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RESEARCH

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Evaluation of low-and middle-income countries according to cardiovascular disease risk factors by using pythagorean fuzzy AHP and TOPSIS methods

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Abstract

Background Cardiovascular disease risk factors play a crucial role in determining individuals' future health status and significantly affect health. This paper aimed to address cardiovascular disease risk factors in low- and middle-income countries using multi-criteria decision-making methods.

Methods In line with this objective, 22 evaluation criteria were identified. Due to the unequal importance levels of the criteria, the interval-valued Pythagorean Fuzzy AHP (PF-AHP) method was employed for weighting. The TOPSIS method was utilized to rank the countries.

Results The application of interval-valued PF-AHP revealed that metabolic, behavioral, and economic factors are more important in contributing to disease risk. Among adults, tobacco use prevalence was identified as the most significant risk factor. According to the TOPSIS method, Lebanon, Jordan, Solomon Islands, Serbia, and Bulgaria ranked highest, while Timor Leste, Benin, Ghana, Niger, and Ethiopia ranked lowest.

Conclusions Identifying disease risk factors and preventing or reducing risks are crucial in combating cardiovascular diseases. Therefore, it is recommended that countries ranking higher take remedial actions to reduce disease risk.

Keywords Pythagorean fuzzy sets, AHP, TOPSIS, Cardiovascular disease, Multiple criteria decision making

Introduction

It is often assumed that all individuals understand the concept of illness similarly. Nonetheless, the definition of illness exhibits variability across societies and temporal contexts. In this context, illness can be conceptualized as the absence of dynamic well-being that aligns with the multifaceted demands of life, encompassing physical, mental, and social dimensions by age, culture, and individual responsibility. Diseases are a cumulative result of all protective and harmful events that affect people's health throughout their lives [1]. Chronic or Noncommunicable Diseases (NCDs) mainly include cardiovascular diseases, cancers, and diabetes [2]. NCDs are caused by behavioral, metabolic, and environmental risk factors and usually occur due to societal conditions and lifestyle habits such as poor nutrition, tobacco use, excessive alcohol consumption, and physical inactivity. Degenerative, genetic, hereditary, and environmental factors are also crucial in the formation of diseases. The development of illness is a complex process involving the contribution of

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multiple factors [3]. 74% (74%) of all deaths worldwide are attributed to NCDs. 86% (86%) of premature deaths from NCDs occur in low- and middle-income countries. Tobacco use, physical inactivity, alcohol consumption, and unhealthy eating are the four main risk factors contributing to NCDs [4]. These risk factors are fundamental behavioral risks and pose widespread threats created by economic transitions, rapid urbanization, and lifestyles [3]. Physical, social, environmental, and lifestyle factors influence NCDs. It is emphasized that progress in city health depends on the strength of healthcare systems and shaping urban environments. Urban settlements, as a social determinant of health, bring along socioeconomic, environmental, and occupational influences that exacerbate the impact of these risk factors. NCDs threaten human health and have significant economic implications for cities [5]. Factors such as global improvements in education and income levels, changes in dietary habits, and the control of infectious diseases increase life expectancy. While an increase in life expectancy is desirable, it also leads to an increase in NCDs [6]. NCDs are a significant public health problem that leads to increasing inequalities between countries and within populations [7], and they are influenced by factors such as rapid unplanned urbanization, the globalization of unhealthy lifestyles, and population aging [8]. Air quality generally deteriorates in many low- and middle-income countries parallel to large-scale urbanization and economic development [9, 10].

Furthermore, due to population aging and lifestyle changes, the global prevalence of NCDs has rapidly increased, making them a leading cause of death and disability worldwide [11]. NCDs are considered one of the most significant health challenges of the 21st century [12]. It is crucial to control the risk factors that contribute to the development of NCDs in order to reduce deaths caused by NCDs [4]. In the next 20 years, NCDs are projected to become the leading cause of death in low- and middle-income countries. The increasing prevalence of NCDs in these countries, driven by extreme poverty, nutritional changes, and lifestyle modifications, poses a significant threat to public health [3]. NCDs encompass various diseases that affect cardiovascular, neurological, respiratory, and other organ systems [11]. Cardiovascular diseases (CVDs), cancers, diabetes, and chronic respiratory diseases are the main NCDs [3].

In 2016, deaths related to heart and vascular diseases accounted for 31% of total deaths [12]. In 2019, CVDs were responsible for 38% of the 17 million premature deaths (under the age of 70) caused by NCDs. CVDs encompass a group of disorders affecting the heart and blood vessels, including coronary heart disease, cerebrovascular disease, peripheral artery disease, rheumatic heart disease, congenital heart disease, and all heart diseases related to deep vein thrombosis and pulmonary embolism [13]. In other words, CVDs refer to diseases affecting the heart and blood vessels [3]. Tobacco use, insufficient physical activity, alcohol consumption, unhealthy eating, hypertension, diabetes, high blood cholesterol, age, globalization, urbanization, and income are risk factors for CVDs [12, 14–16]. CVDs risk factors are crucial in determining individuals' future health conditions. Risk factors for CVDs include the main risk factors for NCDs and social determinants such as aging, income, urbanization, and physiological factors like high blood pressure (hypertension), high blood cholesterol, and high blood sugar [15]. Addressing multiple risk factors rather than focusing on one risk factor to prevent diseases [17]. Most premature deaths resulting from NCDs can be prevented by improving health systems to effectively and equitably meet the healthcare needs of patients. Additionally, it is stated that significant prevention can be achieved by developing public policies targeting non-health sectors that address common risk factors such as tobacco use, unhealthy diet, physical inactivity, and harmful alcohol consumption [18].

Identifying countries with high CVDs risk potential is important for preventing and controlling the disease. There are many criteria to be considered for the evaluation of these countries. Such problems with many conflicting criteria can be considered as a multi-criteria decision making (MCDM) problem. MCDM methods enable decision makers to make decisions more confidently in the face of uncertainty, complexity and conflicting objectives. The AHP method is one of the most frequently used MCDM methods for determining criteria weights [19]. However, the input data for AHP analysis is based on human judgment; therefore, the data may always be imprecise and uncertain to some extent [20]. The MCDM methods can be extended with fuzzy sets to represent real-life uncertainty [21]. Fuzzy sets proposed by Zadeh [22], have been successfully integrated with AHP to minimize uncertainty. After the introduction of fuzzy sets, fuzzy sets have been extended in various ways by many researchers [23], such as intuitionistic fuzzy sets (IFs) [24], neutrosophic sets [25], hesitant fuzzy sets [26], Pythagorean fuzzy sets (PFSs) [27], picture fuzzy sets [28], orthopair fuzzy sets [29], spherical fuzzy sets [30], fermatean fuzzy sets [31]. PFSs are an extension of intuitionistic fuzzy sets used to express experts' judgments about uncertainty and ambiguity in decision-making problems [32]. Therefore, this paper used AHP augmented by interval-valued Pythagorean fuzzy numbers (PFNs) to weight the risk factors.

In this paper, CVDs risk factors were determined first, and the weights of these factors were calculated using the interval-valued PF-AHP, one of the MCDM methods. Then, using these obtained weights, low- and middle-income countries were ranked by the TOPSIS method according to their CVDs risk potentials. This paper is significant because it examines the CVDs risk factors, which account for 32% of all deaths within NCDs [13], specifically in low- and middle-income countries. By evaluating multiple risk factors from the perspective of low- and middle-income countries, the research is expected to contribute to CVDs prevention and control efforts by identifying countries with the highest disease risk and the greatest need for preventive interventions.

Methodology

The paper used interval-valued PF-AHP for weighting criteria, and the TOPSIS method was used for ranking alternatives. The theoretical information about the methods used in the sub-sections of this section is provided.

Basic concepts of interval-valued pythagorean fuzzy sets

Classic MCDM methods generally assume that all criteria' weights and importance levels are expressed with precise values so that alternatives can be ranked without any problems [33]. However, most decisions in real-world situations are made in an uncertain or uncertain environment [34]. The fuzzy logic theory introduced by Zadeh [22] is suitable for subjective reasoning and qualitative evaluation in the evaluation processes of decision-making problems [35]. After the introduction of fuzzy sets, fuzzy sets have been extended in various ways by many researchers, such as IFs [24], neutrosophic fuzzy sets [25] and hesitant fuzzy sets hesitant fuzzy sets [26].

PPFs, proposed by Yager [27], are a generalization of IFs. PFs are also defined with both membership and non-membership functions, just like. Unlike ifs, the sum of the two degrees of function can be more than 1, but for PFs the sum of the squares of the degrees cannot be more than 1. Therefore, if the problem involves more fuzziness and uncertainty, PFs are more powerful than IFs in resolving uncertainty [21]. Experts can use interval numbers instead of crisp numbers to reflect uncertainty better when evaluating criteria and alternatives in decision-making processes [35]. The preliminary information about interval-valued Pythagorean fuzzy sets (IVPFSs) used in this paper is provided below [34].

Definition 1 An IVPFS in is defined as

$$A = \left\{ \langle x, \left[\mu_A^L(x), \mu_A^U(x)\right], \left[\nu_A^L(x), \nu_A^U(x)\right] \rangle | \, x \in X \right\} \tag{1}$$

where $0 \le \mu_A^L(x) \le \mu_A^u \le 1,\ 0 \le \nu_A^l(x) \le \nu_A^u \le 1$ and $(\mu_A^U(x))^2 + (\nu_A^U(x))^2 \le 1$.

Similar to PFSs, for each element $x \in X$, its hesitation interval relative to A is given as

$$\pi_A(x) = \left[\pi_A^L(x), \pi_A^U(x)\right] = \sqrt{1 - \left(\mu_A^U(x)\right)^2 - \left(\nu_A^U(x)\right)^2}, \sqrt{1 - \left(\mu_A^L(x)\right)^2 - \left(\nu_A^L(x)\right)^2} \tag{2}$$

For an IVPFS A, the pair $\langle [\mu_A^L(x), \mu_A^U(x)], [\nu_A^L(x), \nu_A^U(x)] \rangle$ is called an interval-valued interval-valued Pythagorean fuzzy number (IVPFN). For convenience, is often denoted by $\langle [a,b],[c,d] \rangle$ where

$$[a,b] \subset [0,1], [c,d] \subset [0,1] \text{ and } b^2 + d^2 \le 1 \tag{3}$$

Obviously, $\alpha^+ = \langle [1,1],[0,0] \rangle$ is the largest IVPFN, and $\alpha^- = \langle [1,1],[0,0] \rangle$ is the smallest IVPFN.

Definition 2 Let, and be IVPFNs then

$$\alpha_1 \wedge \alpha_2 = \langle \left[min\{a_1, a_2\}, min\left\{b_1, b_2\right\}\right], \left[max\{c_1, c_2\}, max\left\{d_1, d_2\right\}\right] \rangle \tag{4}$$

$$\alpha_1 \vee \alpha_2 = \langle \left[max\{a_1, a_2\}, max\left\{b_1, b_2\right\}\right], \left[min\{c_1, c_2\}, min\left\{d_1, d_2\right\}\right] \rangle \tag{5}$$

$$\alpha_1 \oplus \alpha_2 = \langle \left[\sqrt{a_1^2 + a_2^2 - a_1^2 a_2^2}, \sqrt{b_1^2 + b_2^2 - b_1^2 b_2^2}\right], [c_1 c_2, d_1 d_2] \rangle \tag{6}$$

$$\alpha_1 \otimes \alpha_2 = \langle [a_1 a_2, b_1 b_2], \left[\sqrt{c_1^2 + c_2^2 - c_1^2 c_2^2}, \sqrt{d_1^2 + d_2^2 - d_1^2 d_2^2}\right] \rangle \tag{7}$$

$$\lambda . \alpha = \langle \left[\sqrt{1 - \left(1 - a^2\right)^\lambda}, \sqrt{1 - \left(1 - b^2\right)^\lambda}\right], \left[c^\lambda, d^\lambda\right] \rangle,\ \lambda > 0 \tag{8}$$

$$\alpha^\lambda = \langle \left[a^\lambda, b^\lambda\right], \left[\sqrt{1 - \left(1 - c^2\right)^\lambda}, \sqrt{1 - \left(1 - d^2\right)^\lambda}\right] \rangle,\ \lambda > 0 \tag{9}$$

Definition 3 Let be IVPFNs, the score function of is defined as follows:

$$s(\alpha) = \frac{1}{2}\left[a^2 + b^2 - c^2 - d^2\right],\ s(\alpha) \in [-1,\ 1] \quad (10)$$

Definition 4 Let be IVPFNs, the accuracy function of is defined as follows:

$$a(\alpha) = \frac{1}{2}\left[a^2 + b^2 + c^2 + d^2\right],\ a(\alpha) \in [0,\ 1] \quad (11)$$

For any two IVPFNs, α_1, α_2, the comparison rule is defined as follows:

1. if $s(\alpha_1) > s(\alpha_2)$, then $\alpha_1 > \alpha_2$;
2. if $s(\alpha_1) = s(\alpha_2)$, then:

(a) if $a(\alpha_1) > a(\alpha_2)$, then $\alpha_1 > \alpha_2$;
(b) if $a(\alpha_1) > a(\alpha_2)$, then $\alpha_1 = \alpha_2$.

Definition 5 Let, be a collection of IVPFN, then the function interval-valued Pythagorean fuzzy weighted averaging operator (and

$$IVPFWA_w(\alpha_j, \alpha_j, \ldots, \alpha_j) = \langle \left[\sqrt{1 - \prod_{j=1}^{n}(1 - a_j^2)^{w_j}}, \sqrt{1 - \prod_{j=1}^{n}(1 - b_j^2)^{w_j}}, \right], \left[\prod_{j=1}^{n} c_j^{w_j}, \prod_{j=1}^{n} d_j^{w_j}\right] \rangle \quad (12)$$

where w_j is the weight of α_j $(j = 1,2,\ldots,n)$, $w_j \in [0,\ 1]$ and $\sum_{j=1}^{n} w_j = 1$.

Interval-valued pythagorean fuzzy AHP

In recent years, the interval-valued PF-AHP method has been used in the literature to solve various problems. Among these, it is mostly used in risk assessment problems. For example; Ilbahar et al. [36], weighting probability, severity and frequency parameters used in risk assessment in the field of occupational health and safety; Ak and Gul [37], weighting risk parameters in information security; Yucesan and Kahraman [38], weighting risk parameters for hydroelectric power plants; Ayyildiz and Taskin Gumus [21], weighting critical risk factors for hazardous material transportation operations. Shete et al. [20] used it to evaluate the factors that enable innovation in the supply chain. Yucesan and Gul [19] used Fuzzy TOPSIS methods together to evaluate hospital service quality. Çalık [32] integrated Pythagorean Fuzzy TOPSIS method and used it in green supplier selection problem. Lahane and Kant [39] used the performance results of the circular supply chain together with the Pythagorean fuzzy CoCoSo method to calculate the weights of the enablers in the ranking problem. Boyacı and Şişman [40] used it for weighting the criteria in the pandemic hospital location selection problem. The steps of interval-valued PF-AHP are as follows [36]:

Step 1
Construct the compromised pairwise comparison matrix $R = (r_{ik})_{mxm}$ with linguistic evaluations of experts' opinions based on Table 1.

Step 2
Calculate the differences matrix $D = (d_{ik})_{mxm}$ between the lower and upper values of the membership and non-membership functions by using Eqs. (13–14).

$$d_{ik_L} = \mu_{ik_L}^2 - v_{ik_U}^2 \quad (13)$$

$$d_{ik_U} = \mu_{ik_U}^2 - v_{ik_L}^2 \quad (14)$$

Table 1 Linguistic scale for interval-valued PF-AHP

Linguistic terms	IVPFNs			
	μ_L	μ_U	v_L	v_U
Certainly Low Importance – CLI	0	0	0.9	1
Very Low Importance – VLI	0.1	0.2	0.8	0.9
Low Importance – LI	0.2	0.35	0.65	0.8
Below Average Importance – BAI	0.35	0.45	0.55	0.65
Average Importance – AI	0.45	0.55	0.45	0.55
Above Average Importance – AAI	0.55	0.65	0.35	0.45
High Importance – HI	0.65	0.8	0.2	0.35
Very High Importance – VHI	0.8	0.9	0.1	0.2
Certainly High Importance – CHI	0.9	1	0	0
Exactly Equal – EE	0.1965	0.1965	0.1965	0.1965

Step 3

Calculate the interval multiplicative matrix $S = (s_{ik})_{mxm}$ by using Eqs. (15–16).

$$S_{ik_L} = \sqrt{1000^{d_L}} \quad (15)$$

$$S_{ik_U} = \sqrt{1000^{d_U}} \quad (16)$$

Step 4

Calculate the determinancy value $\tau = (\tau_{ik})_{mxm}$ of the r_{ik} using by Eq. (17).

$$\tau_{ik} = 1 - \left(\mu_{ik_U}{}^2 - \mu_{ik_L}{}^2\right) - \left(v_{ik_U}{}^2 - v_{ik_L}{}^2\right) \quad (17)$$

Step 5

Multiply the determinancy degrees with $S = (s_{ik})_{mxm}$ matrix for obtaining the matrix of weights, $T = (t_{ik})_{mxm}$, before normalization by using Eq. (18).

$$t_{ik} = \left(\frac{S_{ik_L} + S_{ik_U}}{2}\right)\tau_{ik} \quad (18)$$

Step 6

Calculate the normalized priority weights w_i by using Eq. (19).

$$w_i = \frac{\sum_{k=1}^{m} t_{ik}}{\sum_{i=1}^{m}\sum_{i=1}^{m} t_{ik}} \quad (19)$$

TOPSIS

Hwang and Yoon [41] have proposed TOPSIS method for ranking alternatives. Due to its simple application and comprehensibility, the TOPSIS is widely utilized. In this method, the optimal solution is determined as the alternative that is closest to the ideal solution while being farthest from the negative-ideal solution. Several studies have applied TOPSIS to resolve MCDM issues in multiple fields, such as supply chain management, business and marketing administration, production systems, chemical engineering, human resources management, and energy management [42]. The steps of the TOPSIS method are stated below [43]:

Step 1

Identifying objectives and defining evaluation criteria.

Step 2

Decision matrices with evaluation criteria are created in the alternatives columns in the rows. a_{ij} in A decision matrix shows the actual value of alternative $i$in A matrix according to the criterion j.

$$A = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ \cdots & \cdots & \cdots & \cdots \\ a_{m1} & a_{m2} & \cdots & a_{mn} \end{bmatrix}$$

Step 3

After creating the decision matrix, the normalized decision matrix (R) is obtained using Eq. (20).

$$r_{ij} = \frac{a_{ij}}{\sqrt{\sum_{i=1}^{m} a_{ij}^2}}\ i = 1,2,\ldots m;\ \ j = 1,2,\ldots,n$$

$$R = \begin{bmatrix} r_{11} & r_{12} & \cdots & r_{1n} \\ r_{21} & r_{22} & \cdots & r_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ \cdots & \cdots & \cdots & \cdots \\ r_{m1} & r_{m2} & \cdots & r_{mn} \end{bmatrix} \quad (20)$$

Step 4

First, the evaluation criteria' relative weight values (w_j: i: 1, 2,., n) are determined according to the purpose. Then, the weighted normalized decision matrix (V) is created by multiplying elements in each column of the R matrix with the corresponding w_j value.

$$V = \begin{bmatrix} w_1 r_{11} & w_2 r_{12} & \cdots & w_n r_{1n} \\ w_1 r_{21} & w_2 r_{22} & \cdots & w_n r_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ \cdots & \cdots & \cdots & \cdots \\ w_1 r_{m1} & w_2 r_{m2} & \cdots & w_n r_{mn} \end{bmatrix}$$

Step 5

The weighted evaluation factors in the V matrix, which are the largest of the column values (the smallest if the corresponding evaluation factor is minimized) are selected to create the ideal solution set. The ideal solution and the negative ideal solution can be calculated using Eqs. (21) and (22) respectively. In both formulations, Jrepresents the benefit (maximization), and J' represents the cost (minimization) value.

$$A^* = \left\{\left(\max_i v_{ij} | j \in J\right), \left(\min_i v_{ij} | j \in J'\right)\right\} \quad (21)$$

$$A^- = \left\{\left(\min_i v_{ij} | j \in J\right), \left(\max_i v_{ij} | j \in J'\right)\right\} \quad (22)$$

Values obtained from Eq. (21) can be shown as $A^* = \left\{v_1^*, v_2^*, \ldots, v_n^*\right\}$ and values obtained from Eq. (22) can be shown as $A^- = \left\{v_1^-, v_2^-, \ldots, v_n^-\right\}$.

Step 6

In the TOPSIS method, the Euclidean distance approach is used to find the deviation of the evaluation factor value for each decision point from the ideal and negative ideal solution set. The distance of alternative J_i to the ideal solution (S_i^*) and the distance from the negative ideal solution (S_i^-) are calculated using Eqs. (23) and (24) respectively.

$$S_i^* = \sqrt{\sum_{j=1}^{n} (v_{ij} - v_j^*)^2} \tag{23}$$

$$S_i^- = \sqrt{\sum_{j=1}^{n} (v_{ij} - v_j^-)^2} \tag{24}$$

Step 7

The relative proximity to the ideal solution (C_i^*) is calculated by using the Eq. (25).

$$C_i^* = \frac{S_i^-}{S_i^- + S_i^*}\ 0 \leq C_i^* \leq 1 \tag{25}$$

Step 8

Alternatives are ranked according to the relative proximity to the ideal solution (C_i^*).

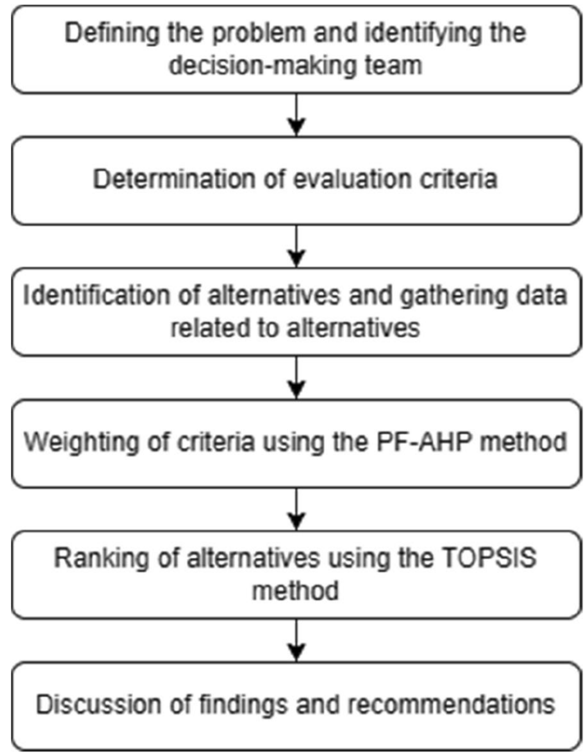

Fig. 1 Methodology for ranking countries

Case Study

This paper ranks low- and middle-income countries based on cardiovascular disease risks. For this purpose, the flowchart of the applied methodology is shown in Fig. 1.

Definition of Criteria

A comprehensive literature review was conducted prior to selecting the criteria. The criteria were selected and grouped based on the World Health Organization (WHO) sources, primarily the "*Noncommunicable Diseases Country Profiles 2018*" report. In addition, consultations were held with four cardiology experts to finalize the grouping of criteria. A total of 22 factors were included for evaluation under seven main factor categories: socio-demographic, economic, behavioral, metabolic, health system and national capacity, and others. The criteria considered in the research were compiled from the WHO and The World Bank databases. The most recent data available for low- and middle-income countries were considered. The desired value was minimum for criteria with a minimization direction, while the desired value was maximum for criteria with a maximization direction. The research aimed to obtain a ranking from the country with the highest cardiovascular disease risk to the country with the lowest risk. Therefore, factors that increase disease risk were encoded with a maximization direction, while factors that reduce disease risk were encoded with a minimization direction and included in the evaluation. The main and sub-criteria, along with their direction and code, are provided in Table 2, and additional information about the criteria is presented below the table.

The rapid increase in urban population and the expansion of cities bring along environmental issues such as wastewater, noise, and air pollution [44, 45]. People living in cities are exposed to NCDs and injuries. Additionally, alcohol and substance addiction rates are higher in urban areas [45]. Unregulated globalization and unplanned urbanization also increase the likelihood of exposure to CVDs risk factors. Moreover, unplanned urbanization restricts opportunities for physical activity and increases exposure to environmental pollution [14].

The prevalence of chronic NCDs increases with aging. Furthermore, multiple diseases can coexist in the same individual during old age. Chronic diseases negatively impact the clinical picture of the elderly and reduce treatment effectiveness. Therefore, as the elderly population increases, the number of individuals at risk of developing chronic diseases also rises [46]. The increase in the proportion of the elderly population leads to a shift of health issues towards NCDs observed in the elderly population

Table 2 Risk factors

Criterion Direction	Main Criteria	Sub-Criteria Number	Description of the Sub-Criteria
Maximization Criterion	Socio-Demographic Factors C1	C1.1	Urban population (percentage of total population)
		C1.2	Population aged 65 and above (percentage of total population)
		C1.3	PM2.5 air pollution, average annual exposure (micrograms per cubic meter)
	Economic Factors C2	C2.1	Unemployment rate (percentage of total labor force)
		C2.2	GINI Index
	Behavioral Factors C3	C3.1	Prevalence of tobacco use among adults (%)
		C3.2	Per capita alcohol consumption among adults aged 15+ (Annual liters of pure alcohol)
		C3.3	Prevalence of insufficient physical activity among adults aged 18 and above (age-standardized estimate) (%)
		C3.4	Average population salt intake, adults aged 20 and above (grams per day)
	Metabolic Factors C4	C4.1	Prevalence of high blood pressure among adults aged 18 and above (%)
		C4.2	Prevalence of high blood sugar among adults aged 18 and above (%)
		C4.3	Prevalence of obesity among adults, BMI >= 30 (age-standardized estimate) (%)
		C4.4	Average total cholesterol (age-standardized estimate)
		C4.5	Prevalence of diabetes (percentage of population aged 20 to 79)
		C4.6	Prevalence of hypertension among adults aged 30–79
Minimization Criterion	Factors Related to the Healthcare System C5	C5.1	Number of physicians (per 10,000 population)
		C5.2	Number of nurses and midwives (per 10,000 population)
		C5.3	Current health expenditure per capita ($)
		C5.4	Number of hospital beds (per 10,000 population)
	Factors Related to National Capacity C6	C6.1	Existence of operational policies/strategies/action plans for cardiovascular diseases
		C6.2	Existence of evidence-based national guidelines/protocols/standards for the management of cardiovascular diseases
		C6.3	Presence of cardiovascular risk classification in 50% or more primary healthcare facilities

[6]. It is noted that NCDs and related deaths increase with age worldwide. Accordingly, it can be stated that the prevalence of NCDs will rise with the increase in the elderly population [8]. The aging population is associated with increased age-related diseases, particularly dementia, cardiovascular diseases, and cerebrovascular diseases [47].

It can be said that the risk factors for NCDs are closely associated with income inequality. Income distribution represents a measure of social class differences in society and is related to health outcomes. NCDs risk factors can be indirectly linked to the economic status of countries, not just the population's health status. In this context, the GINI coefficient, an economic inequality indicator, has been included as a risk factor in the study. The GINI coefficient is the literature's most commonly used measure of inequality [48]. The GINI coefficient provides a numerical measure that gives an idea about income distribution. The coefficient ranges from 0 to 1, where 0 represents perfect equality and 1 represents perfect inequality [49]. Poverty, unemployment, unhealthy housing, hazardous environments, and lack of access to medical services and healthy food are all associated with obesity, smoking, and alcohol addiction and form the basis of social inequalities in NCDs morbidity and mortality [3].

The air we breathe contains emissions from motor vehicles, industries, heating, commercial sources, tobacco smoke, and emissions from household fuels. Air pollution harms individuals' health, particularly those vulnerable due to age or existing health conditions. Air pollution is a significant cause of deaths, hospital admissions, and exacerbation of symptoms, primarily related to heart and respiratory diseases [50]. The disease burden attributable to air pollution is estimated at the same level as other key global health risks, such as unhealthy diet and tobacco use. It is stated that exposure to air pollution leads to millions of deaths and loss of healthy life years every year. The World Health Assembly recognized air pollution as a risk factor for NCDs in 2015 [51].

Particulate matter (PM) is a complex mixture of various chemical and physical components in urban and non-urban environments. PM 2.5 refers to particles with an aerodynamic diameter equal to or smaller than 2.5 μm [11]. Exposure to PM has been associated with various cardiovascular diseases. Consistent evidence from epidemiological and experimental studies demonstrates that short and long-term exposure to PM, particularly to the finest particles, is associated with cardiovascular morbidity and mortality [52]. Air pollution becomes an independent risk factor for cardiovascular morbidity and mortality. Studies have shown a strong association between PM in air pollution and increased cardiovascular diseases such as myocardial infarction, cardiac arrhythmias, ischemic stroke, vascular dysfunction, hypertension, and atherosclerosis [52, 53]. It is also noted that PM 2.5 is identified as the primary cause of the adverse cardiovascular effects of air pollution on human health [54, 55]. In addition to increased morbidity and mortality, the disease burden resulting from air pollution also imposes a significant economic burden. Consequently, ways to improve air quality worldwide and reduce the public health burden and associated costs of air pollution are being sought [11].

Diabetes occurs as a result of insufficient production or release of insulin in the pancreas, leading to decreased or lost effectiveness of insulin due to genetic or environmental factors [3]. Diabetes is a lifelong disease that restricts dietary choices, increases the risk of kidney and eye diseases in the long term, and requires individuals with diabetes to make lifestyle changes [14]. In other words, diabetes is a chronic disease that requires continuous medical care and self-management education to prevent acute complications and reduce the risk of long-term complications [56]. Additionally, diabetes also leads to elevated blood sugar levels. Diabetes is both a standalone disease and a significant risk factor for CVDs [3]. CVDs are the most common cause of morbidity and mortality in individuals with type 1 or 2 diabetes. Generally, individuals with diabetes also have other comorbidities, such as obesity, hypertension, and dyslipidemia, contributing to increased CVDs risk [56, 57].

Tobacco, primarily in cigarette consumption, is a significant health risk. Cigarette smoking is the most prevalent tobacco use [3]. There is a significant contribution of cigarette smoking to the development of mortality and morbidity related to CVDs. Identifying the relationship between smoking and heart disease dates back to the 1940s. Since then, various studies have demonstrated that smoking increases the risk of CVDs, stroke, sudden death, heart attack, peripheral vascular diseases, and aortic aneurysms. Smoking remains one of the most common preventable causes of mortality worldwide [16]. Every year, more than 8 million people die from tobacco use. Most tobacco-related deaths occur in low- and middle-income countries, often targeted by intense tobacco industry intervention and marketing efforts [58]. The health risks of smoking arise from direct tobacco use and exposure to secondhand smoke [14]. Some individuals are exposed to secondhand smoke despite not being smokers themselves. Exposure to secondhand smoke leads to adverse health outcomes and causes 1.2 million deaths annually. Approximately half of children breathe air contaminated with tobacco smoke, and each year, 65,000 children die from diseases attributed to passive smoking [58]. Nutritional habits are critical factors in the causes of NCDs [3]. It can be said that obesity is one of the most significant risk factors, along with smoking. Obesity refers to increased body fat compared to lean body mass due to an imbalance between energy intake and expenditure [59]. Both overweight and obesity have reached epidemic levels globally in high-income and low-income countries [3]. The rise of obesity and overweight can be attributed to the increased consumption of high-fat and high-sugar foods, the growing sedentary nature of many forms of work, changing modes of transportation, and increased urbanization leading to decreased physical activity [60]. The most commonly used and well-known method for assessing obesity is Body Mass Index (BMI) [59]. BMI is a simple height-to-weight ratio widely used to classify overweight and obesity in adults. It is calculated by dividing a person's weight in kilograms by the square of their height in meters (kg/m2). For adults, overweight is defined as a BMI equal to or greater than 25, and obesity is defined as a BMI equal to or greater than 30 [60]. With an increase in BMI, undesired metabolic effects such as blood pressure, cholesterol, triglycerides, and insulin resistance are affected, leading to an increased risk of coronary heart disease, ischemic stroke, and type 2 diabetes [3].

Excessive calorie intake, high cholesterol, salt consumption, and low physical activity levels are fundamental factors contributing to the high prevalence of CVDs worldwide [3]. Obesity can lead to various structural and functional changes in the heart. Due to the structural alterations, it induces on the heart, obesity alone increases the risk of CVDs. The coexistence of obesity and hypertension intensifies the impact on the structure and function of the heart. Various studies suggest that obesity is an independent risk factor for all-cause mortality in individuals with coronary heart disease. In addition to being an independent risk factor for CVDs, there is increasing evidence that obesity contributes to other risk factors, such as hypertension [59].

Blood pressure is the force exerted by the circulating blood on the walls of the body's major blood vessels, known as arteries. Hypertension refers to a condition when blood pressure is excessively high [61]. High blood pressure is the leading cause of death and disability, particularly cardiovascular diseases, in adults. The risk of cardiovascular diseases progressively increases with elevated blood pressure [62, 63]. Obesity is one of the most significant risk factors for hypertension. Other risk factors include alcohol consumption, sodium intake through diet, and a sedentary lifestyle [59]. Hypertension is a fundamental risk factor for all cardiovascular diseases, including coronary heart disease, heart failure, ischemic stroke, and peripheral vascular disease [3]. Hypertension is often called the "*silent killer*" because most people with hypertension are unaware of the problem. This is because hypertension may not have any warning signs or symptoms. Therefore, regular blood pressure measurements are necessary [61]. Hypertension is a significant risk factor for coronary heart disease, chronic kidney disease, and ischemic/hemorrhagic stroke. Although the exact cause of hypertension is unknown in most cases, high salt intake, overweight/obesity, excessive alcohol consumption, physical inactivity, stress, air pollution, and smoking increase the likelihood of hypertension [14].

Alcohol consumption is a modifiable risk factor for CVDs [64]. Heavy alcohol consumption is a significant cause of death and disability [65]. Excessive or lifelong high alcohol intake is harmful to most cardiovascular functions. High alcohol consumption increases morbidity and mortality by causing cardiovascular dysfunction and structural damage. It also contributes to developing hypertension, dyslipidemia, and diabetes mellitus [66]. There is a relationship between high-dose alcohol consumption and CVDs, certain cancers, and liver diseases. The relationship between alcohol consumption and CVDs is complex and closely related to the amount and consumption pattern [3]. The quantity, type, and pattern of alcohol consumption can have different associations with health outcomes [67]. Research suggests that moderate and high doses of alcohol consumption have adverse effects on CVDs, while low doses of alcohol (1–2 drinks per day) are associated with a lower risk of CVDs [64, 68, 69]. Additionally, many individuals do not follow a regular drinking pattern, and low-to-moderate consumption can pose a risk for CVDs when combined with heavy/episodic drinking periods [69]. High alcohol intake has been associated with increased mortality [67]. High alcohol consumption also increases the risk of stroke and peripheral artery disease [65]. The cardiovascular system is sensitive to the harmful effects of alcohol. Alcohol is an active toxin that widely spreads in the body, causing multiple simultaneous and synergistic effects, and both excessive and lifelong consumption and light doses are not recommended [66]. Physical activity is any bodily movement produced by skeletal muscles that requires energy expenditure. It can be performed in various forms, such as walking, cycling, dancing, and yoga, and can be integrated into daily tasks or household chores [70]. Physical inactivity is a proven risk factor for premature death and certain noncommunicable diseases [71] and harms mental health and quality of life [72]. Insufficiently physically active individuals have an estimated 20–30% higher risk of death for any reason than those who are active. On average, it is believed that 30 min of physical activity per day can reduce the risk of ischemic heart disease by 30% and the risk of diabetes by 27% [3]. However, with adequate duration and intensity, all physical activity can provide health benefits when performed regularly. Regular physical activity has been proven to help prevent and treat noncommunicable diseases such as cardiovascular disease, stroke, diabetes, and breast and colon cancer. It also assists in preventing hypertension, overweight, and obesity and improves mental health, quality of life, and well-being [70]. Promoting non-motorized modes of transportation such as walking and cycling is recommended to reduce physical inactivity, as well as encouraging active recreation and sports participation during leisure time and implementing national policies [72].

Salt is one of the major determinants of high blood pressure and increased cardiovascular risk worldwide [3, 73]. The impact of salt on health can be likened to other dietary and lifestyle changes, such as healthy eating, increasing physical activity, and reducing smoking [62]. In recent years, substantial evidence has shown a cause-and-effect relationship between salt intake and cardiovascular and renal damage. Increased salt intake is reported to raise arterial pressure, leading to adverse cardiovascular and renal outcomes [73, 74]. Excessive salt intake also adversely affects cardiovascular and renal morbidity and mortality [57]. The recommended average salt intake is <5 g per day per individual to prevent CVDs. Reducing salt intake to the recommended levels significantly impacts the prevention of CVDs [3]. Consuming less than 5 g of salt daily for adults helps reduce blood pressure and the risk of cardiovascular diseases, stroke, and coronary heart disease. The primary benefit of reducing salt intake is the corresponding decrease in high blood pressure [75]. It is noted that reducing salt intake lowers blood pressure and decreases the risk of cardiovascular diseases [62]. If global salt consumption is reduced to the recommended levels, it is estimated that approximately 2.5 million deaths could be prevented each year [75].

High cholesterol levels increase the risk of heart disease and stroke [76, 77]. Globally, one-third of ischemic heart disease can be attributed to high cholesterol. Overall, it is estimated that high cholesterol contributes to 2.6 million deaths. Elevated total cholesterol is a significant contributing factor to the burden of disease related to ischemic heart disease and stroke [76]. High cholesterol has no signs or symptoms, so cholesterol control is the only way to understand it [77]. Cholesterol is measured in milligrams per deciliter (mg/dL). High cholesterol is a total cholesterol level above 200 mg/dL, known as hyperlipidemia. Certain health conditions, such as type 2 diabetes and obesity, can increase the risk of high cholesterol. Lifestyle factors such as consuming a diet high in saturated and trans fats and lack of physical activity also contribute to an increased risk of high cholesterol [77]. It is noted that every 10% increase in weight leads to a 10–15 mg/dL increase in cholesterol levels. Weight loss, on the other hand, helps lower LDL cholesterol and triglyceride levels while increasing HDL cholesterol levels. These changes improve the lipid profile and reduce cardiovascular risk [59].

Cardiovascular diseases pose a significant challenge for low- and middle-income countries, as these nations often lack sufficient access to early detection and treatment programs for individuals at risk and integrated primary healthcare services [78]. Considering that healthcare infrastructure and healthcare workforce affect healthcare service delivery and, consequently, health status, infrastructure factors such as the number of physicians, nurses, and hospital beds were taken into account in the scope of the research. A significant portion of the burden of diseases can be reduced by controlling the primary risk factor. It can be said that strategy action plans, standards, and protocols serve this purpose.

Definition of alternatives

All countries that are members of the United Nations (UN) can become members of the WHO. Other countries are accepted as members when a simple majority of the World Health Assembly approves their applications. WHO members are grouped according to regional distribution. There are a total of 194 member states, with 47 in the African Region, 21 in the Eastern Mediterranean Region, 53 in the European Region, 35 in the Region of the Americas, 11 in the South-East Asia Region, and 27 in the Western Pacific Region [79]. More than three-quarters of deaths from cardiovascular diseases occur in low- and middle-income countries [13]. Therefore, the assessment is limited to low- and middle-income countries, excluding high-income countries. Out of the 194 WHO member countries, 133 are low- and middle-income countries [80]. Complete data is available for 90 out of the 133 countries. Accordingly, the research is based on the alternatives provided by 90 low- and middle-income countries. The alternatives, their codes, and the regions they belong to are given in Table 3. In the following steps, the countries will be referred to by their codes.

Weighting of criteria

For the evaluation of the cardiovascular disease risk potential of low and middle-income countries, a classification has been made under 6 main criteria and a total of 22 sub-criteria as given in Table 2. The criteria given in Table 2 have different weights. In this paper, the interval-valued PF-AHP method was used to calculate criterion weights. An expert decision-making team has been determined to evaluate the criteria. The decision-makers consist of a total of 5 experts, including 3 from the field of Cardiovascular Surgery with more than 10 years of experience and academic titles, and 2 from the field of Cardiology. These experts are experienced and specialized physicians who have been working in the field of Cardiovascular Surgery or Cardiology at a university hospital for many years. Each decision-maker evaluated the main criteria and sub-criteria under each main criterion in accordance with the classification given in Table 2. Due to the large number of steps in the interval-valued PF-AHP method, the application steps of the method have been explained through the Socio-Demographic sub-criteria. All evaluations except for the Socio-Demographic sub-criteria are additionally provided in Tables A2, A3, A4, A5, A6 and A7.

In the calculation of the weights of socio-demographic sub-criteria using the interval-valued PF-AHP method, firstly, each decision maker (DM) compared the criteria pairwise using the linguistic scale given in Table 1 (Table 4). Then, linguistic comparisons were converted to IVPFNs using the scale given in Table 1 (Table 5). When there are multiple DMs, the compromised pairwise comparison matrix is calculated using the IVPFWA given in Eq. (10). The aggregated pairwise comparison matrix is given in Table 6. To calculate the difference between the lower and upper values of the membership and non-membership functions, the difference matrix $D = (d_{ik})_{mxm}$can be obtained by applying Eqs. (11–12) (Table 7). The interval multiplicative matrix $S = (s_{ik})_{mxm}$ was calculated by applying Eqs. (13–14) (Table 8). Then, the determinancy values were calculated using Eq. (15) (Table 9). The determinancy degrees and the $S = (s_{ik})_{mxm}$ matrix were multiplied using Eq. (16) (Table 10). Finally, criterion weights were obtained by using the normalization method given in Eq. (17) (Table 11).

Table 3 Alternatives and regions

African Region					
Algeria (A1)	Benin (A6)	Botswana (A8)	Burkina Faso (A11)	Cabo Verde (A12)	Cameroon (A13)
Chad (A14)	Comoros (A17)	Congo (A19)	Democratic Rep. of the Congo (A18)	Cote d'Ivoire (A21)	Eswatini (A25)
Ethiopia (A26)	Gambia (A28)	Ghana (A30)	Kenya (A39)	Lesotho (A43)	Liberia (A44)
Madagascar (A45)	Malawi (A46)	Mali (A49)	Mauritania (A50)	Mauritus (A51)	Mozambique (A56)
Namibia (A58)	Niger (A60)	Nigeria (A61)	Rwanda (A67)	Sao Tome and Principe (A69)	Senegal (A70)
Sierra Leone (A72)	South Africa (A74)	Tanzania (A77)	Togo (A80)	Uganda (A84)	Zambia (A89)
Zimbabwe (A90)					
Eastern Mediterranean Region					
Egypt (A24)	Iran (A34)	Iraq (A35)	Jordan (A37)	Lebanon (A42)	Morocco (A55)
Pakistan (A62)	Tunusia (A81)	Yemen (A88)			
European Region					
Armenia (A3)	Belarus (A5)	Bosnia and Herzegovina (A7)	Bulgaria (A10)	Georgia (A29)	Kazakhstan (A38)
Kyrgyzstan (A40)	Moldova (A53)	Russian Federation (A66)	Serbia (A71)	Turkey (A82)	Turkmenistan (A83)
Ukraine (A85)	Uzbekistan (A86)				
Region of the Americas					
Argentina (A2)	Brazil (A9)	Colombia (A16)	Costa Rica (A20)	Dominican Republic (A22)	Ecuador (A23)
Guatemala (A31)	Jamaica (A36)	Mexico (A52)	Paraguay (A63)	Peru (A64)	Suriname (A76)
South-East Asia Region					
Bangladesh (A4)	India (A32)	Indonesia (A33)	Maldives (A48)	Myanmar (A57)	Nepal (A59)
Sri Lanka (A75)	Thailand (A78)	Timor Leste (A79)			
Western Pacific Region					
China (A15)	Fiji (A27)	Lao People's Democratic Rep. (A41)	Malaysia (A47)	Mongolia (A54)	Phillippines (A65)
Samoa (A68)	Solomon Islands (A73)	Viet Nam (A87)			

Table 4 Pairwise linguistic comparisons of Socio-demographic sub-criteria

DM	Criteria	C1.1	C1.2	C1.3
DM1	**C1.1**	EE	VLI	VLI
	C1.2	VHI	EE	VHI
	C1.3	VHI	VLI	EE
DM2	**C1.1**	EE	VLI	EE
	C1.2	VHI	EE	VHI
	C1.3	EE	VLI	EE
DM3	**C1.1**	EE	CLI	VLI
	C1.2	CHI	EE	HI
	C1.3	VHI	LI	EE
DM4	**C1.1**	EE	CLI	CLI
	C1.2	CHI	EE	AAI
	C1.3	CHI	BAI	EE
DM5	**C1.1**	EE	VLI	EE
	C1.2	VHI	EE	VHI
	C1.3	EE	VLI	EE

Similar steps were followed in calculating the weights of the main criteria and other sub-criteria. These calculated weights are the local weights of the criteria. The local weights of the main criteria and sub-criteria are given in columns 2 and 4 of Table 12, respectively. However, each sub-criterion has a level of importance based on the weight of the main criterion to which it is linked in the hierarchical structure. For this reason, global weights were obtained by multiplying all sub-criteria weights with the main criteria weights. The sum of the global weights of all sub-criteria is 1. Thus, the weights of all sub-criteria can be compared with each other. The global weights of all sub-criteria are given in Table 12.

According to the results obtained through the interval-valued PF-AHP method for determining the level of importance, it can be observed that the C4, C3, and C2 main criteria have higher levels of importance compared to the other main criteria, while the C6, C5, and C1 criteria have lower levels of importance. Based on these results, it can be said that metabolic, behavioral,

Table 5 Pairwise comparisons of Socio-demographic sub-criteria obtained by using PFNs

DM	Criteria	C1.1	C1.2	C1.3
DM1	**C1.1**	(0.1965, 0.1965, 0.1965, 0.1965)	(0.1, 0.2, 0.8, 0.9)	(0.1, 0.2, 0.8, 0.9)
	C1.2	(0.1965, 0.1965, 0.1965, 0.1965)	(0.1, 0.2, 0.8, 0.9)	(0.1965, 0.1965, 0.1965, 0.1965)
	C1.3	(0.1965, 0.1965, 0.1965, 0.1965)	(0, 0, 0.9, 1)	(0.1, 0.2, 0.8, 0.9)
DM2	**C1.1**	(0.5, 0.4, 0.4)	(0.7, 0.3, 0.2)	(0.2, 0.8, 0.1)
	C1.2	(0.3, 0.7, 0.2)	(0.5, 0.4, 0.4)	(0.3, 0.7, 0.2)
	C1.3	(0.8, 0.2, 0.1)	(0.7, 0.3, 0.2)	(0.5, 0.4, 0.4)
DM3	**C1.1**	(0.5, 0.4, 0.4)	(0.6, 0.4, 0.3)	(0.8, 0.2, 0.1)
	C1.2	(0.4, 0.6, 0.3)	(0.5, 0.4, 0.4)	(0.6, 0.4, 0.3)
	C1.3	(0.2, 0.8, 0.1)	(0.4, 0.6, 0.3)	(0.5, 0.4, 0.4)
DM4	**C1.1**	(0.5, 0.4, 0.4)	(0.6, 0.4, 0.3)	(0.8, 0.2, 0.1)
	C1.2	(0.4, 0.6, 0.3)	(0.5, 0.4, 0.4)	(0.6, 0.4, 0.3)
	C1.3	(0.2, 0.8, 0.1)	(0.4, 0.6, 0.3)	(0.5, 0.4, 0.4)
DM5	**C1.1**	(0.5, 0.4, 0.4)	(0.6, 0.4, 0.3)	(0.8, 0.2, 0.1)
	C1.2	(0.4, 0.6, 0.3)	(0.5, 0.4, 0.4)	(0.6, 0.4, 0.3)
	C1.3	(0.2, 0.8, 0.1)	(0.4, 0.6, 0.3)	(0.5, 0.4, 0.4)

Table 6 Aggregated pairwise comparison matrix of Socio-demographic sub-criteria

Criteria	C1.1	C1.2	C1.3
C1.1	(0.1965, 0.1965, 0.1965, 0.1965)	(0.0775, 0.1555, 0.8492, 1)	(0.1399, 0.1777, 0.7285, 1)
C1.2	(0.8492, 1, 0.0775, 0.1555)	(0.1965, 0.1965, 0.1965, 0.1965)	(0.7405, 0.8546, 0.1988, 0.3024)
C1.3	(0.7285, 1, 0.1399, 0.1777)	(0.1988, 0.3024, 0.7405, 0.8546)	(0.1965, 0.1965, 0.1965, 0.1965)

Table 7 The difference matrix of Socio-demographic sub-criteria

Criteria	C1.1	C1.2	C1.3
C1.1	(0, 0)	(−0.9940, −0.6970)	(−0.9804, −0.4992)
C1.2	(0.6970, 0.9940)	(0, 0)	(0.4569, 0.6908)
C1.3	(0.4992, 0.9804)	(−0.6908, −0.4569)	(0, 0)

Table 8 The interval multiplicative matrix of Socio-demographic sub-criteria

Criteria	C1.1	C1.2	C1.3
C1.1	(1, 1)	(0.0323, 0.0901)	(0.0338, 0.1784)
C1.2	(11.1049, 30.9729)	(1, 1)	(4.8460, 10.8696)
C1.3	(5.6069, 29.5552)	(0.0920, 0.2064)	(1, 1)

Table 9 The determinacy values of Socio-demographic sub-criteria

Criteria	C1.1	C1.2	C1.3
C1.1	1	0.703	0.5187
C1.2	0.703	1	0.7661
C1.3	0.5187	0.7661	1

Table 10 Socio-demographic sub-criteria weights before normalization

Criteria	C1.1	C1.2	C1.3
C1.1	1	0.043	0.055
C1.2	14.7908	1	6.0199
C1.3	9.1198	0.1143	1

and economic factors are more important in the formation of disease risk. It is concluded that factors related to national capacity, the healthcare system, and socio-demographic factors have a lower level of importance.

The burden of NCDs is increasing rapidly in low- and middle-income countries. It is known that 77% of all deaths due to NCDs occur in low- and middle-income countries. Most of these deaths are also due to CVDs factors such as changing living conditions, alcohol and tobacco use, urbanization and air pollution, changes in eating habits, and lack of physical activity increase the risk of death [8]. In this context, it is considered essential

Table 11 Socio-demographic sub-criteria weights

Criteria	Weights
C1.1	0.0331
C1.2	0.6581
C1.3	0.3088

Table 12 Main and sub-criteria weights

Main-criteria	Weights	Sub-criteria	Local weights	Global weights
C1	0.0142			
		C1.1	0.0331	0.0005
		C1.2	0.6581	0.0094
		C1.3	0.3088	0.0044
C2	0.0790			
		C2.1	0.3973	0.0314
		C2.2	0.6027	0.0476
C3	0.3699			
		C3.1	0.7572	0.2801
		C3.2	0.0261	0.0097
		C3.3	0.1397	0.0517
		C3.4	0.0770	0.0285
C4	0.4368			
		C4.1	0.1858	0.0811
		C4.2	0.2289	0.1000
		C4.3	0.1569	0.0685
		C4.4	0.1001	0.0437
		C4.5	0.1607	0.0702
		C4.6	0.1677	0.0732
C5	0.0403			
		C5.1	0.3598	0.0145
		C5.2	0.2212	0.0089
		C5.3	0.3941	0.0159
		C5.4	0.0249	0.0010
C6	0.0597			
		C6.1	0.5376	0.0321
		C6.2	0.1839	0.0110
		C6.3	0.2786	0.0166

to address CVDs risk factors from the point of view of low- and middle-income countries.

When looking at the sub-criteria, it is determined that the C3.1, C4.2, C4.1, C4.6, and C4.5 criteria have higher levels of importance than others. On the other hand, the C1.1, C5.4, C1.3, C5.2, and C1.2 criteria have a lower level of importance. The sub-criterion with the highest importance level is the prevalence of tobacco use in adults. This can be explained by the fact that tobacco use is a significant risk factor for cardiovascular and respiratory diseases and many types of cancer and other debilitating health conditions [58]. Additionally, tobacco use is one of the greatest public health threats, with more than 8 million tobacco-related deaths annually. Therefore, tobacco control remains a global health priority [81]. The second and third important sub-criteria are high blood sugar and blood pressure. The prevalence of hypertension and diabetes is also ranked high. Based on the results, it can be said that behavioral risk factors, especially metabolic ones, have a higher impact on the emergence of the disease compared to other criteria. High blood pressure, smoking, diabetes, and lipid abnormalities are major modifiable risk factors for CVDs [82]. Metabolic, behavioral, environmental, and social risk factors are major drivers of CVDs [83]. Another reason for these factors to be ranked high is that the level of importance of the main criteria is higher than that of other criteria. Urban population, number of hospital beds, air pollution rate, nurses and midwives, and population aged 65 and over are considered sub-criteria with the lowest level of importance. Although these criteria pose a risk for cardiovascular diseases, it is determined that they pose a lower risk level than other criteria. All socio-economic factors are ranked at lower levels. This result can be associated with the low level of importance of the main criterion.

Ranking of alternatives

The TOPSIS method was used to rank low- and middle-income countries. The importance levels of criteria calculated using the interval-valued PF-AHP method, as provided in Table 12, were utilized in applying the method. Data pertaining to countries were obtained from the WHO and The World Bank databases and the WHO's "*Noncommunicable Diseases Country Profiles 2018*" report, per the established criteria. The decision matrix containing the data of 90 alternative countries is given in Table A1 as an annex to the paper. Alternatives were ranked by applying Eqs. (20–25) to the decision matrix. The relative closeness values (C^{*}) calculated for each alternative as a result of the application of the TOPSIS method and the ranking according to these values are given in Table 13.

According to the TOPSIS results, Lebanon (A42), Jordan (A37), Solomon Islands (A73), Serbia (A71), and Bulgaria (A10) ranked at the top. The respective countries' higher importance level and benefit-oriented values of criteria C3.1, C4.1, C4.2, C4.5, and C4.6 can interpret this result. Criterion C3.1, which is particularly significant compared to other criteria, has been decisive in the ranking results. Timor Leste (A79), Benin (A6), Ghana (A30), Niger (A60), and Ethiopia (A26) are the countries that rank at the bottom. The countries at the lower ranks can be interpreted by the low values of the maximization-oriented criterion, which have higher importance

Table 13 Relative closeness of alternatives and final rank

Alt.	C^*	Rank	Alt.	C^*	Rank	Alt.	C^*	Rank	Alt.	C^*	Rank	Alt.	C^*	Rank
A1	0.4156	39	A19	0.2504	59	**A37**	**0.6543**	**2**	A55	0.2463	61	**A73**	**0.6430**	**3**
A2	0.4618	28	A20	0.1862	78	A38	0.4389	34	A56	0.6179	6	A74	0.4380	36
A3	0.4778	23	A21	0.2321	65	A39	0.1911	77	A57	0.3015	50	A75	0.3966	42
A4	0.5706	12	A22	0.2787	56	A40	0.4493	31	A58	0.5086	18	A76	0.4973	21
A5	0.5309	15	A23	0.2215	70	A41	0.5009	20	A59	0.1680	84	A77	0.4036	41
A6	0.1434	87	A24	0.5460	14	**A42**	**0.6597**	**1**	A60	0.1343	89	A78	0.5718	11
A7	0.5967	7	A25	0.2346	64	A43	0.4214	37	A61	0.4670	27	A79	0.1458	86
A8	0.3588	46	**A26**	**0.1304**	**90**	A44	0.1792	80	A62	0.2620	58	A80	0.4844	22
A9	0.2905	52	A27	0.5081	19	A45	0.4413	33	A63	0.1994	74	A81	0.5867	9
A10	0.6401	5	A28	0.2154	72	A46	0.1936	76	A64	0.3872	43	A82	0.1950	75
A11	0.2476	60	A29	0.5774	10	A47	0.4535	30	A65	0.5108	17	A83	0.1565	85
A12	0.2294	67	A30	0.1383	88	A48	0.4386	35	A66	0.4750	25	A84	0.4754	24
A13	0.1773	81	A31	0.2693	57	A49	0.1845	79	A67	0.2393	63	A85	0.2184	71
A14	0.1751	82	A32	0.4686	26	A50	0.2290	68	A68	0.5596	13	A86	0.3283	48
A15	0.4432	32	A33	0.5890	8	A51	0.4544	29	A69	0.2046	73	A87	0.4046	40
A16	0.2311	66	A34	0.2979	51	A52	0.3245	49	A70	0.1728	83	A88	0.3722	44
A17	0.3649	45	A35	0.4173	38	A53	0.5179	16	A71	0.6412	4	A89	0.2828	55
A18	0.2833	54	A36	0.2854	53	A54	0.3325	47	A72	0.2440	62	A90	0.2268	69

levels. In summary, countries with high values for maximization-oriented criteria and low values for minimization-oriented criteria ranked higher. Additionally, as with criterion C3.1, high-importance level criteria have impacted the ranking results.

It is stated that in Lebanon (A42), cardiovascular diseases are the leading cause of morbidity and mortality and also the primary cause of hospital admissions. It is stated that the burden of cardiovascular diseases is caused by the migration of nurses at a high rate, and the lack of workforce has a negative impact on patient outcomes [84]. With generally limited knowledge, attitude, and practice towards CVDs, the Lebanese population needs targeted national campaigns on CVDs to prevent and alleviate complications from CVDs [85]. In a paper conducted in Lebanon in 2017, it was concluded that the highest declared awareness of CVDs risk factors was related to smoking [86]. In our research, the most critical risk factor was found to be smoking. In this context, it can be stated that the relevant research supports the results of our paper.

It is stated that between 1990 and 2019, the burden of CVDs decreased in Jordan, but the prevalence of the disease and the number of deaths increased. CVDs remain the leading cause of death in Jordan [87]. Jordan ranked second in the research.

Ranking third is the Solomon Islands (A73) Pacific Region country. Other Pacific countries ranked differently in the research. A study on Pacific people revealed that the epidemiology of CVDs varies according to specific ethnic groups, place of birth, and country of residence [88]. The relevant research results are parallel to our research results.

In the ranking obtained from the TOPSIS method, it can be observed that the majority of the countries at the top are from the "*European Region*." Following that, the "*Eastern Mediterranean Region*" is represented. The countries at the bottom are primarily from the "*African Region*", followed by the "*South East Asia Region*". It can be said that urbanization, an aging population, and increasing air pollution are parallel with the development level. The obtained result can be explained by the lower level of development in the African region compared to the countries in the European Region.

Scenario analysis

In this section, scenario analyses are conducted to analyze the impact of changes in criteria weights on the final rankings. For this purpose, five different scenarios were created and tested. The scenarios and their descriptions are summarized in Table 14. According to the criteria weights determined from the scenarios, final rankings were obtained by the TOPSIS method for each scenario. Table 15 shows the rankings obtained as a result of five different scenarios.

When the final rankings obtained as a result of the scenarios are analyzed, it is seen that Lebonanon (A42), which ranked first in the ranking obtained by evaluating all criteria (Table 13), also ranked first in the S5 scenario. This can be explained by the fact that the sum of the importance levels of the sub-criteria under the main

Table 14 Descriptions of scenarios

Scenario	Descriptions
S1	All criteria weights are equal (0.0455)
S2	Main criteria weights are equal. Main criteria weights are distributed to sub-criteria in proportion to their local weights.
S3	Only the sub-criteria under main criterion C3 were evaluated according to their weights.
S4	Only the sub-criteria under main criterion C4 were evaluated according to their weights
S5	Only the sub-criteria under main criteria C3 and C4 were evaluated according to their weights.

criteria C3 and C4 is approximately 0.8. Similarly, Solomon Islands (A73) ranks third in Table 13 and second in the S5 scenario. However, Ethiopia (A26) ranks last in both the final ranking in Table 13 and in the S3 and S5 scenarios. This can be explained by the fact that Ethiopia (A26) has low values in most of the criteria with high importance levels. Apart from these cases, when the rankings obtained as a result of the other scenarios are analyzed, it is seen that there are significant differences. This is due to the fact that the importance levels of the main criteria C1, C2, C5, and C6 are considerably lower than the main criteria C3 and C4. When the scenarios are examined, it is seen that the S5 scenario gives the closest results to the research results. Studies in the literature confirm that behavioral and metabolic risk factors are more significant than other factors [12, 83, 89–94]. A42 ranks first in the research result and the S5 scenario. The S3 scenario gives similar results. In the S3 scenario, A42 ranked fourth. The rankings in other scenarios are different. The order of A37 is the same for scenarios S1 and S2. It is seen that the closest result is again in the S5 scenario. A73 ranks second in the S5 scenario. For A73, the rankings of S3 and S4 are very close. A73 ranks seventh in S3 and eighth in S4. A26 ranks last in the research. The country coded as A26 also ranked last in S3 and S5 scenarios.

Conclusion

In the paper, 22 criteria were identified to assess the risk of cardiovascular disease in low and middle-income countries. Due to the varying importance levels of the criteria, the interval-valued PF-AHP method was used to calculate the importance levels of the criteria. Five expert physicians were consulted for the evaluation of the criteria. As a result of the assessments, the criteria with the highest importance levels were determined to be adult tobacco use prevalence (C3.1), Raised blood glucose among adults aged 18 years and older (C4.2), Raised blood pressure among adults aged 18 years and older (C4.1), Hypertension prevalence among adults aged 30–79 years (C4.6), and Diabetes prevalence among individuals aged 20–79 years (C4.5). On the other hand, the criteria with the lowest importance levels were found to be Urban population (C1.1), Hospital beds per 10,000 population (C5.4), PM2.5 air pollution, mean annual exposure (C1.3), Nurses and midwives per 10,000 population (C5.2), and Population aged 65 years and older (C1.2). According to the results of the interval-valued PF-AHP, the criterion with the highest importance level was identified as adult tobacco use prevalence. It is believed that measures such as restricting smoking or implementing smoke-free policies can help reduce the risk of disease. Therefore, policies aimed at reducing tobacco use can be adopted, such as increasing cigarette prices, restricting cigarette advertisements, and educating the public about the dangers of smoking.

Following the interval-valued PF-AHP, the determined importance levels of the criteria and compiled data for countries, the TOPSIS method was applied, and country rankings were obtained. The ranking results show that the countries with higher cardiovascular risk are Lebanon, Jordan, Solomon Islands, Serbia, and Bulgaria, in that order. On the other hand, the countries ranked at the bottom are Timor-Leste, Benin, Ghana, Niger, and Ethiopia, respectively.

Reducing the burden of cardiovascular disease or death from any cause for individuals and societies can be achieved by better understanding cardiovascular risk factors and region- and gender-specific factors in disease development [95]. Countries ranking high in TOPSIS results are those with the highest cardiovascular risk. In this context, it is recommended that these countries engage in various activities to reduce the risk of cardiovascular disease. Measures can be taken not only for CVDs but also for lifestyle and habits that play a role in the development of NCDs. It is advisable to ensure and maintain a safe environment, raise awareness among the community about environmental factors that pose a risk of disease, and assist with lifestyle changes that contribute to health risks. Individuals can be encouraged to adopt a healthy diet, limit salt consumption, engage in regular exercise, quit smoking, aim for and maintain a healthy body weight, and manage stress, all of which can help reduce cardiovascular disease risk at the individual level.

Table 15 Scenario analysis

S1				**S2**				**S3**				**S4**				**S5**			
Alt.	**Rank**	**Alt.**	**Rank**	**Alt.**	**Rank**	**Alt.**	**Rank**	**Alt.**	**Rank**	**Alt.**	**Rank**	**Alt.**	**Rank**	**Alt.**	**Rank**	**Alt.**	**Rank**	**Alt.**	**Rank**
A1	17	A46	68	A1	22	A46	72	A1	39	A46	70	A1	23	A46	74	A1	38	A46	75
A2	77	A47	69	A2	65	A47	82	A2	28	A47	36	A2	27	A47	12	A2	28	A47	29
A3	71	A48	89	A3	23	A48	88	A3	22	A48	24	A3	25	A48	46	A3	25	A48	34
A4	13	A49	37	A4	27	A49	30	A4	9	A49	75	A4	39	A49	76	A4	12	A49	79
A5	**90**	A50	18	A5	89	A50	16	A5	13	A50	62	A5	24	A50	61	A5	15	A50	66
A6	52	A51	42	A6	58	A51	57	A6	86	A51	42	A6	86	A51	5	A6	87	A51	30
A7	62	A52	61	A7	35	A52	76	A7	8	A52	58	A7	26	A52	10	A7	7	A52	48
A8	39	A53	85	A8	5	A53	83	A8	46	A53	17	A8	51	A53	33	A8	46	A53	16
A9	73	A54	10	A9	41	A54	19	A9	56	A54	50	A9	35	A54	18	A9	51	A54	49
A10	82	A55	55	A10	75	A55	51	**A10**	**2**	A55	57	A10	19	A55	77	**A10**	**3**	A55	61
A11	28	A56	53	A11	26	A56	71	A11	52	**A56**	**1**	A11	87	A56	60	A11	62	A56	6
A12	45	A57	31	A12	24	A57	6	A12	66	A57	48	A12	59	A57	54	A12	68	A57	52
A13	14	A58	19	A13	20	A58	25	A13	83	A58	14	A13	69	A58	45	A13	84	A58	19
A14	36	A59	30	A14	39	A59	32	A14	81	A59	84	A14	68	A59	65	A14	81	A59	83
A15	83	A60	23	A15	81	A60	17	A15	23	A60	88	A15	44	A60	88	A15	32	A60	88
A16	54	**A61**	**2**	A16	33	A61	18	A16	71	A61	40	A16	41	A61	4	A16	64	A61	27
A17	63	A62	32	A17	63	A62	40	A17	44	A62	60	A17	48	A62	37	A17	45	A62	57
A18	4	A63	47	**A18**	**2**	A63	43	A18	49	A63	77	A18	63	A63	57	A18	58	A63	74
A19	76	A64	74	A19	42	A64	80	A19	69	A64	34	A19	32	A64	66	A19	59	A64	43
A20	48	A65	80	A20	52	A65	84	A20	72	A65	16	A20	78	A65	34	A20	78	A65	17
A21	35	A66	87	A21	28	A66	87	A21	59	A66	20	A21	79	A66	31	A21	67	A66	22
A22	27	A67	50	A22	37	A67	59	A22	65	A67	54	A22	20	A67	85	A22	53	A67	63
A23	75	A68	26	A23	69	A68	66	A23	64	A68	27	A23	56	**A68**	**2**	A23	65	A68	13
A24	**1**	A69	20	A24	12	A69	11	A24	31	A69	78	**A24**	**1**	A69	62	A24	14	A69	76
A25	12	A70	29	**A25**	**3**	A70	34	A25	76	A70	79	A25	53	A70	72	A25	72	A70	80
A26	56	A71	81	A26	55	A71	70	**A26**	**90**	**A71**	**3**	A26	84	A71	21	**A26**	**90**	A71	5
A27	41	A72	46	A27	78	A72	47	A27	35	A72	55	**A27**	**3**	A72	73	A27	18	A72	60
A28	24	A73	25	A28	15	A73	67	A28	67	A73	7	A28	71	A73	8	A28	73	**A73**	**2**
A29	67	**A74**	**3**	A29	60	**A74**	**1**	A29	12	A74	41	A29	14	A74	17	A29	10	A74	36
A30	60	A75	72	A30	49	A75	79	A30	89	A75	38	A30	82	A75	43	A30	89	A75	42
A31	33	A76	21	A31	45	A76	29	A31	63	A76	26	A31	30	A76	11	A31	56	A76	21
A32	8	A77	66	A32	14	A77	77	A32	19	A77	37	A32	50	A77	38	A32	26	A77	40
A33	49	A78	78	A33	61	A78	74	A33	6	A78	5	A33	47	A78	67	A33	8	A78	11
A34	59	A79	58	A34	53	A79	56	A34	53	A79	87	A34	28	A79	81	A34	50	A79	86
A35	5	A80	7	A35	10	A80	8	A35	45	A80	30	A35	9	A80	16	A35	37	A80	23
A36	11	A81	38	A36	21	A81	38	A36	74	A81	15	A36	15	A81	7	A36	54	A81	9
A37	9	A82	84	A37	9	A82	85	A37	10	A82	85	A37	6	A82	36	A37	4	A82	71
A38	88	A83	57	**A38**	**90**	A83	54	A38	33	A83	82	A38	22	**A83**	**90**	A38	33	A83	85
A39	65	A84	70	A39	64	A84	62	A39	68	A84	21	A39	89	A84	29	A39	77	A84	24
A40	79	A85	15	A40	73	A85	36	A40	25	A85	73	A40	42	A85	52	A40	31	A85	70
A41	34	A86	86	A41	48	A86	86	A41	11	A86	47	A41	75	A86	40	A41	20	A86	47
A42	40	A87	64	A42	31	A87	68	A42	4	A87	29	A42	13	A87	80	**A42**	**1**	A87	41
A43	22	A88	6	A43	4	A88	7	A43	32	A88	43	A43	58	A88	49	A43	39	A88	44
A44	44	A89	16	A44	46	A89	13	A44	80	A89	51	A44	70	A89	55	A44	82	A89	55
A45	43	A90	51	A45	50	A90	44	A45	18	A90	61	A45	83	A90	64	A45	35	A90	69

Primary and secondary preventive activities should be implemented to reduce the burden of CVDs, along with institutional support, public education, community-based risk reduction efforts, healthy work environments, information systems for monitoring morbidity, and well-informed healthcare personnel [3]. The approach to CVDs prevention should be multidisciplinary, focusing on reducing overall risk by considering multiple risk factors rather than individual ones. The goal of preventing heart and vascular diseases is to decrease fatal and non-fatal atherosclerotic events, complications, and the need for percutaneous or surgical revascularization while improving and extending quality of life [14]. To achieve this goal, a comprehensive assessment of total cardiovascular risk and a corresponding treatment strategy is necessary. Within this framework, remedial actions can be undertaken. In the fight against cardiovascular diseases, identifying cardiovascular risk factors and preventing or minimizing these risks should be targeted. Educating the community about the benefits of healthy eating and regular physical activity for a healthier life is recommended. Developing and implementing policies aimed at reducing CVDs risk would be beneficial. Countries with a high CVDs risk can support policies that promote healthy eating and physical activity. Activities such as improving the accessibility of healthy foods, limiting advertisements that encourage the consumption of unhealthy foods, and implementing healthy eating programs in schools and workplaces can be pursued. Strengthening healthcare services can enhance early diagnosis and treatment options. Information campaigns can be organized to raise awareness about CVDs screening and risk assessment. Increasing the number of expert physicians who assess and manage CVD risk is also considered beneficial.

As a result of the evaluations, the risk factors with the highest and lowest levels of importance were identified. Prioritization of CVDs risk factors can contribute to managing disease risk, providing education and counseling services, improving community health, and increasing community awareness. In addition, prioritization of CVDs risk factors can provide health professionals with education and counseling according to risk factors. Identifying high-risk factors may provide the opportunity to take the necessary measures for these factors and early intervention. In this way, health outcomes related to the disease can be improved, but the burden on health systems can also be reduced. Health professionals can decide on forming clinical guidelines according to more critical risk factors. At the same time, community health programs can be designed by considering more critical risk factors. Sorting risk factors according to their severity can help health professionals decide which risk factors should be addressed first. Prioritization of CVDs risk factors may also be helpful in the design of social health policies.

The approach proposed in this paper to rank low- and middle-income countries regarding cardiovascular disease risk factors has some limitations. Some of these problems are related to the MCDM method, while others are related to the data. The results obtained in the interval-valued PF-AHP method used to weight cardiovascular disease risk factors were calculated as a result of the personal judgments of the decision-making team. In future studies, the results can be discussed with the participation of more decision makers. PFSs and the linguistic scale used are not universal. Different fuzzy set extensions and scales can be used in different studies. It could not be included in this paper due to the limited number of countries sharing data for the "red meat consumption" criterion, which may be effective in the formation of cardiovascular disease. In addition, some low- and middle-income countries could not be evaluated due to lack of data on the criteria used. Providing this missing data allows countries to be re-ranked according to their risk potential.

Supplementary Information

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Supplementary Material 1.

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Authors' contributions
GZA is responsible for communicating with the interviewers, acquisition of data, interpretation of data and drafting of the article. BÖ is responsible for determining the methodology, performing mathematical calculations, and drafting and supervising the article. All authors have reviewed the article. All the authors read and approved the final manuscript.

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Data availability
No datasets were generated or analysed during the current study.

Declarations

Ethics approval and consent to participate
On December 30, 2022, Ethical Permission was obtained from the Social and Human Sciences Research Ethics Committee of Ondokuz Mayıs University with decision number 2022 – 1182. The principles of the Declaration of Helsinki were followed in the collection of research data and in all processes associated with this research.

Consent for publication
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