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Assessing Equity in Healthcare Facility Resource Allocation in Yemen: An Entropy-TOPSIS Analysis

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***Abstract*—**The objective of this study is to investigate the fairness of healthcare facility resource allocation in Yemen and provide insights and suggestions for promoting fairness in their allocation. The Health Resource Concentration and Entropy-TOPSIS models were used to assess the fairness of healthcare facility resource allocation, taking into account the geographical population distribution in Yemen. According to the study, there are disparities in the allocation of healthcare resources in Yemen based on both geographical concentration and population. The governorates of Amanat Al Asimah, Aden, Ibb, Al Mahwit, and Taizz were found to have a higher level of fairness in facility resource allocation than other governorates based on geographical concentration. However, the allocation of health facilities by geographical concentration was deemed unfair, with a very low concentration of health facilities in Al Maharah, Hadramaut, Socotra, Al Jawf, and Shabwah. Additionally, the governorates of Socotra, Amran, Hadramaut, and Al Maharah were found to have a fair allocation of health facilities that can meet the needs of the concentrated population. On the other hand, Sa'ada, Hajjah, and Hudaydah were found to have a shortage of at least 86% of health facility types relative to the population size. The Entropy-TOPSIS model found that Marib, Socotra, Al Maharah, Aden, and Hadramaut had the highest comprehensive health facility resource concentration scores. In light of these findings, the study suggests enhancing the fairness of healthcare facility resource allocation in Yemen by improving coordinated development.

Keywords-Entropy-TOPSIS model; fairness; geographical concentration; healthcare equity, healthcare facilities; healthcare resources; population concentration; resource allocation.

I. INTRODUCTION

Supporting healthcare planning and management, enhancing healthcare system efficiency, improving health outcomes, and ensuring access to quality healthcare services are all crucial for sustainability, as they can lead to a healthier population, a more productive workforce, and a stronger economy [1]. Fairness in healthcare resource allocation is essential for achieving these goals [2]. It helps to ensure that all individuals have equal opportunities to access healthcare services, reduces healthcare disparities, improves health outcomes for disadvantaged populations, and promotes the efficient and effective use of resources [3]. Furthermore, it can contribute to the sustainability of healthcare systems and help build a healthier, more productive, and sustainable society [4]. The equitable allocation of healthcare resources is closely linked to meeting the needs of all individuals in a balanced and equal manner and is an important factor in ensuring a stable and healthy society [5].

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However, the Republic of Yemen faces significant problems related to inadequate and uneven allocation of healthcare resources [6], as well as significant differences in distribution between Yemen's governorates [7]. Many factors exacerbate this problem and its negative effects.

Yemen is a country that has been facing protracted conflict, economic crisis, and political instability [8], [9]. The conflict in Yemen has severely affected the healthcare system, with many health facilities facing difficult working conditions and limited resources and some having been damaged or destroyed [10]. According to the United Nations Office for the Coordination of Humanitarian Affairs (OCHA), as of early 2021, over 50% of Yemen's health facilities had been damaged or destroyed due to ongoing conflict. This has severely impacted the ability of Yemen's healthcare system to provide essential services to the population, leading to a shortage of health facilities and personnel, which has negatively impacted the quality of healthcare services and health outcomes [11]. Additionally, the economic crisis made it difficult for the government to allocate sufficient funds for the healthcare sector, exacerbating an already dire situation.

The ongoing conflict in Yemen, coupled with an economic crisis and political instability, has resulted in a shortage of health facilities, limiting access to quality healthcare services and exacerbating the mismatch between healthcare resource availability and need [7]. This has led to a lack of a fair and equitable allocation of resources. Previous studies indicate that this has resulted in health disparities, particularly in remote or conflict-affected areas, further compounding the challenges faced by vulnerable groups [6–11]. The situation has contributed to increased morbidity and mortality rates, especially among marginalized groups [12], and widened the gap between those with access to quality healthcare services and those without. This situation has become one of the most prominent factors contributing to the cycles of poverty, poor health, and social unrest in Yemen [13].

Therefore, addressing the fairness and equity problem of healthcare facility allocation in Yemen is crucial. Prioritizing the analysis of justice in distribution can help address the negative effects of the inadequate and uneven distribution of healthcare facilities in Yemen and ensure access to quality healthcare services for all.

There have been numerous studies on health equity, with several quantitative methods used to measure the fairness of healthcare resource distribution, including the Gini coefficient, Lorenz curve, Theil index, and concentration index. For example, some studies used the Gini coefficient, Theil index, and concentration index to analyze healthcare resource distribution, while others used the Entropy-TOPSIS method. Yu et al. [14], Pu [15], and Rój [16] used the former methods to study physician allocation in China, the fairness of public medical and health resource distribution, and healthcare resource distribution in Poland, respectively. Meanwhile, Ya-Qing et al. [5] and Li et al. [17] used the Entropy-TOPSIS method to measure medical resource allocation equity in the Yangtze River Economic Belt and to compare health human resource allocation internationally.

The Entropy-TOPSIS method offers several advantages. It can handle both qualitative and quantitative criteria, which leads to a more precise and trustworthy ranking of healthcare resource allocation by considering the relative importance of each criterion. Moreover, it is an impartial tool for attribute evaluation, and its index weight has strong objectivity, ensuring the evaluation conclusion's scientific nature [18]. The TOPSIS method is also effective in solving the multi attribute decision-making problem with finite solutions and can better integrate other methods. When Entropy and TOPSIS are combined, they provide a clear evaluation principle, strong operability, and a wide range of adaptation [19]. This approach has been successfully used in many cases and does not impose strict restrictions on data distribution or sample size [20].

Therefore, while all quantitative methods have their own strengths and limitations, the entropy-TOPSIS method is a promising approach for measuring the fairness of healthcare resource allocation and can provide valuable insights for policymakers.

A. Problem Statement

To achieve a fair allocation of healthcare resources in Yemen, it is crucial to overcome the challenges that hinder the effectiveness of the resource allocation management system. Therefore, it is of utmost importance to analyze the differences in the distribution and availability of health facility resources. Despite previous research efforts, the issue of fair health facility allocation in Yemen remains unresolved, and several challenges persist.

However, the lack of local studies specifically addressing this issue limits our understanding of the challenges related to the fair allocation of health resources and infrastructure. While previous research has addressed aspects of health resources and infrastructure, equity in distribution remains unresolved.

For example, a study conducted by Naseeb Qirbi and Sharif A. Ismail [21] discusses the impact of armed conflict on the health system and health outcomes in Yemen. Another study [22] highlights the devastating impact of the ongoing war in Yemen on maternal and child health and the urgent need to secure essential resources. A study [23] estimated access to healthcare facilities in Yemen using geospatial analysis. A fourth study [24] analyzes the impact of conflict on electricity setups and healthcare facilities in Yemen and reveals that most facilities have no electricity.

While these studies focus on different aspects of healthcare delivery and access, their findings collectively highlight the challenges that the Yemeni healthcare system faces. For

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instance, the study by Qirbi and Ismail [21] concludes that the conflict in Yemen has resulted in a humanitarian disaster on a large scale in a short period of time and calls for the planning of longer-term health system reconstruction. The study by Carrasco et al. [23] reveals that access to healthcare facilities in Yemen is limited, and travel time to the nearest healthcare facility is often long. The study by Al-Mekhlafi et al. [24] shows that most healthcare facilities in Yemen have no electricity, which can significantly affect the quality of care provided.

Additionally, there is a scarcity of local studies that utilize decision support techniques and MCDM approaches to analyze and address such types of evaluation and analysis problems. Limited local studies exist, such as [25–33]. However, this lack of utilization of advanced techniques may prevent decision-makers from making informed and effective decisions regarding the allocation of healthcare resources in Yemen. Therefore, there is a need for further research in this area that focuses on local studies and utilizes advanced decision support techniques to address the problem of fair health facility allocation in Yemen.

This will provide valuable information by identifying gaps and disparities in the allocation of related resources, which can help decision-makers in healthcare planning and management. By implementing a fair and effective allocation system, Yemen can ensure the sustainability of its healthcare system and improve the health outcomes of its population.

B. Objectives of the Study

The objective of this study is to investigate the fairness of healthcare facility resource allocation in Yemen using the entropy weight TOPSIS method. The study aims to provide valuable insights into the allocation of healthcare facility resources in Yemen and to offer guidance for promoting the development of healthcare initiatives in the country.

The study is organized as follows: In Section 2, the materials and methods utilized in the study are described. Section 3 presents the results obtained from the investigation. Section 4 comprises the discussion, where the findings are analyzed and interpreted. Finally, the study concludes with a comprehensive summary of its key findings and their potential implications for future research.

II. MATERIALS AND METHODS

A. Data Source

The study focused on Yemeni governorates as the research subjects, as shown in Table 1. The Central Statistical Organization (CSO) estimated the population and geographic area (in KM2) of the governorates, which are also displayed in the table. The research data, including health facility data, the CSO estimated population for 2023, and geographic areas, were obtained from various sources: HeRAMS-MoPHP, Yemen HeRAMS Dataset 2020: List of Health Facilities [34]; UNFPA-Yemen, Population Projection Dataset, Final, 2023 [35]; National Information Center [36]; and Statistical Yearbook-2022 of the Central Statistical Organization [37].

To evaluate the performance of health facilities in each governorate, the study used a set of performance data on the number of primary health care centers and clinics, the number of primary health care complexes and units, the total number of secondary health care district hospitals, and the total number of tertiary health care hospitals among all governorates. This set of data was defined using [34]. The study also included a set of performance data on the total number of beds, the total number of private drug stores and pharmacies, and the total number of private laboratories, which were obtained using [37]. The CSO estimated population and the geographic area in square kilometers for each set were calculated using [35] and [36], respectively.

B. Criteria selection

To assess the fairness of health facility resource allocation in Yemen, this study utilized available datasets on health facilities and indicator data [34–37]. This study selected a set of indicators that comprehensively reflect the allocation of health facilities, taking into account the availability and relevance of the data. Table 2 displays the key indicators identified by the study to measure and evaluate the fairness of health facility allocation.

TABLE I. THE ESTIMATED POPULATION AND GEOGRAPHIC AREA OF YEMENI GOVERNORATES [35],[36].

Governorate	CSO estimated population for 2023	Geographic area, KM2
Abyan	629000	16943
Aden	1115000	750
Al Bayda	843000	9314
Al Dhale'e	859000	4099
Al Hudaydah	3747000	117145
Al Jawf	656000	39495
Al Maharah	186000	67297
Al Mahwit	797000	2328
Amanat Al Asimah	3769616	390
Amran	1109000	7911
Dhamar	2221000	7586
Hadramaut	1656644	187543
Hajjah	2472000	8227
Ibb	3170000	5552
Lahj	1111000	12648
Marib	384230.9	17405
Raymah	657000	1915
Sa'ada	1290000	11375
Sana'a	1612384	11877
Shabwah	711000	42584
Socotra	75355.67	5489

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Taizz	3556000	10008

C. Measuring tools

1) Measuring Health Facility Concentration and Population Agglomeration

The concentration of health facilities is a metric that quantifies the proportion of medical and healthcare resources that are distributed within a specific geographic area. The calculation formula (1) for this metric is [5],[38]:

$$HFAG_i = \frac{\left(\frac{HF_i}{HF_n}\right) x100\%}{\left(\frac{GA_i}{GA_n}\right) x100\%} = \frac{\left(\frac{HF_i}{GA_i}\right)}{\left(\frac{HF_n}{GA_n}\right)} \quad (1)$$

The equation presented earlier consists of various parameters that reflect different dimensions of health facility distribution in a given governorate (i). is used to denote the level of health facility concentration within a specific governorate. The variable indicates the quantity of a particular type of health facility owned by the governorate (i), while representing the total count of health facilities owned by all governorates in Yemen. Likewise, it denotes the geographic size of the governorate (i), whereas it represents the total geographic area of all governorates.

TABLE II. EQUITY INDICATORS SELECTED FOR THE STUDY OF HEALTH FACILITY RESOURCE ALLOCATION IN YEMEN

C	Equity Indicators
C1	Number of Primary Health Care Centers and Clinics
C2	Number of Primary Health Care Complexes and Units
C3	Total Number of Secondary Health Care-District Hospitals
C4	Total Number of Tertiary Health Care Hospitals
C5	Total Number of Beds
C6	Total Number of Private Drug Stores and Pharmacies
C7	Total Number of Private Laboratories

$$PAG_i = \frac{\left(\frac{PA_i}{PA_n}\right) x100\%}{\left(\frac{GA_i}{GA_n}\right) x100\%} = \frac{\left(\frac{PA_i}{GA_i}\right)}{\left(\frac{PA_n}{GA_n}\right)} \quad (2)$$

This equation consists of four parameters: PAG_i denotes the level of population concentration in a specific governorate (i); GA_i and GA_n denote the geographic size of governorate (i) and the total geographic area of all governorates, respectively. Additionally, PA_i, and PA_n denote the population of a specific governorate and the total population of all governorates, respectively.

The health facility agglomeration degree is a health resource allocation fairness evaluation method that considers both the geographic and population factors of Yemen. Unlike other commonly used methods such as the Gini coefficient and differentiation index, this metric takes into account the concentration of health facilities in relation to the geographic size and population density of particular governorates in Yemen. In this study, the fairness of healthcare resource allocation is assessed by focusing on whether healthcare facilities are distributed equitably across different governorates based on the concentration of healthcare facilities in a geographic area and the concentration of the population in that area.

2) Entropy - TOPSIS model

The Entropy-TOPSIS (Technique for Order Preference by Similarity to the Ideal Solution) method is a multicriteria decision-making approach used to rank alternatives by comparing their performance against a set of criteria. The Entropy-TOPSIS method involves several steps. First, the decision criteria are identified and weighted. Next, the performance of each alternative with respect to each criterion is evaluated and normalized. Then, the entropy measure is used to assess the degree of uncertainty and diversity among the normalized values. After the entropy measure is calculated, the TOPSIS method is applied to rank the alternatives. This involves calculating the distance of each alternative to the ideal and anti-ideal solutions, which represent the best and worst possible outcomes for each criterion. Finally, a closeness coefficient is calculated for each alternative, and the alternatives are ranked based on their proximity to the ideal solution.

The implementation steps of the Entropy-TOPSIS model are as follows [18]:

a) Step 1: Establish a decision matrix X_{ij}.

To establish a decision matrix for evaluating health resource allocation in Yemen, the following steps should be implemented: Identify the alternatives being considered, which in this case are the Yemeni governorates; identify the criteria being evaluated, which in this case are C1-C7; and create a matrix with the governorates as rows and the criteria as columns. Each cell in the matrix will represent the score for the corresponding alternative with respect to the corresponding criterion. Finally, use Equation (3) to define the decision matrix:

$$X_{ij} = \begin{matrix} x_{11} & x_{12} & \ldots. & x_{1n} \\ \ldots & \ldots & \ldots. & \ldots\ldots \\ x_{m1} & x_{m2} & \ldots. & x_{mn} \end{matrix} \quad (3)$$

Each cell (x_{ij}) in the decision matrix represents the score for the corresponding alternative (i), where i=1, 2, …, , m, and the corresponding criterion (j), where j=1,2,..,n. The value of m is the number of governorates being considered, which in this case

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is 22. The value of n is the number of indicators being evaluated, which in this case is 8.

b) Step 2: Construct the normalized matrixP_{ij}

. This involves normalizing the scores in the decision matrix to make them comparable across different criteria. There are various normalization methods that can be used. In this study, the normalization formula (4) was used to normalize the original matrix:

$$p_{ij} = \frac{X_{ij}}{\sum_{i=1}^{m} X_{ij}} \quad (4)$$

c) Step 3: Calculate the entropy value E_j

. Entropy is used to measure the degree of diversity among the normalized scores for each criterion. The entropy value and weight for each criterion are calculated based on the normalized scores using (5).

$$E_j = -K \sum_{i=1}^{m} p_{ij} * ln\ p_{ij} \quad (5)$$

The expression "K" is defined as the inverse of the natural logarithm of the total number of governorates, denoted by "m". This expression is considered stable. The value of "E_j" falls between zero and one. When the information entropy of an indicator is lower, it implies that the indicator value varies significantly. As the amount of information increases, the indicator's weight in the comprehensive evaluation also increases.

d) Step 4: Divergence and Entropy Weights.

. Divergence weights are calculated to reflect the degree of divergence among the normalized scores for each criterion. Entropy weights are then calculated using the divergence weights and the entropy values. Equation (6) is utilized to compute the degrees of divergence (D_j), and (7) to obtain the entropy weight (W_j) of each indicator (j).

$$D_j = 1 - E_j \quad (6)$$

$$W_j = \frac{D_j}{\sum_{j=1}^{n} D_j} \quad (7)$$

e) Step 5: Construct the weighted matrix S_{ij} based on the normalized matrix P_{ij} and the weight of each indicator W_j.

This involves multiplying the normalized scores in the matrix by the corresponding weights to obtain a weighted score for each alternative and criterion.

f) Step 6: Calculate the Euclidean distances

The Euclidean distance is calculated for each alternative with respect to the positive and negative ideal solutions. In this step, the Euclidean distances D_i^+ and D_i^- of each evaluation object from the positive ideal solution S_j^+ and the negative ideal solution S_j^- are calculated using equations (8) and (9).

The positive ideal solution represents the best possible outcome for each criterion, while the negative ideal solution represents the worst possible outcome.

$$D_i^+ = \sqrt{\sum_{j=1}^{n} (s_{ij} - S_j^+)^2}, \qquad S_j^+ = \max\{s_{1j}, s_{1j}, \dots, s_{mj} \quad (8)$$

$$D_i^- = \sqrt{\sum_{j=1}^{n} (s_{ij} - S_j^-)^2}, \qquad S_j^- = \min\{s_{1j}, s_{1j}, \dots, s_{mj} \quad (9)$$

g) Step 7 Compute the composite score index (relative proximity).

In this step, the composite score index (relative proximity) is computed for each alternative. This involves calculating a composite score based on how close the alternative is to the positive and negative ideal solutions. The composite score is calculated using equation (10), which results in a value between 0 and 1. A value closer to 1 indicates that the alternative is closer to the positive ideal solution, indicating a higher level of health resource allocation in the area. On the other hand, a value closer to 0 indicates that the alternative is closer to the negative ideal solution, indicating a lower level of health resource allocation in the area.

$$C_i = \frac{D_i^-}{D_i^+ + D_i^-} \quad (10)$$

D. Data organization and statistical analysis techniques

This study involved performing various statistical analyses and calculations, such as determining the agglomeration degree, and the entropy - TOPSIS analysis. To organize and perform these calculations, the study utilized Microsoft Excel.

III. RESULTS

A. Analysis of the Geographic Allocation of Health Facilities in Yemen

1) Concentration of Fully Operational Health Facilities by Geographic Location

. Table 3 presents the results of the analysis for two types of agglomeration in Yemen: health facility resource agglomeration (HFAG) and population agglomeration (PAG). An HFAG value greater than 1 indicates that health facility resources are distributed more intensively in certain areas, while a value less than 1 suggests that the allocation is insufficient. A value of 1

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means that health facility resources are distributed evenly across the geographical area.

According to the data in Table 3, health facilities in Amanat Al Asimah, Aden, Ibb, Al Mahwit, and Taizz exhibit a significant concentration with a very high HFAG value, ranking them among the top 5 governorates in Yemen. Conversely, Al Maharah, Hadramaut, Socotra, Al Jawf, and Shabwah have HFAG values less than 1, indicating that the allocation of health facilities by geographical area is unfair and that the concentration of health facilities is very low.

TABLE III. THE CONCENTRATION OF HEALTH FACILITIES AND POPULATION IN YEMENI GOVERNORATES

Governorate	C1	R	C2	R	C3	R	C4	R	C5	R	C6	R	C7	R	PAG_i	R
Abyan	0.82	16	1.34	15	1.66	16	0.44	18	0.98	15	0.55	17	1.09	13	0.7	15
Aden	19.99	2	3.85	10	8.34	2	49.6	2	65.4	2	61.9	2	94.6	2	26.8	2
Al Bayda	2.53	12	1.59	14	3.02	11	2.4	11	1.51	14	1.18	13	1.52	10	1.6	13
Al Dhale'e	5.75	7	6.43	5	3.05	9	3.63	8	1.97	11	3.51	7	4.04	5	3.8	9
Al Hudaydah	0.3	19	0.49	18	0.4	19	0.19	21	0.3	20	0.54	18	0.71	15	0.6	16
Al Jawf	0.24	21	0.27	20	0.24	20	0.38	19	0.12	22	0.15	21	0.25	19	0.3	19
Al Maharah	0.07	22	0.09	22	0.14	22	0.11	22	0.14	21	0.08	22	0.09	21	0	22
Al Mahwit	2.76	10	14	2	6.72	3	6.39	6	5.51	5	4.85	4	2.71	8	6.2	6
Amanat Al Asimah	45.3	1	15.8	1	24.1	1	95.4	1	188	1	226	1	153	1	174.2	1
Amran	2.57	11	5.39	8	5.14	6	4.7	7	2.72	8	4.4	5	2.64	9	2.5	10
Dhamar	6.56	6	6.26	6	5.77	5	1.96	13	3.44	6	3.96	6	3.01	7	5.3	8
Hadramaut	0.25	20	0.24	21	0.22	21	0.24	20	0.37	19	0.21	20	0.35	17	0.2	21
Hajjah	2.99	9	5.42	7	3.04	10	3.62	9	3.18	7	2.92	8	3.83	6	5.4	7
Ibb	13.8	3	6.74	4	5.07	7	10.7	4	8.66	3	19	3	12.5	3	10.3	3
Lahj	1.23	13	2.84	12	2.72	13	1.77	14	1.77	13	1.17	14	1.47	11	1.6	14
Marib	0.4	18	0.57	17	2.69	14	2.14	12	1.83	12	0.58	16	0.18	20	0.4	17
Raymah	13.1	4	9.15	3	3.27	8	11.7	3	2	9	2.01	9	1.03	14	6.2	5
Sa'ada	0.99	14	1.78	13	2.2	15	0.65	16	0.76	16	1.61	10	0.35	18	2	12
Sana'a	3.97	8	2.91	11	2.9	12	2.51	10	1.99	10	1.49	11	1.46	12	2.4	11
Shabwah	0.45	17	0.62	16	0.81	17	0.52	17	0.45	17	0.38	19	0.08	22	0.3	18
Socotra	0.98	15	0.43	19	0.57	18	1.36	15	0.38	18	1.02	15	0.36	16	0.2	20
Taizz	8.99	5	4.37	9	5.94	4	7.44	5	6.18	4	1.26	12	4.06	4	6.4	4

Amanat Al Asimah, Aden, Ibb, Al Mahwit, and Taizz have the highest degree of agglomeration for all indicators, except healthcare beds, with a value greater than 2.71. This suggests that health facilities in those areas are excessively concentrated in terms of geographical allocation. Additionally, Raymah, Dhamar, Al Dhale'e, Hajjah, Amran, Sana'a, Al Bayda, and Lahj exhibit a high concentration of all indicators, except for Laboratories in Raymah, Drug Stores, and Pharmacies in Lahj and Al Bayda, with a value greater than 1.46 for all indicators. These areas have an average ranking between 6 and 13 among the 22 governorates.

Furthermore, health facility concentration was low in Al Hudaydah, Al Jawf, Al Maharah, Hadramaut, Shabwah, and Socotra, indicating limited access to healthcare services and an inequitable distribution of health facilities in these areas.

Based on the previous findings, it can be concluded that the allocation of all health facilities by geographic area is not absolutely fair, as there are some limited cases where there is a slight concentration of value, either slightly above or below one. However, this suggests a relative level of equity in distribution. For example, the Abyan, Socotra, and Sa'ada governorates have values slightly lower than one for criterion C1, while the Shabwah governorate has a concentration value of 0.81 for criterion C3, and the Abyan governorate has a concentration value of 0.98 for criterion C5, indicating a relatively low concentration. On the other hand, the Abyan, Socotra, Taiz, Lahj, and Al Bayda governorates have values slightly higher than one for criteria C2 and C4, while the Abyan and Raymah governorates have a concentration value of no more than 1.09 for criterion C7, indicating a relatively low concentration

2) Concentration of Healthcare Facilities by Population

To assess whether health facilities are allocated fairly according to population size, we can use the ratio of the concentration of health facilities to the concentration of the population. A ratio greater than 1 indicates an excess of health

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facilities for the population size, while a ratio less than 1 indicates an insufficient allocation of health facilities relative to the population size. When the ratio is close to 1, it suggests a fair allocation of health facilities according to population size, meeting the healthcare needs of the concentrated population. Table 4 provides additional information regarding this analysis.

According to the analysis, the concentration ratios of primary Health Care Centers and Clinics vary across governorates. Governorates of Socotra, Raymah, Sana'a, Hadramaut, Al Bayda, and Al Dhale'e have ratios greater than 1, indicating a surplus of primary Health Care Centers and Clinics relative to the population size, while Hajjah, Al Hudaydah, Sa'ada, Al Mahwit, and Amanat Al Asimah governorates have ratios less than 1, indicating a shortage of primary Health Care Centers and Clinics relative to the population size. Governorates with ratios close to 1, such as Marib, Abyan, Amran, and Dhamar, suggest a fair allocation of primary Health Care Centers and Clinics that can meet the needs of the concentrated population.

TABLE IV. RATIO OF THE CONCENTRATION OF HEALTH FACILITIES AND THE CONCENTRATION OF POPULATION IN YEMENI GOVERNORATES

Governorate	C1	R	C2	R	C3	R	C4	R	C5	R	C6	R	C7	R
Abyan	1.23	12	2.01	4	2.48	4	0.66	18	1.46	7	0.82	12	1.64	4
Aden	0.75	17	0.14	21	0.31	21	1.85	6	2.44	3	2.31	2	3.53	1
Al Bayda	1.55	5	0.98	15	1.85	7	1.47	9	0.93	12	0.72	17	0.93	10
Al Dhale'e	1.52	6	1.7	8	0.81	15	0.96	16	0.52	19	0.93	11	1.07	8
Al Hudaydah	0.52	19	0.85	18	0.69	17	0.33	21	0.53	18	0.94	10	1.24	6
Al Jawf	0.82	15	0.89	16	0.79	16	1.26	10	0.39	20	0.5	20	0.83	13
Al Maharah	1.44	8	1.89	5	2.8	2	2.22	3	2.77	2	1.66	5	1.88	3
Al Mahwit	0.45	21	2.26	1	1.09	12	1.04	14	0.89	13	0.79	14	0.44	19
Amanat Al Asimah	0.26	22	0.09	22	0.14	22	0.55	19	1.08	9	1.3	8	0.88	12
Amran	1.02	13	2.13	2	2.03	6	1.86	5	1.08	10	1.74	4	1.05	9
Dhamar	1.24	11	1.19	13	1.09	11	0.37	20	0.65	16	0.75	15	0.57	17
Hadramaut	1.56	4	1.52	9	1.36	9	1.5	8	2.33	4	1.31	7	2.22	2
Hajjah	0.55	18	1	14	0.56	18	0.67	17	0.59	17	0.54	19	0.71	14
Ibb	1.34	10	0.65	20	0.49	20	1.04	13	0.84	14	1.85	3	1.21	7
Lahj	0.78	16	1.8	6	1.72	8	1.12	12	1.12	8	0.74	16	0.93	11
Marib	1.01	14	1.44	11	6.78	1	5.37	2	4.6	1	1.45	6	0.46	18
Raymah	2.13	2	1.48	10	0.53	19	1.89	4	0.32	22	0.32	21	0.17	22
Sa'ada	0.48	20	0.87	17	1.08	13	0.32	22	0.37	21	0.79	13	0.17	21
Sana'a	1.62	3	1.19	12	1.18	10	1.02	15	0.81	15	0.61	18	0.6	16
Shabwah	1.5	7	2.07	3	2.69	3	1.74	7	1.48	6	1.26	9	0.28	20
Socotra	3.94	1	1.73	7	2.3	5	5.48	1	1.53	5	4.11	1	1.45	5
Taizz	1.4	9	0.68	19	0.93	14	1.16	11	0.97	11	0.2	22	0.63	15

Regarding the allocation of primary Health Care Complexes and units, Al Mahwit, Amran, Shabwah, Abyan, and Al Maharah have the highest concentrations, indicating a relatively higher concentration of Complexes and units. Amanat Al Asimah, Aden, and Ibb have the lowest ratios, indicating insufficient allocation of Yemeni primary Health Care Complexes and units according to the population size. The ratio of concentration of primary Health Care Complexes and units in Sana'a, Dhamar, Hajjah, Al Bayda, and Al Jawf is close to 1, indicating a fair allocation.

The allocation of District Hospitals based on population size varies across governorates. Marib, Al Maharah, Shabwah, Abyan, Socotra, and Amran have higher concentration levels, indicating a relatively higher number of District Hospitals compared to their population size. On the other hand, the ratio of District Hospitals to population size in Hajjah, Raymah, Ibb, Aden, and Amanat Al Asimah is less than 1, indicating a shortage of District Hospitals in those governorates. Therefore, further optimization in the allocation of District Hospitals in these governorates is necessary to ensure healthcare needs are met.

The allocation of tertiary Health Care hospitals based on population size also varies across governorates. Socotra, Marib, Al Maharah, Raymah, and Amran have higher concentration levels, indicating a relatively higher number of tertiary Health Care hospitals compared to their population size. On the other hand, the ratio of tertiary Health Care hospitals to population size in Sa'ada, Al Hudaydah, Dhamar, Amanat Al Asimah, and

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Abyan is less than 1, indicating a shortage of tertiary Health Care hospitals in those governorates. Therefore, further optimization in the allocation of tertiary Health Care hospitals in these governorates is necessary to meet healthcare needs. The ratio of concentration of tertiary Health Care hospitals in Ibb, Al Mahwit, Sana'a, Al Dhale'e, and Hajjah is close to 1, indicating a fair allocation.

The concentration of beds in Marib, Al Maharah, Aden, and Hadramaut is relatively higher than that in other governorates, indicating a more favorable allocation of beds. Conversely, the ratio of beds to population size in Al Hudaydah, Al Dhale'e, Al Jawf, Sa'ada, and Raymah is less than 1, suggesting a shortage of beds in those governorates. Therefore, optimization of the allocation of beds in those governorates is necessary to meet healthcare needs.

Regarding the allocation of drug stores and pharmacies based on population size, it varies across governorates. Socotra, Aden, Ibb, Amran, and Al Maharah have higher concentration levels, indicating a relatively favorable allocation. Conversely, the ratio of Drug Stores and Pharmacies to population size in Hajjah, Al Jawf, Raymah, and Taizz is less than 1, indicating a shortage of these resources in those governorates. Further optimization in the allocation of Drug Stores and Pharmacies is necessary in those areas.

Finally, the allocation of medical laboratories based on population size also varies across Yemeni governorates. Aden, Hadramaut, Al Maharah, Abyan, and Socotra have a relatively higher number of medical laboratories per person, indicating a favorable allocation. However, the ratio of medical laboratories to population size in Al Mahwit, Shabwah, Sa'ada, and Raymah is less than 1, indicating a shortage of these resources in those governorates. Therefore, further optimization in the allocation of medical laboratories is necessary in those areas to meet healthcare needs.

B. Evaluating Agglomeration Through the Entropy and TOPSIS Models

According to Table 5, the entropy weights assigned to secondary health care district hospitals (C3) and tertiary health care hospitals (C4) in Yemeni governorates are the top two, suggesting that these two resources have a more significant influence on the overall concentration of health facilities in Yemen. In contrast, primary health care centers, clinics, and complexes have the lowest entropy weights, indicating that they contribute the least to the overall concentration level.

The TOPSIS method is utilized to determine the comprehensive score index (relative proximity) C for each governorate. A governorate with a higher comprehensive score index is ranked higher and has a more concentrated allocation of health facilities.

Table 6 shows that Marib, Socotra, Al Maharah, Aden, and Hadramaut occupy positions in the top 5 comprehensive scores, indicating a relatively high level of comprehensive health facility resource concentration in these governorates.

TABLE V. ENTROPY WEIGHTS OF HEALTH FACILITY RESOURCES IN YEMENI GOVERNORATES

	C1	**C2**	**C3**	**C4**	**C5**	**C6**	**C7**
Ej	0.948	0.958	0.900	0.906	0.921	0.933	0.926
Dj	0.052	0.042	0.100	0.094	0.079	0.067	0.074
Wj	0.103	0.084	0.196	0.184	0.156	0.131	0.146
R	6	7	1	2	3	5	4

TABLE VI. COMPREHENSIVE SCORE INDEX AND RANKING OF HEALTH FACILITY RESOURCE AGGLOMERATION IN YEMENI GOVERNORATES

Governorate	D_i^+	D_i^-	C_i	**R**
Abyan	0.046	0.019	0.294	7
Aden	0.047	0.028	0.374	4
Al Bayda	0.049	0.015	0.229	9
Al Dhale'e	0.054	0.011	0.169	13
Al Hudaydah	0.057	0.009	0.135	17
Al Jawf	0.056	0.008	0.132	19
Al Maharah	0.036	0.028	0.432	3
Al Mahwit	0.054	0.010	0.161	15
Amanat Al Asimah	0.058	0.008	0.128	20
Amran	0.045	0.019	0.291	8
Dhamar	0.056	0.009	0.133	18
Hadramaut	0.045	0.022	0.326	5
Hajjah	0.058	0.006	0.093	22
Ibb	0.053	0.013	0.194	11
Lahj	0.050	0.014	0.212	10
Marib	0.026	0.054	0.670	1
Raymah	0.056	0.012	0.176	12
Sa'ada	0.058	0.007	0.103	21
Sana'a	0.053	0.010	0.163	14
Shabwah	0.045	0.020	0.310	6
Socotra	0.034	0.041	0.546	2
Taizz	0.055	0.009	0.145	16

In contrast, Hajjah, Sa'ada, Amanat Al Asimah, Al Jawf, and Dhamar are ranked among the bottom 5 in comprehensive scores, suggesting a low level of comprehensive health facility resource concentration in these governorates.

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IV. DISCUSSION

A. Distribution equity by governorates' geographical area and population varies considerably, and an equitable distribution of health institutions is not currently in place.

According to the allocation of health facility resources in Yemen by geographical area, the concentration of health facilities is highest in Amanat Al Asimah, Aden, Ibb, Al Mahwit, and Taizz, while the concentration of those resources is low in Al Hudaydah, Al Jawf, Al Maharah, Hadramaut, Shabwah, and Socotra. On the other hand, based on population density, the concentration of health facilities is highest in Socotra, Raymah, Sana'a, Hadramaut, Al Bayda, and Al Dhale'e, while the concentration of those resources is low in Hajjah, Al Hudaydah, Sa'ada, Al Mahwit, and Amanat Al Asimah.

These results suggest that there is a significant disparity in the distribution of health facility resources across different regions in Yemen, with some regions having a high concentration of health facilities based on geographical area and others having a high concentration based on population density. This indicates that residents in areas with a high concentration of health facilities have better access to healthcare resources, while residents in areas with a low concentration may have limited access to healthcare services.

To promote justice and improve the health situation and sustainability in those regions, several actions can be taken. One key approach is to increase investment in healthcare infrastructure and resources in areas with a low concentration of healthcare facilities, whether based on geographical area or population density [40–41]. This could involve building new healthcare facilities, upgrading existing facilities, and increasing the number of healthcare workers in those areas. According to [42] and [43], investing in healthcare infrastructure can help reduce health inequalities, improve health outcomes, and strengthen health systems.

Another approach is to prioritize the recruitment and retention of healthcare professionals in areas with a low concentration of health facilities, regardless of the basis of the disparity [44]. This could involve offering financial incentives, training opportunities, and other benefits to healthcare professionals who work in those areas [45]. Studies have shown that these incentives, such as loan repayment programs, signing bonuses, housing assistance, salary supplement programs, and tax incentives, can be effective in recruiting healthcare professionals to underserved areas and in retaining them in rural areas [46–47].

Efforts should also be made to improve transportation and communication infrastructure in those regions, which can help promote justice and improve the health situation and sustainability in those areas [48]. This could involve improving roads, bridges, and other transportation infrastructure, as well as increasing access to telemedicine and other remote healthcare services.

Overall, addressing the unequal distribution of healthcare resources in Yemen will require a comprehensive and coordinated effort from the government, healthcare providers, and other stakeholders. By promoting justice and improving access to healthcare resources in all regions, it may be possible to reduce health disparities and improve the overall health situation and sustainability in Yemen.

B. The analysis using the entropy weight method shows that there is an uneven distribution of healthcare resources in Yemeni governorates.

District hospitals and tertiary hospitals have a higher concentration than primary healthcare centers, clinics, units, and complexes. This uneven distribution can create disparities in access to healthcare services for residents in different governorates.

The Entropy-TOPSIS method reveals that Marib, Socotra, Al Maharah, Aden, and Hadramaut have the highest comprehensive scores, indicating a relatively high concentration of health facilities.

On the other hand, Hajjah, Sa'ada, Amanat Al Asimah, Al Jawf, and Dhamar rank lowest in comprehensive scores, indicating a poor level of comprehensive health facility resource agglomeration.

The high concentration of secondary and tertiary health care resources may indicate that these resources are prioritized in the allocation of healthcare resources in Yemen. However, this concentration may also indicate that residents in governorates with lower concentrations of these resources may have limited access to primary healthcare services.

To promote a better health situation in Yemen, it is essential to address the disparities in the distribution of healthcare resources across governorates. One approach is to increase investment in primary healthcare resources to improve access to basic healthcare services for residents in all governorates [49]. This could involve building new healthcare centers and clinics, upgrading existing facilities, and increasing the number of healthcare workers in those areas. Another approach is to increase investment in tertiary healthcare resources in governorates with a low concentration of these resources. This could involve building new tertiary hospitals, upgrading existing facilities, and increasing the number of healthcare workers in those areas. Additionally, it is crucial to consider the types of resources necessary for each particular governorate to ensure a balanced distribution of healthcare resources. By implementing these approaches, it may be possible to reduce health disparities and improve the overall health situation in Yemen.

C. Limitations, future work, and implications of the study

The study has several limitations, including its sole focus on the distribution of healthcare facilities at the governorate level without considering the distribution at the district level. Additionally, qualitative data such as patient satisfaction or healthcare outcomes were not incorporated, and the study relied on secondary data sources that may not be completely up-to-date or accurate. The study also did not explore the reasons behind the disparities in healthcare facility resource allocation. Future research could investigate these limitations by exploring the reasons behind the disparities, incorporating qualitative data, and examining the distribution at the district or village level.

The findings of this study have several potential implications and applications. They could be used to inform policy decisions regarding the allocation of healthcare resources in Yemen, highlighting the need for further investment in healthcare infrastructure and resources in areas with a low concentration of healthcare facilities. The study emphasizes the importance of prioritizing the recruitment and retention of healthcare professionals in areas with a low concentration of health facilities. Additionally, the study suggests that improving transportation and communication infrastructure in certain regions could help promote justice and improve the health situation and sustainability in those areas.

Overall, this study provides a comprehensive analysis of the distribution of healthcare facility resources in Yemen using a novel approach. It highlights significant disparities in healthcare facility resource allocation across different governorates in Yemen and provides suggestions for addressing these disparities and improving the overall distribution of healthcare resources in Yemen.

V. CONCLUSIONS

This study investigated the fairness of healthcare facility resource allocation in Yemen using the entropy-weighted TOPSIS method. An evaluation system was developed based on health resource concentration and MCDM using entropy and TOPSIS, with a comprehensive consideration of various facility resource allocation indicators. Therefore, this study found that the distribution of equity by governorates' geographical area and population varies considerably, and an equitable distribution of health institutions is not currently in place.

The analysis using the entropy weight method shows that there is an uneven distribution of healthcare resources in Yemeni governorates. Based on the results presented, there are some suggestions to address the disparities in the distribution of healthcare resources in Yemen:

- Increase investment in healthcare infrastructure and resources in areas with a low concentration of healthcare facilities, whether based on geographical area or population density. This could involve building new healthcare facilities, upgrading existing facilities, and increasing the number of healthcare workers in those areas.
- Prioritize the recruitment and retention of healthcare professionals in areas with a low concentration of health facilities, regardless of the basis of the disparity. This could involve offering financial incentives, training opportunities, and other benefits to healthcare professionals who work in those areas.
- Improve transportation and communication infrastructure in those regions, which can help promote justice and improve the health situation and sustainability in those areas. This could involve improving roads, bridges, and other transportation infrastructure, as well as increasing access to telemedicine and other remote healthcare services.
- Increase investment in primary healthcare resources to improve access to basic healthcare services for residents in all governorates. This could involve building new healthcare centers and clinics, upgrading existing facilities, and increasing the number of healthcare workers in those areas.
- Increase investment in tertiary healthcare resources in governorates with a low concentration of these resources. This could involve building new tertiary hospitals, upgrading existing facilities, and increasing the number of healthcare workers in those areas.
- Consider the types of resources necessary for each particular governorate to ensure a balanced distribution of healthcare resources.
- Implement a comprehensive and coordinated effort from the government, healthcare providers, and other stakeholders to address the unequal distribution of healthcare resources in Yemen.

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