International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 15 Issue 07 , July - 2026

Data Envelopment Analysis Model to Evaluate Health Regions Efficiency of Uttrakhand (India)

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Abstract - The main emphasize of this study to evaluate the efficiency of healthcare regions in India from a period 2021-2025 by employs Data Envelopment Analysis (DEA). The study takes a regional approach, offering a holistic view of the entire healthcare system. Inputs such as number of beds, physicians, and nurses, along with outputs like outpatients and inpatients, were considered. The study not only provides efficiency scores but also identifies reference health regions, benchmarks, and tangible targets for improvement. The findings contribute to the understanding of regional healthcare dynamics, offering actionable insights for policymakers, facilitating evidence-based resource allocation, and informing strategies for continuous improvement. Future research directions include a global benchmarking analysis and a qualitative exploration of policy implications. This study bridges the gap between academic research and practical policy considerations, emphasizing the importance of adaptability and resilience in healthcare systems.

Key elements- efficiency scores, policymakers, qualitative exploration

1. INTRODUCTION

We reviewed recent research on the efficiency of public healthcare systems using DEA, which is one of the leading methods for efficiency analysis. Through a systematic review, we investigated research trends in terms of research purposes, specific DEA techniques.

For the successful management and effective operation of the public healthcare system, objective and accurate measurement of the efficiency of the public healthcare system is required. When the level of efficiency of the system is objectively and properly diagnosed, problems can be identified and solutions can be developed based on them. Efficiency has long been an important research area in operations and service management. Researchers have been using several methods to measure efficiency. Data Envelopment Analysis (DEA) is one of the most widely adopted techniques, and DEA is a non-parametric method that has been used to measure the efficiency of various social and economic systems [1]. Through DEA, the efficiency of a Decision-Making Unit (DMU) can be measured and the levels of efficiency of different DMUs can be compared [2]. Research on the public healthcare industry has also employed DEA to analyze the efficiency of healthcare systems. Ever since Nunamaker, T.R [3]'s initial study that measured the efficiency of nursing services using DEA, various studies analyzed efficiencies using DEA in the healthcare industry [4,5]. Applying the efficiency concept to the healthcare industry, which is based on the primary public interest of human health, is by no means straightforward [6]. However, many researchers have successfully conducted empirical studies analyzing the efficiency of healthcare services and systems using DEA [6]. DEA has now been positioned as a leading method for efficiency analysis in the public healthcare sector [6,7], and healthcare research has become one of the research areas that most actively uses DEA [7,8]. As a result, there has been a gradual increase in the use of the DEA method to measure the efficiency of the public health field. With the recent COVID-19 crisis, the importance of measuring efficiency in the public health sector is expected to increase even further. Therefore, we review the recent studies in the public healthcare area that analyzed the efficiency using DEA.

Many countries are trying to establish a public healthcare system that can effectively cope with the pandemic. With this shifting healthcare environment, great attention is being paid to the efficient allocation and utilization of limited medical resources [9].

Indian healthcare system has undergone significant development in the recent years. However, concerns regarding efficiency and resource utilization persist. Several studies have employed DEA to analyze the efficiency of specific healthcare entities such as public hospitals [10–12]. These studies have provided valuable insights into individual hospital performance but lack a comprehensive picture of the healthcare system at the regional level. This study aims to address this gap by applying DEA to evaluate the efficiency of healthcare system at the regional level. This macro-level approach offers several advantages:

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 15 Issue 07 , July - 2026

Holistic perspective: By analyzing regional performance, we gain a broader understanding of the overall healthcare system's efficiency, capturing inter-regional variations and potential disparities.

Policy-relevant insights: Evaluating regional efficiency provides valuable insights for policymakers to formulate targeted interventions and resource allocation strategies for specific regions.

Addressing equity concerns: A regional focus allows for identifying potential inequities in healthcare access and resource distribution across different regions.

By utilizing DEA, this study will identify efficient and inefficient health regions. In fact, benchmarking regional performance against the best practices will reveal areas excelling in efficiency and those requiring improvement. In addition, the decomposing inefficiency within each region will pinpoint areas needing targeted interventions, such as resource allocation, operational improvements, or capacity building. Furthermore, the findings will provide valuable evidence to inform policymakers in formulating strategies for enhancing regional healthcare efficiency and ensuring equitable access to quality care across the country.

2. METHODOLOGY

2.1 . Data Envelopment Analysis:

DEA is a non-parametric method for evaluating performance and to determine the relative efficiency of a group of comparable Decision-Making Units (DMUs) [13]. The DEA utilizes linear programming methods to analyze observed inputs and outputs by constructing an efficient production frontier derived from optimal practices. Each DMU's efficiency is assessed in comparison to this frontier. In mathematical terms, let x_{ij} and y_{rj} denote the inputs and outputs of a DMU j, respectively with m inputs, s outputs, and n DMUs. The output-oriented DEA model measuring the efficiency of a given DMU k is:

$$\text{Min}E_k = \frac{\sum_{i=1}^{m} v_i x_{ik}}{\sum_{r=1}^{s} u_r y_{rk}} \qquad (1)$$

Subject to

$$\frac{\sum_{i=1}^{m} v_i x_{ik}}{\sum_{r=1}^{s} u_r y_{rk}} \geq 1; j = 1,2, \dots \dots \dots . n$$

and $\text{u}_\text{r}, v_i \geq 0 \; \forall \, r, i$

Where u_r indicates the weight assigned to the output r and v_i is the weight assigned to the input i, Model (1) is a fractional programming model converted into linear programming, as follows:

$$\text{Min}E_k = \sum_{i=1}^{m} v_i x_{ik} \qquad (2)$$

Subject to

$$\sum_{r=1}^{s} u_r y_{\text{rk}} = 1$$

and $\sum_{i=1}^{m} v_i x_{ik} - \sum_{r=1}^{s} u_r y_{\text{rk}} \geq 0; j = 1,2, \dots \dots \dots n$

$\text{u}_\text{r}, v_i \geq 0 \; \forall \, r, i$

2.2. Data

The main emphasize of this study to examine the efficiency of hospital management in all health regions of Uttarakhand (UK). The DEA method is utilized to assess the efficiency of resource utilization in delivering high-quality healthcare. DEA has been utilized in numerous studies to assess efficiency [14]. Government of UK prioritizes providing strong healthcare services to its population. For the most recent financial year, the UK government allocated 6.4% of its total expenditure to health. This is slightly higher than the average health allocation of all other Indian states. As of 2022, Uttarakhand has 696 government hospitals,

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ISSN: 2278-0181
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showing a steady increase in public health infrastructure. The state's public system includes 13 district hospitals, 79 community health centres (CHCs), 578 primary health centres (PHCs), and several specialized, private hospitals like the Himalayan Institute Hospital Trust and Shri Guru Ram Rai Institute of Medical Sciences. [18-20]

Public health facilities are distributed between two sectors: governmental sectors and the private sector. Health facilities are categorized based on their mission, equipment, technical level, and territorial competence. They include primary health care centers, hospitals, specialized units (such as cardiology, oncology, diabetes, and endocrinology), central and regional laboratories, and clinics (such as smoking cessation). In this study, all 13 district wise health regions are considered DMUs for the efficiency of DEA measurements.

2.3. Input and Output Selection

While holding immense potential, big data in healthcare faces challenges like security, privacy, and integrating diverse data sources effectively. A. Alghamdi at all [15] review the use and effectiveness of data analytics in healthcare, examining secondary data sources such as books, journals, and other reputable publications between 2000 and 2020. The main challenge when using DEA to evaluate hospital efficiency, as in other real-world scenarios, is the careful selection of appropriate inputs and outputs. This topic is still commonly debated. In a recent preprint [16], a systematic review of 80 articles on DEA application in hospitals, specifically examining input and output selection methods, was conducted. The review categorizes hospital efficiency inputs into three groups:

Capacity-related, cost-related, and staff-related, and outputs into two groups: production-related and quality-related. This study focuses on the number of beds (Bs), physicians (Ps), and nurses (Ns) as key factors in healthcare provision. Beds represent physical space for patient care, physicians are medical doctors providing care, diagnosis, and treatment, and nurses include registered nurses and other professionals offering direct patient care. These variables make up the largest percentage of usage in their specific categories. Cost-related inputs were omitted because they are not available. The outputs chosen for this study were the total number of outpatients (Os) and the total number of inpatients (Is). These outputs represent the count of individuals receiving medical services at a hospital without being admitted and those admitted for treatment or surgical procedures requiring an overnight stay, respectively. According to [16], these outputs are commonly used to measure hospital efficiency. The data related to the corresponding regions' inputs and outputs during the 5 years from 2021 to 2025 were collected from statistical yearbooks downloaded from the official website. The data collection process was challenging due to the need to gather information from multiple files for each year of study. Therefore, careful selection, arrangement, and organization were required to create a consolidated, grouped file.

2.4. RESULTS

Between 2021 and 2025, the efficiency of the 13 district wise health regions in UK was evaluated about the performance of their respective hospitals. Max DEA software was used. The efficiency scores and their relative means are presented in Table I.

S.N0	DMUs	2021	2022	2023	2024	2025	Mean
1	Chamoli	0.637	0.695	0.681	0.746	0.762	0.7041
2	Dehradun	0.94	0.935	0.846	0.868	0.786	0.8752
3	Haridwar	0.676	0.549	0.527	0.724	0.847	0.6423
4	Pauri	0.593	0.66	0.654	0.688	0.692	0.6574
5	Rudraprayag	0.761	0.72	0.597	0.698	0.76	0.7073
6	Tehri	0.896	1	1	1	1	0.8992
7	Uttarkashi	0.91	1	0.741	0.731	0.867	0.8497
8	Almora	0.705	0.634	0.659	0.693	0.686	0.6754
9	Bageshwar	0.64	0.759	0.752	0.67	0.957	0.7557
10	Nanital	1	0.988	1	1	1	0.9975
11	Pithoragarh	1	1	0.808	0.826	0.734	0.8737
12	Champawat	0.66	0.535	0.564	0.659	0.565	0.5966
13	Udham Singh Nagar	0.816	0.614	0.569	0.653	0.648	0.66

TABLE I. EFFICIENY SCORES

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ISSN: 2278-0181
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The scores ranged from 0.527 to 1, with a higher score indicating greater efficiency. The average DEA efficiency score for all health regions is 0.7238. The health regions, Tehri and Nanital, demonstrated exceptional efficiency in providing hospital services, achieving a perfect score of 1 on the DEA scale. This achievement is remarkable considering the region's limited healthcare resources, including a low number of physicians, beds, and nurses. The region has the lowest average number of physicians (372) and the second lowest average number of beds and nurses (490 and 1054, respectively). Uttarakhand is often ranked among the "Achievers" in NITI Aayog reports, showing steady incremental progress rather than volatile swings. Another interesting finding refers to the health region Dehradun, the capital of UK. This region ranks is much better over the last five years of study, with an efficiency mean of 0.7041, despite having the highest amounts of inputs and outputs compared to other regions. The health regions Uttarkashi, Nanital and Pithoragarh achieved an efficiency score of 1 at least once over the five year study period, with an overall efficiency mean exceeding 0.9. Tehri and Nainital showed low DEA efficiency scores, whereas Almora and Bageshwar had fluctuating DEA efficiency scores over the study period. It is crucial to mention that DEA efficiency scores are comparative, not definitive. A score of 1 indicates that a health region is the most efficient among those included in the study, not necessarily perfectly efficient. Figure 1 shows the distribution of obtained efficiency means by health region.

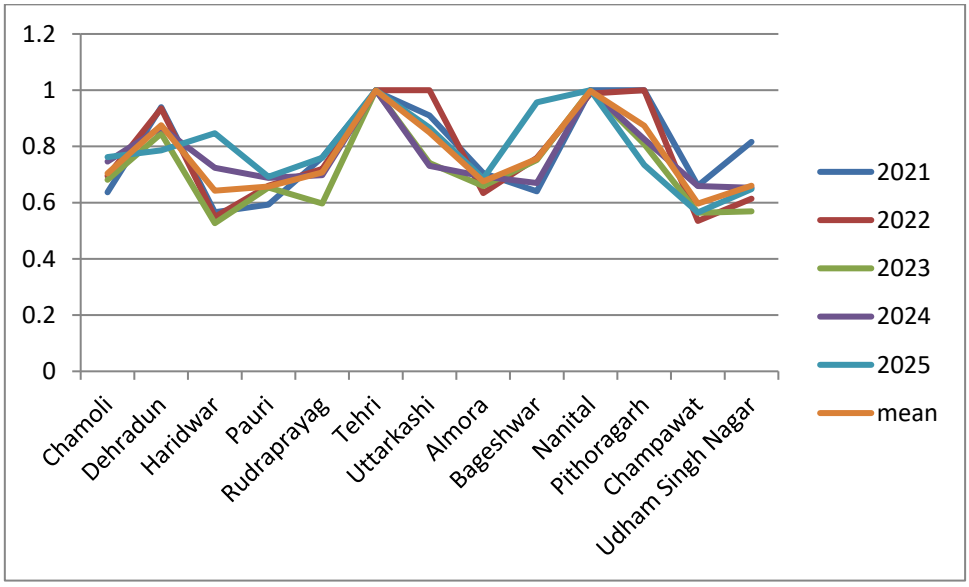

Fig. 1- efficiency means by health region

At this point, it is important to investigate the possible correlation between the number of hospitals and the efficiency scores in each health region. Increasing the number of hospitals could have advantages such as enhanced accessibility and specialization. However, it may also result in greater complexity in management and challenges in distributing resources. By computing the coefficient of correlation - 0.17 is obtained, indicating that there is no significant relationship between these two variables. This outcome also suggests the possibility that additional external factors, such as the size of the hospital, the distribution of specializations, and the density of the regional population, may have an impact on the obtained efficiency scores. Regrettably, the unavailability of relevant data prevents us from accomplishing this task in the current study.

3. ANALYSIS AND DISCUSSION

From Table I, the efficiency mean for each year of the study could be deduced (Fig. 2). Between 2021 and 2025, UK state hospital's mean efficiency scores showed a dynamic trajectory. Following a peak in 2021, the score somewhat increased in 2022 before declining in 2023 and 2024. Interestingly, 2025 saw a notable resurgence to 0.8320.

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ISSN: 2278-0181
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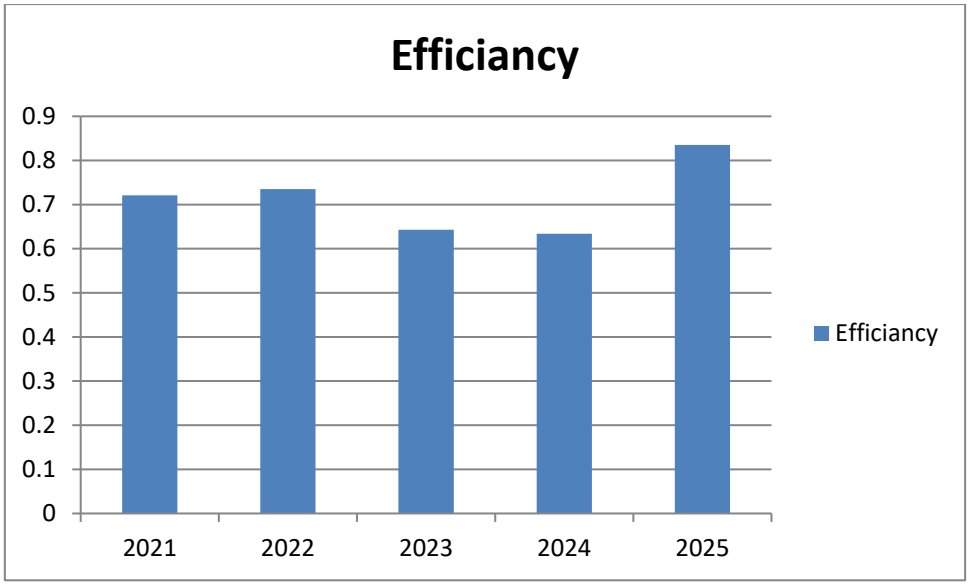

Fig. 2. Efficiency means for each year of the study

However, the effect of the COVID pandemic in 2021 on healthcare services may account for a portion of the observed fluctuations. The pandemic probably put a strain on systems, changed how resources were allocated, and required modifications to protocols, which may have an impact on the variations in efficiency scores from year to year. The deviation of the efficiency score averages can be better understood by examining changes in the input and output amounts. It is evident from the same figure that 2021– 2022 saw a significant decline in output, particularly in terms of the overall number of outpatients. The fact that the COVID pandemic peaked in this particular year may explain this. Actually, unexpected disruptions in the health-care systems brought on by the pandemic, which affected almost every nation on the globe, not just India, may directly affect the way that patients register as both inpatients and outpatients. The impact of the COVID on health decisions in hospitals was discussed in [17]. UK government health centre have taken many preventative measures to safeguard public health during COVID pandemic. This included postponing non-urgent surgeries to shield vulnerable patients from potential infections, prioritizing critical cases in hospitals while directing others to healthcare centers, and introducing a mobile application allowing residents to book appointments, review healthcare providers, and obtain prescriptions remotely. These measures aimed to curb the spread of the virus and prioritize the well-being of the citizens. The 2021 recovery could be seen as the hospitals' adaptive efficiency in response to the crisis. This year, the total number of outpatients and inpatients almost reached the levels seen before the pandemic. Between 2021 and 2022, there was a slight rise in the number of physicians. Since the main objective is to find a way to improve efficiency among inefficient DMUs, measuring efficiency is more of a means than a goal. One of the advantages of the DEA is that it illustrates the extent to which inefficient DMUs can outperform other DMUs by decreasing the quantity of its inputs or increasing the quantity of its outputs. One approach to this is through the use of a dual model. Using the dual of model (2), this study ascertains potential improvements that inefficient health regions can achieve.

The explicit model is described as Max φ subject to the condition

$$\varphi\, y_{rk} - \sum_{j=1}^{n} \lambda_j y_{rj} \leq 0; r = 1,2, \ldots \ldots s$$

And $\sum_{j=1}^{n} \lambda_j x_{ij} - x_{ik} \leq 0; i = 1,2, \ldots \ldots m; \lambda_j \geq 0, j = 1,2, \ldots \ldots n$

In this model, φ is scalar, such that φ^{-1} represents the proportional increase that will be simultaneously applied to all outputs of the
k^{th} region to make it efficient? Thus, the value of φ^{-1} obtained from resolving this model defines the efficiency score of the k^{th} region. If ($\varphi = 1$), this DMU is considered efficient and inefficient if ($\varphi > 1$); $\varphi^{-1} \in [0, 1]$.

The previous section measured the efficiency scores of the 13 district health regions. Only three regions, represented by DMUs 5, 9, and 11, were found to be efficient in 2025, such that while maintaining their current input and output values, these regions can be considered as references for the other inefficient regions. Table II lists the target values of inputs and outputs for the 10

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ISSN: 2278-0181
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inefficient regions. In other words, this table provides the possible input and output adjustments that these can apply to achieve perfect efficiency. As an example, let us consider the region of Haridwar, denoted by DMU 3. Its efficiency score for 2021 was 0.676, as shown in Table I. To enhance efficiency in this region, the following objectives need to be met: 1037 beds, 1206 physicians, and 5976 nurses in Table II. This region might maintain consistent output levels. Forcing individuals to visit a specific hospital in a particular region to ensure its efficiency is unreasonable. Alternatively, decision-makers in an inefficient health region with given resources can be encouraged to make efforts to take more patients. Table II also provides the reference health region that each inefficient region is compared with in calculating their efficiency scores, in addition to their respective possible benchmarks.

X^*	DMU/Reg	DMU(s) of reference	Benchmark	Target amount				
				beds (Bs)	physicians (Ps)	nurses (Ns)	outpatients (Os)	inpatients (Is)
1	Chamoli	5; 9	0.2857; 0.5787	801	837	1349	235184	37392
2	Dehradun	5; 9; 11	1.2018; 0.4567; 2.052	1947	2131	4047	661524	127154
3	Haridwar	5; 11	0.6321; 0.4176	1037	1206	5976	352190	66551
4	Pauri	5; 9; 11	0.4128; 0.3576; 0.7213	1251	1424	6361	777239	54597
6	Tehri	11	1.0295	671	844	1038	159328	12052
7	Uttarkashi	5	0.7967	964	1062	2265	362443	77719
8	Almora	5	1.3847	1675	1847	3936	629942	135080
10	Nanital	5; 9	0.1374; 0.6973	715	733	1037	189280	24877
12	Champawat	5; 11	0.2409; 1.1247	1024	1243	1819	283654	36667
13	Udham Singh Nagar	5; 9; 11	1.0752; 0.5793; 0.2254	1903	2076	3821	629345	117058

TABLE II. TARGET VALUES OF INPUTS AND OUTPUTS FOR INEFFICIENT REGIONS TO ACHIEVE PERFECT EFFICIENCY

Let us focus on the health region of Haridwar (DMU 3), which is compared to the reference regions of Rudraparyag (DMU 5) and Pithauragarh (DMU 11), with benchmark values of 0.6321 and 0.4176, respectively. Therefore, using the number of beds as an example, the specified target number of beds shown in Table II is calculated as follows:

$$X^*_{Bs(3)} = .6321X^*_{Bs(5)} + .4176X^*_{Bs(11)} = .6321 * 1210 + .4176 * 652 = 1037$$

$$X^*_{Ps(3)} = .6321X^*_{Ps(5)} + .4176X^*_{Ps(11)} = .6321 * 1334 + .4176 * 820 = 1206$$

$$X^*_{Ns(3)} = .6321X^*_{Ns(5)} + .4176X^*_{Ns(11)} = .6321 * 2843 + .4176 * 1009 = 5976$$

$$X^*_{Os(3)} = .6321X^*_{Os(5)} + .4176X^*_{Os(11)} = .6321 * 454931 + .4176 * 154763 = 352190$$

$$X^*_{Is(3)} = .6321X^*_{Is(5)} + .4176X^*_{Is(11)} = .6321 * 97552 + .4176 * 11707 = 66551$$

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
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Where $X^*_{Bs(3)}$denotes the target number of beds for DMU 3, $X^*_{Bs(5)}$ is the current number of beds of DMU 5, and $X^*_{Bs(11)}$ is the current number of beds of DMU 11 ($X^*_{Bs(5)}$; $X^*_{Bs(11)}$; $X^*_{Ps(5)}$; $X^*_{Ps(11)}$; $X^*_{Ns(5)}$; $X^*_{Ns(11)}$; $X^*_{Os(5)}$; $X^*_{Os(11)}$; $X^*_{Is(5)}$ and $X^*_{Is(11)}$ are extracted from Table III).

X^*	DMU/Reg	Current amount				
		beds (Bs)	physicians (Ps)	nurses (Ns)	outpatients (Os)	inpatients (Is)
5	Rudraprayag	1210	1334	2843	454931	97552
9	Bageshwar	787	789	928	181806	16454
11	Pithoragarh	652	820	1009	154763	11707

TABLE III. CURRENT VALUES OF INPUTS AND OUTPUTS FOR EFFICIENT REGIONS (DMUs OF REFERENCE)

By doing so, decision-makers can find areas where they can increase or decrease inputs or outputs to increase efficiency by comparing the current performance to targets. The information gathered can also aid in better resource allocation. Decision makers can give priority to the areas that are located farthest from the efficiency frontier in order to provide them with more resources and assistance. Relevant studies applying DEA to assess the efficiency of the healthcare sector in Uttarakhand have primarily focused on hospital efficiencies. The unique features of the current study compared to prior research can be outlined as follows:

Focusing on regional health efficiency instead of hospital efficiency suggests that using DEA at a regional level can be an effective way to evaluate the efficiency of Saudi Arabia's healthcare system and inform policy decision makers. By studying the practices and strategies of efficient regions, other regions can learn and adopt best practices to improve their own efficiency.

The study's period frame is relatively recent, and its most significant feature is that it includes the COVID pandemic period, which makes it possible to assess its impact on efficiency.

Suggestions for improving efficiency are based on explicit results. Actually, one benefit of the DEA approach is taken advantage of, as evidenced by the identification of reference DMUs and the amounts of inputs that need to be reduced and outputs that need to be increased for the inefficient DMUs.

4. CONCLUSION

This study utilized DEA to evaluate the efficiency of healthcare regions in Uttarakhand, adopting a unique focus on regional efficiency rather than focusing on individual hospitals. Spanning five years and considering inputs such as the number of beds, physicians, and nurses, and outputs including the total number of outpatients and inpatients, the efficiency scores ranged from 0.527 to 1, with an average efficiency score of 0.7238 for all health regions. Notably, the region of Pithauragarh consistently demonstrated exceptional efficiency with a perfect score of 1, despite its limited healthcare resources. The fluctuating efficiency scores observed between 2021 and 2025 reflected the impact of external factors, particularly the second COVID pandemic. The pandemic induced changes in healthcare resource allocation, patient behavior, and operational protocols, influencing the efficiency of healthcare regions. Input Utilization is that the state has improved its ratio of doctors to population, though the concentration remains heavy in Dehradun and Nainital and Outcome Focus is Reductions in the Maternal Mortality Ratio (MMR) and Neonatal Mortality Rate (NMR) are the heaviest weighted factors in these efficiency gain.

One primary contribution of this study is its departure from the conventional hospital-centric approach to efficiency evaluation. The study provides a holistic view of the entire healthcare system, enabling policymakers to identify overarching trends, regional variations, and formulate strategies for system-wide improvement. Additionally, this study uniquely captures the influence of the COVID on healthcare efficiency. By including the pandemic period in the analysis, the research offers valuable insights into the adaptive capacity of the healthcare system during crises and informs strategies for enhancing resilience in the face of unforeseen challenges. Furthermore, explicit suggestions for improvements identify reference health regions and benchmarks, offering decision-makers tangible targets for improvement. This approach empowers regional authorities with actionable insights, facilitating more informed resource allocation and intervention strategies.

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The study's five-year longitudinal analysis provides a dynamic perspective on healthcare efficiency, allowing for the identification of trends and patterns. This contributes to a nuanced understanding of the evolving healthcare landscape, facilitating targeted interventions and adaptive strategies over time. By highlighting these contributions, this study not only advances academic understanding but also provides actionable insights for healthcare policymakers and stakeholders in India, aiding in the continuous improvement of the healthcare system.

In this study, the use of DEA provided valuable insights, but alternative efficiency measurement techniques could be explored in future research to offer a more comprehensive perspective. While this study utilized a comprehensive data set, limitations related to hospital size, specialization distribution, and regional population density, along with other external factors of each health region that could have a significant impact on efficiency scores may be addressed in future research.

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