tourist flow unsuitable for primary contact (MARQUES *et al*., 2024).

The assessment of anthropogenic impacts on the coastal zone must determine whether human actions or economic activities collectively produce positive or negative outcomes (VASCONCELOS; CORIOLANO, 2008).

Studying and monitoring surface water quality is essential for understanding conditions related to anthropogenic activities occurring in the region. This requires the implementation of an environmental quality monitoring program designed to allow systematic tracking of spatiotemporal variations within the ecosystem (GODÓI, 2008). According to Bitar and Ortega (1998), environmental monitoring consists of performing specific measurements and/or observations directed toward a few key indicators and parameters, with the purpose of verifying whether certain environmental impacts are occurring.

The state of Ceará has made efforts toward broad action in integrated coastal management, such as through the Environmental Spatial Project (PEA), which carries out coastline mapping, an important initiative for supporting public decision-making and policy development (SEMA, 2025). The state also operates the Beach Bathing Monitoring Program, whose primary objective is to monitor beach water quality in accordance with Resolutions No. 274/2000 and No. 374/2005.

This service is developed and conducted by the Ceará State Environmental Superintendence (SEMACE). The present study is limited to monitoring the beaches of the municipality of Fortaleza. According to SEMACE (2022), the Beach Bathing Monitoring Program monitors 32 points along the coastline of the state capital. These points are shown in Figure 1 below:

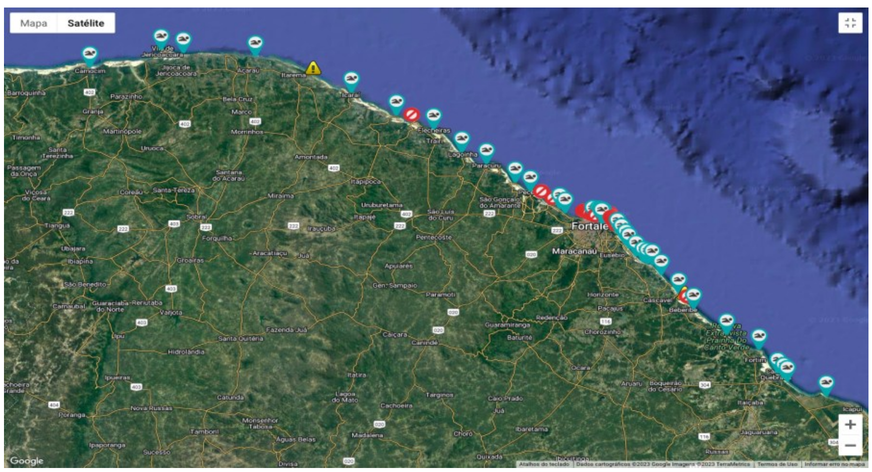

Figure 1 – Bathing Water Quality Monitoring Points for Ceará Beaches. Source: SEMACE (2022).

The Fortaleza shoreline was divided into three major sectors within the Bathing Suitability Monitoring Program, thereby improving the organization of sampling reports through sectors that enable targeted actions to improve bathing suitability indices. Sampling is conducted weekly, and the 32 sampling points are distributed almost evenly across the three sectors, named: Eastern Sector, Central Sector, and Western Sector (SEMACE, 2022). It is noted that the efficiency of this program has a direct impact on the level of beach bathing suitability and may support specific public-sector decisions.

The bibliographic analysis previously discussed in this study revealed that few works on the efficiency of bathing suitability monitoring have been developed using Data Envelopment Analysis. The study by Gambiroža *et al*. (2025) identifies limitations in traditional monitoring based solely on the analysis of fecal indicator bacteria and presents a proposal for a predictive approach associated with additional quantitative techniques aimed at providing more immediate results.

Thus, implementing a quantitative analysis is highly relevant for the bathing suitability context. It can be stated that there is clear value in developing studies on monitoring efficiency using the DEA technique, which is recognized in numerous investigations for its methodological robustness.

2. Methodology

The methodology to be used, from the perspective of its objectives, refers to an exploratory study, as it is also a case study that seeks to develop further information on the subject addressed (PRODANOV; FREITAS, 2013).

The study is descriptive in nature because it is based on the analysis of secondary data regarding the monitoring of bathing suitability on the beaches of Fortaleza (CE). It is also assumed that a quantitative approach will be applied for the treatment of mathematical data, and a qualitative approach will be used for interpreting these results in comparison with federal and state regulations pertinent to the topic under study.

The aim of the research is to analyze the efficiency of bathing suitability monitoring on the beaches of Fortaleza between 2019 and 2021. To achieve this aim, the following methodological steps are proposed: (i) Data collection on bathing suitability monitoring on the beaches of Fortaleza between 2019 and 2021; (ii) Implementation of Data Envelopment Analysis (DEA) to calculate monitoring efficiency for the selected period; (iii) Tabulation of results in descriptive form; (iv) Qualitative analysis of the results; (v) Critical conclusion by the author.

Data Envelopment Analysis, also known as DEA, is a nonparametric approach that evaluates the relationship between various outputs and inputs belonging to the same productive unit. It essentially measures the productive efficiency of these units in using their inputs to generate the reported outputs (CASADO; SOUZA, 2007; PÉRICO; SANTANA; REBELATTO, 2017).

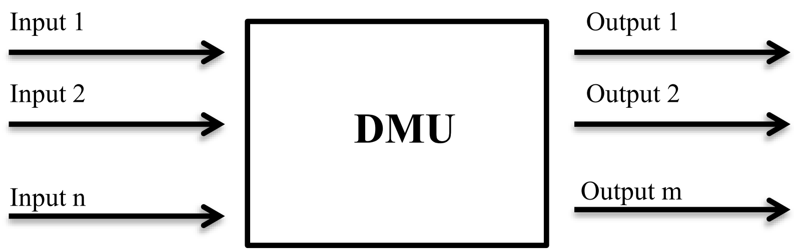

Figure 2 – Basic structure of a DMU.
Source: prepared by the author. Adapted from (PÉRICO, SANTANA, REBELATTO, 2017).

The main studies on DEA identify the productive unit as a Decision Making Unit (DMU). The DMU, also understood as a decision unit, is responsible for processing certain inputs and delivering certain outputs. Figure 2 shows the basic structure of a DMU and the general framework of the analysis performed by DEA. This technique evaluates the level of relative efficiency of independent productive units (compared to a reference within the studied sample), allowing inputs and outputs to be examined together.

The number of inputs and outputs is not necessarily the same, and multiple combinations of inputs and outputs may exist within a DMU. In this efficiency-calculation framework, the concept of productivity is related to the ratio between what is produced and the quantity of inputs used to generate these outputs (CASADO; SOUZA, 2007). The concept of efficiency refers to the ability of a DMU to achieve the best possible result with minimal waste of the inputs associated with that output (MERKERT; ASSAF, 2015).

Depending on the number of inputs and outputs involved in the DEA calculations, it may be necessary to assign weights multiplied by the input and output values in the efficiency-calculation process, as presented below in the equations (CASADO; SOUZA, 2007):

(i) Eficiência = $\frac{Saídas}{Entradas}$

(ii) Eficiência da unidade B = $\frac{u1y1b + u2y2b + \ldots}{v1x1b + v2x2b + \ldots}$

Onde temos que:
u_1 = o peso relacionado a saída 1
y_{1b} = valor da saída 1 da unidade b
v_1 = peso relacionado a entrada 1
x_{1b} = valor da entrada 1 da unidade b.

The efficiency to be calculated receives a value from 0 to 100%, or from 0 to 1. Efficiency calculations in Data Envelopment Analysis can be performed, among other means, using Excel, and allow the detection of efficiency gaps —

that is, how far a productive unit is from the most efficient one — thus enabling a qualitative analysis of possible strategies for efficiency improvement. In this context, this gap is also referred to as relative efficiency, because it is below 100% efficiency, which is considered full efficiency when compared to the other DMUs used in the evaluation (MERKERT; ASSAF, 2015). After processing the data using the efficiency calculation technique, a qualitative analysis of the results is conducted and compared with specific information from the scenario under study.

A widely used application model for Data Envelopment Analysis proposes the following steps (CASADO; SOUZA, 2007): (i) Definition of the DMUs; (ii) Definition of the most appropriate inputs and outputs for the analysis scenario; and (iii) Implementation of the DEA technique and analysis of results.

3. Results and discussion

The following values define each input and output to be used in the DMUs when applying the DEA calculation:

a) **DMU 1** – Management of the Beach Bathing Suitability Monitoring Program – 2019 Period; **INPUTS:** (i) Number of samples collected in the period – 2019: **1,455** e (ii) Monitoring Density of Beach Bathing Suitability in Fortaleza – 2019: **2.58**; **OUTPUTS:** (i) Bathing Suitability – Number of results classified as suitable for bathing (Fortaleza) – 2019: **644** e (ii) Number of bathing suitability bulletins issued in 2019: **62**
b) **DMU 2** – Management of the Beach Bathing Suitability Monitoring Program – 2020 Period; **INPUTS:** (i) Number of samples collected in the period – 2020: **1,043** e (ii) Monitoring Density of Beach Bathing Suitability in Fortaleza – 2020: **2.66**; **OUTPUTS:** (i) Bathing Suitability – Number of results classified as suitable for bathing (Fortaleza) – 2020: **548** e (ii) Number of bathing suitability bulletins issued in 2020: **36**
c) **DMU 3** – Management of the Beach Bathing Suitability Monitoring Program – 2021 Period; **INPUTS:** (i) Number of samples collected in the period – 2021: **1,315** e (ii) Monitoring Density of Beach Bathing Suitability in Fortaleza – 2021: **2.66**; **OUTPUTS:** (i) Bathing Suitability – Number of results classified as suitable for bathing (Fortaleza) – 2021: **717** e (ii) Number of bathing suitability bulletins issued in 2021: **45**

DEA allows the development of different analysis scenarios in which inputs and outputs can be combined to expand the analytical possibilities for the chosen sample. Thus, five implementation scenarios were proposed, each with its respective efficiency results and potential improvement targets. In each scenario, inputs and outputs were combined differently based on the values listed in Tables 1 and 2.

The results for each DEA analysis scenario are presented below:

a) **Scenario 1:** Two inputs and two outputs were combined, representing all available variables for the DEA model. All DMUs achieved 100% efficiency in Scenario 1, meaning full efficiency was reached by all units. The inputs were used in the best possible manner within the analyzed sample.
b) **Scenario 2:** Scenario 2 compared input 1 with output 1 to verify DMU efficiency. DMU2 and DMU3 achieved full efficiency, while DMU1 showed a relative efficiency of 82.30%. This is considered a good efficiency level, as it is close to the efficiency frontier reached by DMU2 and DMU3. In absolute terms, the DEA indicates that with 258 fewer samples, DMU1 would have achieved full efficiency, producing the same output 1 result of 644 suitable-for-bathing points.
c) **Scenario 3:** Scenario 3 evaluated DMU efficiency using input 1 and output 2. In this case, DMU1 and DMU2 reached full efficiency. DMU3 showed a relative efficiency of 90.16% compared to the other DMUs. The slack calculated by DEA indicated that with approximately 130 fewer samples (equivalent to about one month of work) relative to the 2021 collection total, DMU3 would reach the same efficiency level as DMUs 1 and 2.
d) **Scenario 4:** Beginning with Scenario 4, input 2 is tested as the sole input in the DEA model. This is considered a parameter with low potential variation compared with input 1 (number of samples collected), an important point for a more refined analysis. In this scenario, only DMU2 did not achieve full efficiency, reaching a relative efficiency of approximately 97%.
e) **Scenario 5:** In this final scenario, input 2 was compared with output 2 to analyze the selected DMUs. Only DMU1 reached full efficiency. DMU2 and DMU3 showed identical relative efficiency values, approximately 97%. This is the same efficiency level recorded for DMU2 in Scenario 4, where it was the only DMU that did not reach the efficiency frontier. Therefore, in both scenarios where input 2 was the sole input, the DMU that did not reach full efficiency presented the same relative efficiency value of 96.99%.

4. Final considerations

Given the objectives proposed for this research, the main conclusions are presented below. By examining each scenario individually, the following conclusions can be drawn:

a) **Scenario 1:**

In this scenario, it is concluded that no managerial interventions are needed to improve the efficiency of the Beach Bathing Suitability Monitoring Program, as full efficiency has already been achieved. Maintaining current performance levels is sufficient to sustain total efficiency in each management period analyzed.

b) **Scenario 2:**

It is observed that during the period corresponding to DMU1 many points were classified as unsuitable for bathing. A significant number of unsuitable points requires further investigation and targeted public policy interventions to improve the bathing suitability index of the beaches. It is also believed that a deeper analysis of this scenario would enable the program's management to make preventive decisions in future situations with similar patterns.

c) **Scenario 3:**

Although DMU3 presented a high relative efficiency value, this scenario highlights the need for better investigation of the relationship between sample collection activities for bathing suitability analysis and the number of bulletins issued, in order to assess whether any resource waste occurs in these processes.

d) **Scenario 4:**

It is understood that the impacts generated by the COVID-19 pandemic were decisive for the results in this scenario. Even so, relative efficiency remained very high, indicating that moderate interventions aimed at improving performance indicators could have resulted in full efficiency. It is concluded here that changes in the bathing suitability monitoring density have limited influence on variations in efficiency results.

e) **Scenario 5:**

It is observed that the COVID-19 pandemic did not significantly affect the efficiency of the Beach Bathing Suitability Monitoring Program, as DMUs 2 and 3 achieved very high relative efficiency values. It is concluded that moderate public policy interventions could already yield significant improvements toward achieving full efficiency.

Taking a global view of the scenarios proposed for this study's results, it is understood that the efficiency of the Beach Bathing Suitability Monitoring Program—focusing on the city of Fortaleza—demonstrated high efficiency levels. Among all the scenarios analyzed, the lowest efficiency recorded in the DEA calculations was 82.30% (DMU1 in Scenario 2). This indicates that even with the various combinations of inputs and outputs used to generate different analytical perspectives, the resulting relative efficiency values remain very high.

It is therefore concluded that the research question was answered and that both the general and specific objectives of this study were achieved. The data on beach bathing suitability monitoring in Fortaleza were processed using the Data Envelopment Analysis technique, followed by qualitative analysis and interpretation of the chosen sample. These steps led to the conclusion that high efficiency levels were observed.

Nevertheless, the monitoring of bathing suitability along the coastline of Fortaleza still presents opportunities for improvement so that the satisfactory results identified in this study may be maintained and progressively enhanced. Consequently, several dimensions of Fortaleza's society stand to benefit from increasing efficiency.

Acknowledgments

To the Ceará Foundation for the Support of Scientific and Technological Development (Funcap) for the financial support through the maintenance of the scholarship, which made this research possible.

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