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Review

Applying the Sustainability Barometer Approach to Assess Urban Sustainability

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Abstract: Sustainability is a multidisciplinary developing science, and sustainable urban development focuses on socioeconomic, cultural, and environmental dimensions. Sustainable urban development is considered as a form of development covering urban spaces. Therefore, sustainability is regarded as one of the most important issues in urban planning. The present study aims to evaluate urban sustainability in nine regions of Tehran's District 4 using the barometer of sustainability. The study area, covering twenty populous areas with various socioeconomic, cultural, and environmental problems, is located in the northeast of Tehran. The results obtained from overall sustainability and Prescott-Allen ranking indicate that regions 7, 6, 2, 3, and 8 are in medium sustainability level with the scores of 0.492, 0.484, 0.471, 0.411, and 0.457 respectively. However, other regions including regions 9, 1, 4 and 5 with the scores of 0.370, 0.330, 0.281 and 0.274, respectively, were found to be potentially unsustainable. In terms of human and ecosystem well-being, regions 2 and 3 gained the highest score, and regions 9 and 5 had the lowest scores. Based on the results, some practical solutions were provided to improve the sustainability in the area.

Keywords: urban sustainability assessment; barometer of sustainability; sustainability radar; sustainability indicators; district four; Shannon entropy weighting

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1. Introduction

Nowadays, urbanization is rapidly developing around the world. Only 2% of the world's population were living in urban areas in 1800, which rose to 14% in 1900 and 50% in 2008. It is predicted that the urban population will increase to 100% by 2092 [1]. Therefore, little attention has been paid to spatial equality as one of the most important development principles in sustainable urban development. [2]. In general, developed cities are faced with some problems such as urban decay, environmental pollution, infrastructural shortage, social issues, and economic recession [3]. Cities are recognized as complex socioeconomic and environmental ecosystems and provide various welfare services for their citizens, which increase the use of non-renewable resources and lead to various pollutions [4]. Therefore, problems and inadequacies in urban areas will increase and prevent urban sustainability if the principles of sustainable development in urban planning are not considered [5]. For sustainable urban development to be achieved, it is necessary to understand sustainability holistically, which requires understanding concepts, approaches, methods, tools, and techniques [6].

Various methods have been formed in relation to sustainability assessment [7]. However, multicriteria decision-making methods are commonly used and they are divided into multiple-objective decision-making (MODM) and multiple-attribute decision-making (MADM) models. Most of the MADM models such as technique for order performance by similarity to ideal solution (TOPSIS), analytic hierarchy process (AHP), analytic network process (ANP), and preference ranking organization method for enrichment evaluation (PROMETHEE) are considered to rank options [8].

Ameen and Mourshed [9] investigated the development of a sustainability assessment framework in cities of Iraq using the AHP method to rank the urban sustainability indicators. In another study, TOPSIS was used to assess urban sustainability in 16 cities in the Anhui province of China [10]. Furthermore, multicriteria decision-making methods were used to evaluate environmental sustainability in 27 metropolitan areas of Canada, the USA, and region 17 of Tehran in Iran [11,12]. Notably, multicriteria decision-making techniques are used in a limited number of studies to assess urban sustainability. For example, Mateusz et al. [13] studied sustainable development in 27 European countries using the Vlse Kriterijumska Optimizacija Kompromisno Resenje which means multicriteria optimization and compromise solution, in Serbian (Vikor) and TOPSIS methods. Furthermore, Shmelev [14] investigated the sustainability of 12 metropolises in the world using other multicriteria decision-making methods such as elimination et choice in translating to reality (ELECTER) and novel approach to imprecise assessment and decision environment (NAIADA). The multicriteria decision-making techniques such as preference ranking organization method for enrichment evaluation (PROMETHEE) fuzzy logic, analytic network process (ANP) and decision-making trial and evaluation laboratory (DEMATEL) were used in several studies [3,15–17].

According to the results of urban sustainability assessment in the present study, some strategies such as increasing public participation and green space per capita, improving the spatial distribution of infrastructure and urban transport, promoting community culture on environmental issues, using natural resources more rationally, and reducing environmental pollutants are presented. Urban sustainability consists of various dimensions and indicators with interactive effects and may not be easily measurable [18]. Sustainability is an interdisciplinary and complex science. Therefore, it is necessary to use comprehensive methods which are flexible in indicator selection and execution at different scales to evaluate sustainability. Although most of the sustainability assessment tools focus on one aspect of sustainability, a few of them rely on an integrated approach to cover the relations and dynamics of all three aspects of sustainability [19]. This can be considered as the reason why some researchers believe that most of the multicriteria decision-making methods for the evaluation of sustainability are not comprehensive [20]. In this respect, many studies have been done on urban sustainability assessment tools. [6,21–26]. In 1997, a model for sustainability assessment, called the barometric model, was proposed [18,27], and was more accurate and practical compared to the other methods. The approach allowed the identification and determination of appropriate urban planning solutions and strategies.

Assessment of urban sustainability using the barometer approach aided by a sustainability radar tool has been reported in some studies. For instance, Batalhão et al. [28] used 52 indicators to assess the sustainability in the Ribeirão Preto Region of Rio de Janeiro considering two broad dimensions of the barometer method. The results indicated that the Ribeirão Preto is at medium sustainability and has a better performance in terms of human well-being. This method was also used to analyze the sustainability of 10 regions in Tabriz [29]. Another study in India, the sustainability assessment of the Gram Panchayat of Dasudi in central Karnataka, was addressed. This project was conducted by IUCN in 1998–1999, by which 28 indicators were evaluated based on the barometric method. The results indicated that the region is potentially unsustainable [30]. This method has been used in other studies to assess water sustainability and agricultural sustainability [31–33]. This assessment tool was chosen for measuring sustainability in the present study since it has some significant advantages over other approaches:

1. It gives equal attention to people and the ecosystem in quantified and combined themes, since both are essential for sustainable development in the long term. This means that it has two comprehensible and broad dimensions of ecosystem well-being and human well-being, which cover all environmental and human well-being needs.
2. It consists of an analytical hierarchy, developed from a shared vision of sustainability to specific measurements via identifying elements and objectives.

3. It is a powerful visual and analytical tool that helps users articulate and assess overall sustainability and specific areas of concern.
4. Its methodological structure provides a communication performance that allows researchers to combine different indicators and show how each contributes to the performance of themes and the overall vision. Too often, the communicative power of indicators is obscured by hidden assumptions and excessive complexity. This remarkable advantage provides appropriate indicators of socioeconomic and environmental dimensions, which make the effects of the dimensions mutually measurable.
5. Flexibility was the most notable feature of this application method in current research because it can be applied to support a broad range of uses and can be scaled according to needs and resources without losing the central message or sacrificing essential features. This means that it can be applied from the local to the global scale.
6. Its ease of use makes many users prefer this method to mathematical and statistical methods.
7. Its scale is divided into five parts, from zero to one, allowing the user to control the situation in several parts.

The purpose of this paper is to evaluate the urban sustainability of District 4 of Tehran, consisting of twenty neighborhoods, using the barometer model.

2. Materials and Methods

2.1. Study Area

Tehran metropolis covers an area of 730 km^2 and lies between the latitudes of 35°34′ to 35°59′ N and longitudes 51°5′ to 51°53′ E. The southern mountains of Central Alborz cover the northern and northeastern parts of Tehran. The city is surrounded by Savojbolagh Plain on the west and Rey and Bibi Shahrbano Mountains and salt desert plains on the south. The altitude varies from 1000 m in the southern areas to 1700 m in the northern areas of Tehran. Since the city is located on foothills, the weather condition in its different urban areas is very diverse and this gives it a unique feature. In Tehran, the average daily temperature is about 17.6 °C and the average annual rainfall is 247.9 mm. The mean long-term precipitation in Tehran is estimated to be 45 mm in March. Its northern parts have a mild climate during summer and a cold climate in winter, and its central regions have relatively warm summers and mild winters. The required water is mainly supplied from Karaj, Latian and Lar dams and 400 wells around the city. About 1308 plant species, 136 bird species, 38 mammal species, 28 reptile species, 2 amphibian species, and 10 fish species have been identified in Tehran [34]. Being the capital of Iran, Tehran and its 22 regions have a population of about 8,679,936 [35].

In Iran, the urbanization rate is estimated to be 74%, and several populations have settled in Tehran in search of prosperity, educational and recreational facilities, cultural and employment opportunities and income. Rapid growth of urbanization and a high rate of migration to Tehran have made it the most populous city of Iran and caused environmental pollution and population imbalances in its regions. In this study, the urban sustainability in the broadest and the most populated area in the northeast of Tehran (District 4) was investigated using the barometer of sustainability [34].

District 4, with an area of 161.5 km^2, has a population of 917,261 people, including 456,394 men and 460,867 women. This district shares a common border with District 1 at the north, Districts 7, 8 and 13 at the south, Districts 1 and 3 at the west, and Semnan Province at the east (Figure 1). Its 9 regions and 20 neighborhoods along with the related demographic information are presented in Table 1. According to the statistics in 2017, the rate of immigrants entering District 4 is estimated as 39.1%, which is very significant. District 4 plays an important role in supplying the water and electricity of Tehran due to its expanded area and underground water resources including the Latian dam which supplies 30% of the required drinking water. Therefore, the sustainability of 9 regions in this strategic area has been investigated in this study.

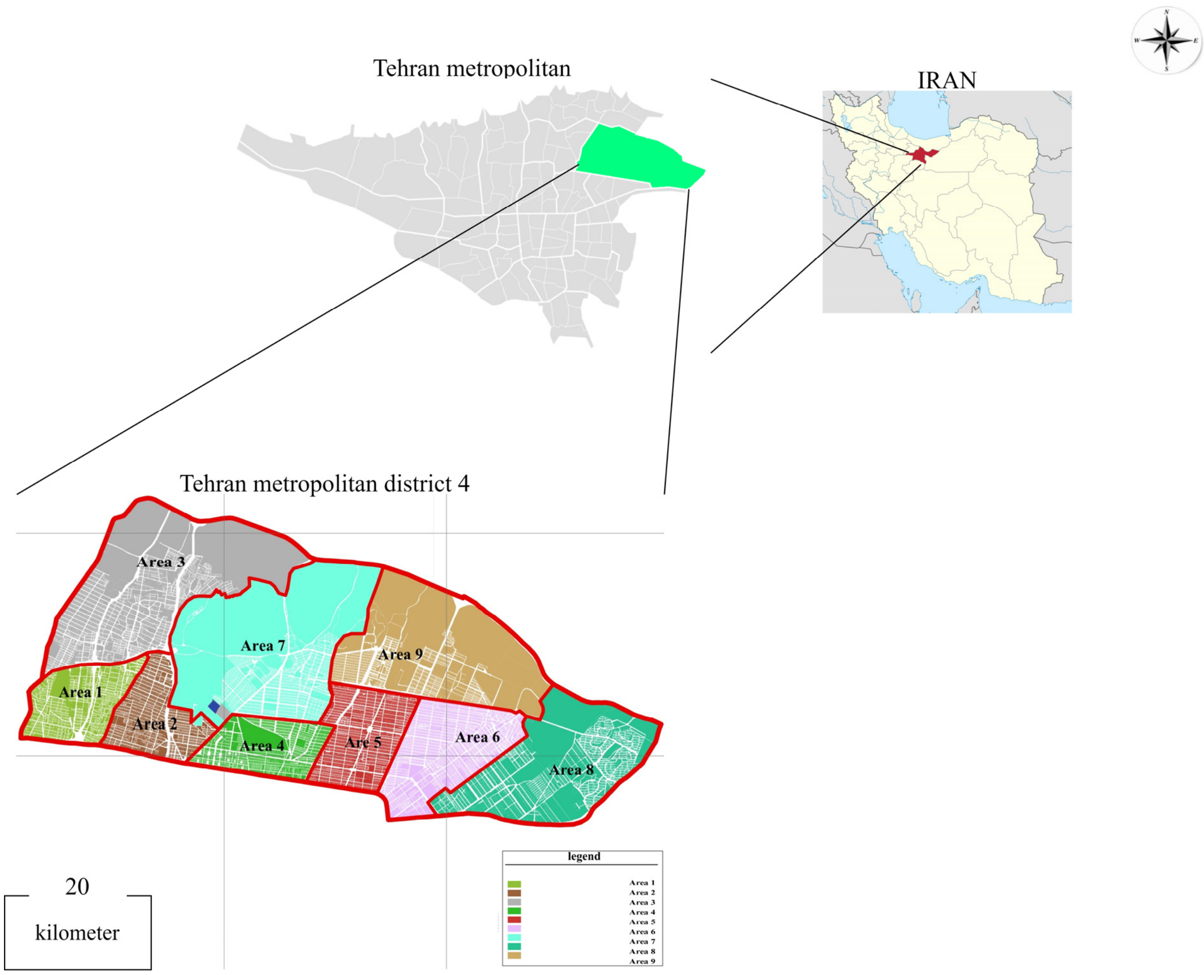


Figure 1. Study area.

Table 1. Specifications of the 9 regions of District 4.

Urban Area	Population	Area (km^2)
1	59,725	3,520,807
2	89,606	3,394,948
3	107,822	11,650,524
4	76,664	3,306,257
5	124,634	4,028,956
6	182,898	5,197,350
7	116,508	12,226,016
8	62,361	8,463,356
9	97,043	9,589,067

2.2. Research Process

To assess the urban sustainability in 9 regions of District 4 of Tehran, 53 indicators were used in two broad levels of ecosystem well-being and human well-being in socioeconomic, environmental, and cultural environments. The steps of the research process are illustrated in Figure 2. Sustainability indicators are the tools that measure the conditions of an urban area by means of a variety of factors [36]. Knowing that indicators are powerful tools for assessing the progress toward sustainable development, in the current research, indicators were selected by studying relevant studies trusted by experts and prominent international centers, such as Mercer, Arcadis, UN, World Health, World Bank, Organization for Economic Co-operation and Development (OECD), and the International Union for Conservation of Nature (IUCN) [27,37–42]. The list of used indicators is given in Table 2 and the detail of indicators' selection is explained in Section 2.3.2.

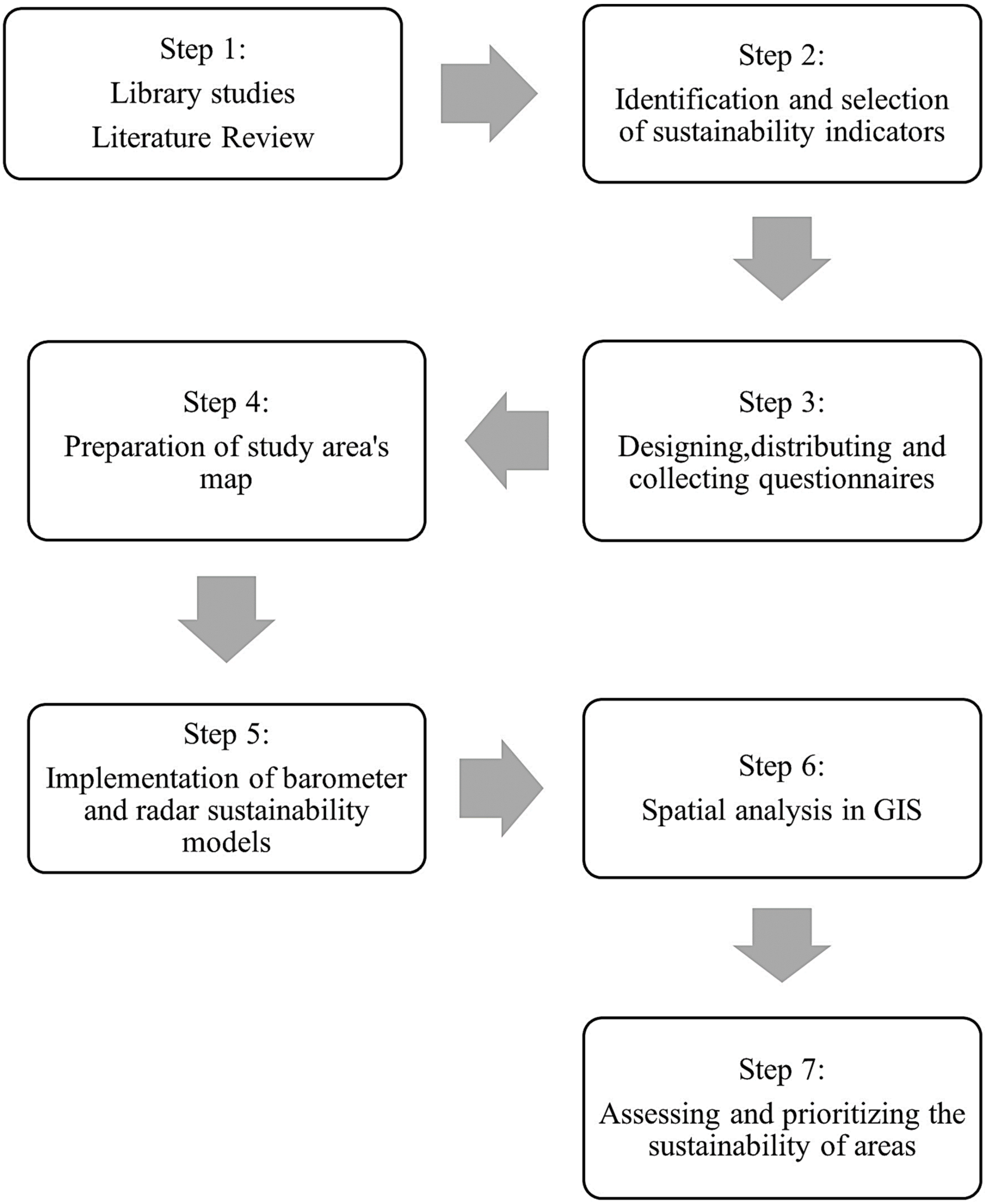


Figure 2. Flowchart of the research process.

Table 2. Final indicators used to assess the urban sustainability in 9 regions of District 4: Ecosystem well-being/environment (1–18) human well-being/socioeconomic and cultural dimensions (19–53).

Main Dimensions	Categories	Components	Basic Indicators	Normalization Values of the 9 Regions								
				1	2	3	4	5	6	7	8	9
Ecosystem well-being (E_1)	Environmental ($E_{1,1}$)	Land use capability ($E_{1,1,1}$)	1. Land use planning per capita %	0.020	0	0.647	0.038	0.585	1	0.652	0.223	0.085
			2. Urban decay ratio %	0.507	1	0.072	0.820	0.527	0.107	0	0.331	0.265
		Health and environmental quality ($E_{1,1,2}$)	3. Number of parks and green spaces collection	0.428	1	0.586	0.413	0.172	0.551	0.310	0.310	0
			4. Parks and green space area %	0.519	0.589	0.461	0.165	0.102	0.298	1	0	0.0008
			5. Number of plant species	1	0.666	0.333	0	0.666	0.333	0.666	0.333	0.333
			6. Air pollution %	0.459	0	1	0.108	0.648	0.459	0.432	0.054	0.495
			7. Water pollution%	0.233	0.077	1	0	0.864	0.330	0.572	0.019	0.203
			8. Noise pollution%	0	0.095	0.047	0.428	0.428	1	0.428	0.190	0.190
			9. Soil pollution %	1	0.952	0.142	0.333	0.190	0.666	0	0.761	0.190
			10. Satisfaction rate with collection of garbage	0.75	1	0.75	0.75	0.5	0.5	0.5	0	0.25
			11. Street and urban space cleaning	0.333	1	1	1	0.666	0.666	0.666	0	0.666
			12. Number of recycling pat	0	1	0.75	0.5	0.5	0	0.5	0.25	0
			13. Waste generation %	0	0.242	0.390	0.108	0.526	1	0.460	0.020	0.302

Table 2. *Cont.*

Main Dimensions	Categories	Components	Basic Indicators	Normalization Values of the 9 Regions								
				1	2	3	4	5	6	7	8	9
		Energy consumption and transportation ($E_{1,1,3}$)	14. Water consumption %	0.0024	0.091	0	0.328	0.004	0.082	0.002	1	0.0028
			15. Power consumption %	0.692	0.832	0.289	0	0.117	0.272	0.688	1	0.030
			16. Natural gas consumption %	0.006	0	0.313	1	0.202	0.470	0.127	0.184	0.500
			17. Mean time to reach the bus stop (minutes)	1	0.148	0.851	0.185	0.296	0.037	0	0.666	0.333
			18. Mean time to reach the subway station (minutes)	0.166	0.277	0.444	0	0.055	0.305	0.361	1	0.916
Human well-being (H_1)	Socioeconomic ($H_{1,1}$)	Safety and security ($H_{1,1,1}$)	19. Security rate for women and children	0.75	1	0.75	0.75	0	0.5	0.5	0.5	0.75
			20. Feeling of security and social peace	0.75	1	0.5	0.5	0	0.75	0.5	0.5	0.75
		Demographic characteristics and social welfare ($H_{1,1,2}$)	21.Population density %	0	0	0.5	0	0.5	1	0.5	0	0.5
			22.Population growth rate %	0.144	0.837	0	0.454	0.725	0.537	0.240	0.685	1
			23.Age variation%	0.751	0.827	0	0.650	0.171	0.771	0.628	0.785	1
			24. Family size	0	0	0.333	0.333	0	0.666	0.666	1	0.666
			25. Sex ratio %	0	0.2	0.2	0.2	0.1	1	0.9	1	0.6
			26.Aging population %	0.906	1	0.195	0.565	0.634	0	0.218	0.233	0.562
			27. Rate of mortality per 1000 people	0	0.242	0.391	0.1373	0.5273	1	0.4608	0.0209	0.3028
			28. Divorce rate per 1000 people	0.931	0.819	0.472	0.820	1	0.165	0.121	0	0.411

Table 2. *Cont.*

Main Dimensions	Categories	Components	Basic Indicators	Normalization Values of the 9 Regions								
				1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
			29. Immigration rate per 1000 people	0	0.121	0.390	0.1371	0.5276	1	0.4609	0.0206	0.3028
			30. Dependency burden or rate	0.302	0.046	0.486	0.254	0.337	0	0.018	1	0.715
			31. Satisfaction with the amount of income	0.25	1	0.75	0.25	0.25	0	0.75	0.75	0
			32. Employment rates	0.359	0.902	1	0.770	0	0.953	0.928	0.252	0.148
			33. Quality of life	0	1	0.75	0	0	0.5	0	0.25	0.25
			34. Average cost of buying one square metre of a house	0.637	0.658	1	0.410	0.400	0.008	0	0.252	0.197
			35. Employment rate per 10,000 people	0.341	0.687	0.076	0.555	0.805	1	0.104	0	0.095
			36. Percentage of female-headed households	0	0.307	0.384	0.153	0.538	1	0.461	0	0.307
			37. Ratio of the population to the people with higher education	0.410	0.330	1	0.174	0.764	0.584	0.660	0	0.421
			38. Literacy rate	0.896	0.778	1	0.657	0.874	0	0.070	0.807	0.756
		Infrastructure and urban services ($H_{1,1,3}$)	39. Number of fire stations	0.5	0.5	1	0	0.5	0.5	1	0.5	0.5
			40. Number of banks	0.379	0.172	1	0.310	0.655	0.344	0.206	0	0.137
			41. Number of petrol stations	0.5	0.5	1	0.5	0	0	0.5	1	0.5

Table 2. *Cont.*

Main Dimensions	Categories	Components	Basic Indicators	Normalization Values of the 9 Regions								
				1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
			43. Number of health centres	0.052	0.210	0.263	0	0.157	0.421	0.368	1	0.263
			44. Access to fire stations (minutes)	0.777	0.555	1	0.444	1	0	0.111	0.111	0
			45. Access to police stations (minutes)	0	0	0.25	0.125	0.125	0	1	0.875	0.25
			46. Access to hospitals (minutes)	0.5	1	0.5	0.125	0	0.75	0.75	0.375	0.75
			47. Access to health centers (minutes)	0.428	1	0.527	0	0.142	0	0.285	0.142	0
	Cultural ($H_{1,2}$)	Cultural places ($H_{1,2.,1}$)	48. Number of cultural corporations	0	0	0	0	0	1	1	0	0
			49. Number of cinemas	0	0	1	0	0	1	1	0	1
			50. Number of libraries	0.25	1	0.75	0	0	0	0.5	0.5	0.25
			51. Number of tourist attractions	0	0	0.5	0	0	0	1	1	1
		Religious places ($H_{1,2.,2}$)	52. Number of religious centers	0	0.5	0	0.1	0	0.4	1	0.6	0.3
			53. Number of mosques	0.2277	0.2273	0.090	0	0.090	1	0.545	0.090	0.2723

The required data were collected by referring to the Iranian Statistics and Information Agency, Tehran Municipality District 4 (Deputy of Urban and Environmental Services, Traffic and Transportation, Social and Cultural Affairs) and the Studies and Planning Centre of Tehran Municipality, although some of the indicators were calculated for the first time in this research. The barometer of sustainability method (IUCN approach) was used to assess the data.

2.3. Barometer of Sustainability Method

The sustainability barometer is a tool developed by Prescott-Allen and the International Union for Conservation of Nature (IUCN) for sustainability assessment. This method is a structured analytical process to assess the progress toward sustainability. In fact, it integrates ecosystem well-being and human well-being to examine the human and environmental progress toward sustainability and can be used to assess the different urban scales.

This method is explained in 7 steps [18], as shown in Figure 3.

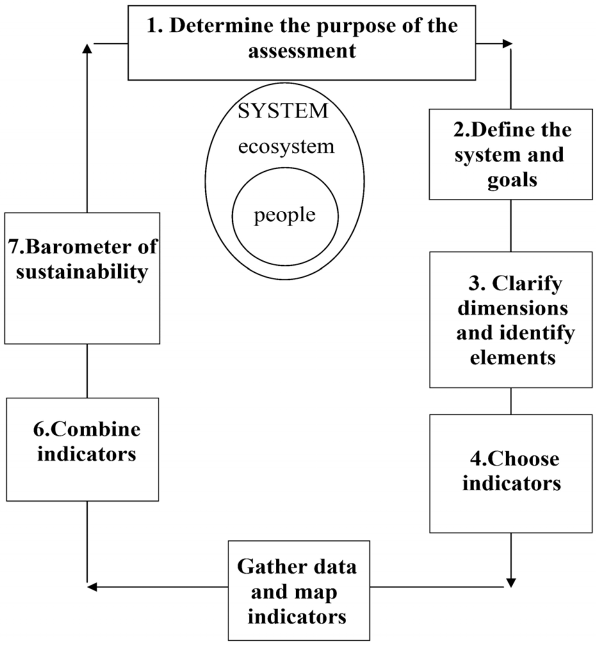


Figure 3. Seven stages of the IUCN approach cycle.

In the present study, sustainable development is human well-being and ecosystem well-being likened to an egg whose yolk is people and white part is ecosystem (Figure 4). In this sense, an egg will be healthy when both parts are in good health. It means that a sustainable society is achieved when both people and the environment are in good condition. People are an integral part of the ecosystem and the well-being of each has a direct effect on both. In fact, human well-being may be provided by over-use of environmental resources such as changing forest land use to agricultural land use, but humans should definitely adapt themselves to the environment to live in prosperity in the future [18].

2.3.1. Stages of the IUCN Approach Cycle

The stages followed in the IUCN approach cycle aim to divide the two broad dimensions into measurable indicators for easier analysis. The first four steps of the cycle contribute to a better understanding of sustainability by introducing the dimensions and criteria, and the last three stages are designed to assess the sustainability of ecosystem well-being and human well-being by combining and evaluating the indicators (Figure 5).

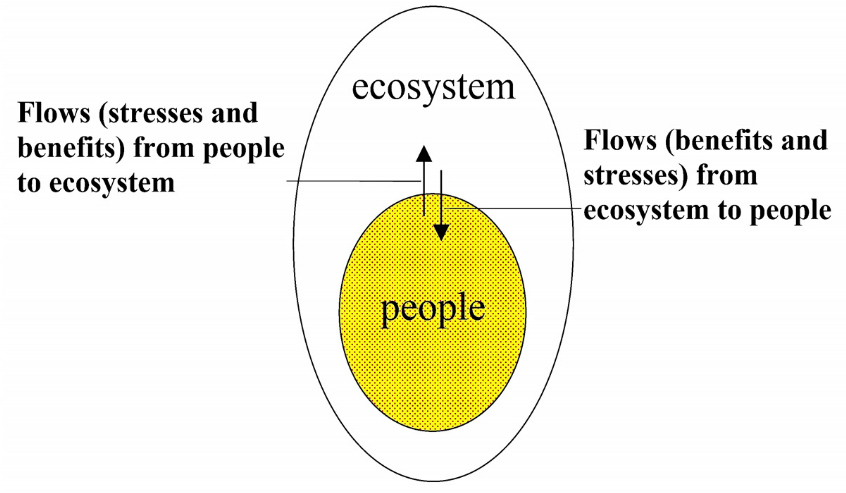


Figure 4. The egg of sustainability.

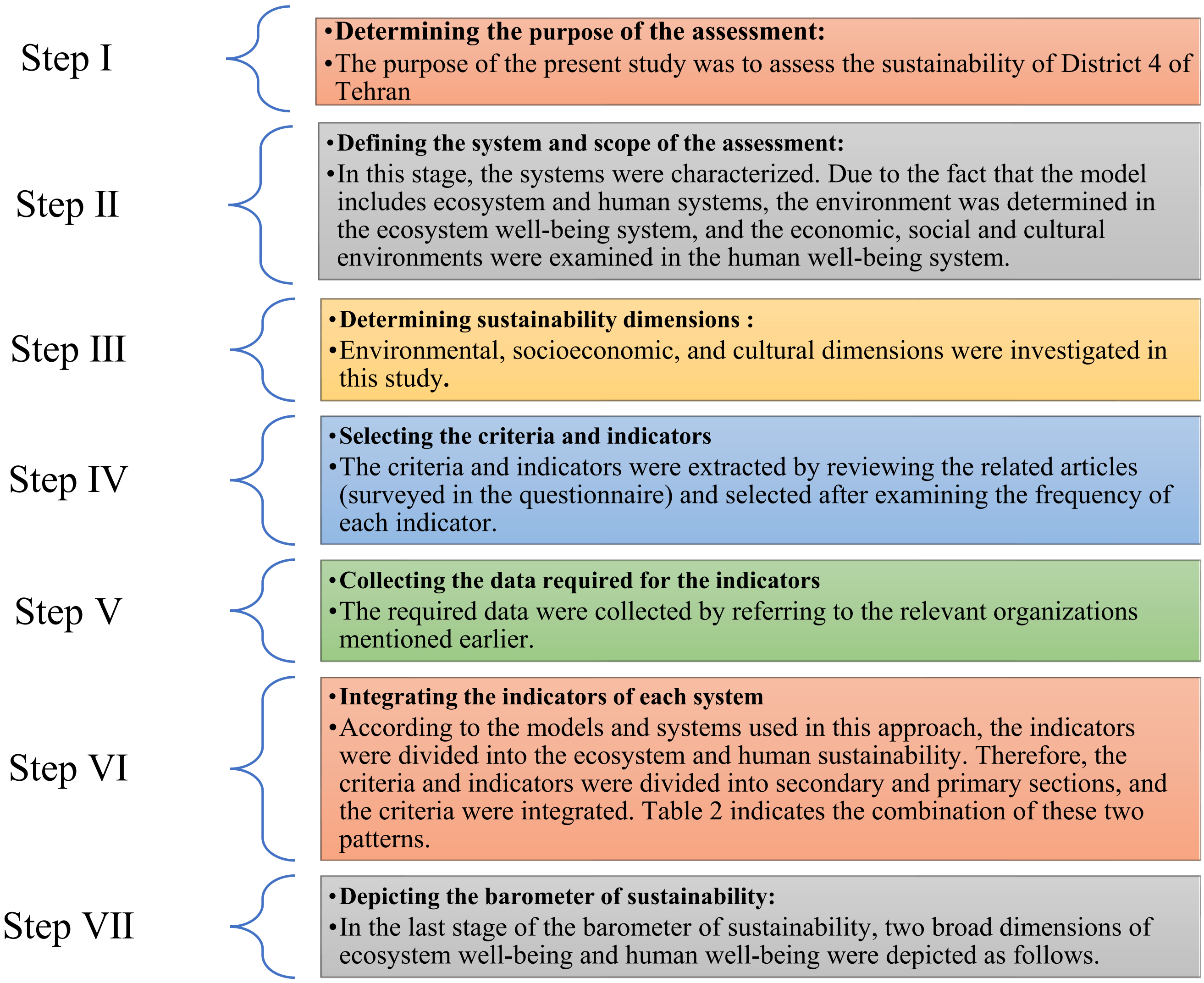


Figure 5. Description of IUCN method steps.

2.3.2. Indicator Selection Process

The major dimensions of urban sustainability are known as environmental, socioeconomic, and cultural. Each aspect focuses on several indicators that can show the status of the specific dimension. Sustainability indicators are significant at all phases of achieving assessment. They can be used as a benchmark for comparing current and past circumstances [43]. The process of literature selection started with the use of Google's general search engine. More than 131 records were identified in Persian and English, of which 541 basic indicators were reviewed under each dimension. (Figure 6) However, it is noticeable that, depending on the scale of the consideration, so many international, national, regional, and local indicators are defined for sustainability. For this reason, the current study tried to choose practical, suitable, and relevant indexes that can be applied at a local scale and present the situation of the study area. In this respect a list of 98 basic indicators were selected based on the most frequently-used references (63 socioeconomic, 27 environmental, and 8 cultural) and a category section shown in Table 2 was set because of the hierarchy structure and calculation pattern of the barometer approach (Figure 6). Then, a questionnaire was designed on a Likert 5 scale (from 1: unimportant to 5: very important) for 98 indicators, which can be seen in Appendix A. The reliability of the questionnaires, using the Cronbach's alpha method, was equal to 0.975 (Cronbach's coefficient should be greater than 0.7 and the closer it is to one, the more reliable the test is). Moreover, Charles Cochran's method was used to determine the sample size according to the District 4 population which was equal to 384 people; thus, some experts, including environmental specialists, university professors and municipality employees, who are familiar with District 4 issues and dwellers in the study areas were interviewed. Finally, according to participants' opinions about the importance of each indicator that was mentioned in the questionnaire forms, a total of 53 indices were defined (Tables 2 and 3).

Table 3. Sources of Indexes.

$E_{1,1}$	
$E_{1,1,1}$	
Indicators	**Source**
Land use planning per capita %	[1,41,44–54]
Urban decay ratio%	[55–58]
$E_{1,1,2}$	
Number of parks and green spaces collection	[8,39,51,57,59–61]
Parks and green space area %	[8,39,46,55,62–66]
Number of plant species	[63,67,68]
Air pollution %	[1,3,37–40,42,63,66,69,70]
Water pollution%	[1,4,39–41,59,63]
Noise pollution%	[9,39,41,57,63,69,71,72]
Soil pollution %	[40,41,45,63,67]
Satisfaction rate with garbage collection	[39,41,50,57,58,72–74]
Street and urban space cleaning	[57,58,72,73,75]
Number of recycling pat	[53,58,72,73]
Waste generation %	[3,8,41,63,76,77]
$E_{1,1,3}$	
Water consumption %	[3,38,39,41,46,50,51,59,63,66,70,78–81]
Power consumption %	[3,46,49,50,62–64,70,77,78]
Natural gas consumption %	[4,39,51,63,64,81]
Mean time to reach the bus stop (minutes)	[1,37–39,41,56,60,63]
Mean time to reach the subway station (minutes)	[3,38,41,46,63,82]

Table 3. *Cont.*

$H_{1,1}$	
$H_{1,1,1}$	
Indicators	**Source**
Security rate for women and children	[41,57,72,73,83–85]
Feeling of security and social peace	[9,42,54,63,72,75,86,87]
$H_{1,1,2}$	
Population density %	[3,8,39,41,63,64,72,74,77]
Population growth rate %	[1,3,39,41,56,59,63,64,88]
Age variation%	[3,58,63]
Family size	[8,53,75,88]
Sex ratio %	[56,58,63,82,89,90]
Aging population %	[39,47,55,76,78]
Rate of mortality per 1000 people	[39,41,43,44,56,61,63,76,77,82,88,89]
Divorce rate per 1000 people	[56,58]
Immigration rate per 1000 people	[39,63,67,71,89,91,92]
Dependency burden or rate	[38,41,51,59,63]
Satisfaction with the amount of income	[41,44,58,71,76,78]
Employment rates	[38,39,41,44,52,59,61,63,67]
Quality of life	[1,4,37,39,41,50,63,65,76,78,80,85,93,94]
Average cost of buying one square metre of a house	[37,38,47,50,59,68,69,76,83,95]
Employment rate per 10,000 people	[58,91]
Percentage of Female-headed households	[58]
Ratio of the population to the people with higher education	[44,56,64,82,91]
Literacy rate	[8,38,41,56,60,61,63,67,68,82]
$H_{1,1,3}$	
Number of fire stations	[5,58,82]
Number of banks	[8,58,72]
Number of petrol stations	[8,55,58,72,81]
Number of hospitals	[8,43,52,53,63,64,77,81,88]
Number of health centers	[53,60,61,63,81]
Access to fire stations (minutes)	[56,58,60]
Access to police stations (minutes)	[55,56,58,60]
Access to hospitals (minutes)	[39,41–43,76]
Access to health centers (minutes)	[3,39,41,43,61,63,76]
$H_{1,2}$	
$H_{1,2,1}$	
Number of cultural corporations	[47,53,56,72]
Number of cinemas	[14,37,72,96]
Number of libraries	[5,47,81,88,96,97]
Number of tourist attractions	[8,39,41,49,51,94]
$H_{1,2,2}$	
Number of religious centers	[8,75,88]
Number of mosques	[56,63,72]

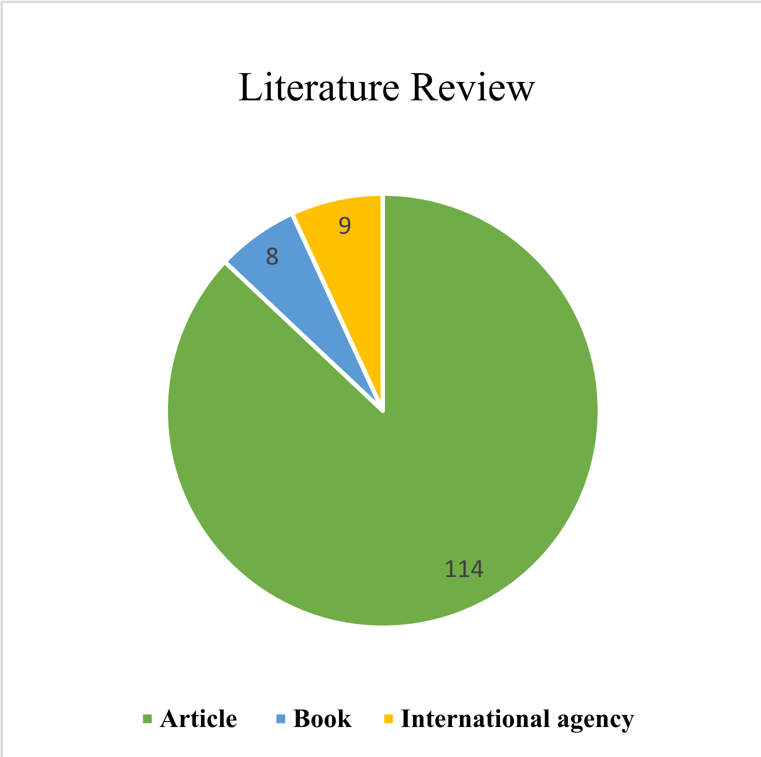


Figure 6. The category of peer-reviewed literature.

2.3.3. Steps of Preparation

1. Preparing the raw data: The initial value of each indicator—obtained based on reference to the relevant organizations—was considered.
2. Preparing the table of the aligned data: Some of the indicators in the raw data table were not aligned. Thus, they were aligned in a way that the non-aligned data were subtracted from a fixed number (100 in this study).
3. Preparing the data table with the real values: The weight of each indicator was calculated using the Shannon entropy weighting method as presented in Equation (1) [98] and multiplied in the aligned data. This weighting system can be expressed in a series of steps. In step 1, the decision matrix has to be normalized using the equation below.

$$P_{ij}=\frac{x_{ij}}{\sum_{i=1}^{m} x_{ij}}, J=1, \ldots, m, i=1, \ldots, n$$

where X_{ij} denotes the measure assigned to a value in an alternative, P_{ij} is a normalized measure of X, i the number of value and j the number of each alternative.

In step 2, the entropy of each value is calculated using the equation below.

$$E_j = -K \sum_{i=1}^{m} p_{ij} \times \ln p_{ij}, \; i = 1, \ldots, n$$

where, E_j the entropy of a given value and K is entropy constant. If P_{ij} is equal to 0, then $\ln P_{ij}$ can be set to 0.

In step 3, d_j that denotes the degree of diversification, has to be calculated using the equation below:

$$d_j = 1 - E_j$$

In step 4, where, dj represents the degree of deviation, and W_j is the weight of indicators.

$$w_j = \frac{dj}{\sum_{j=1}^{n} dj} \quad (1)$$

4. Preparing the table of the same scale data: Since each indicator in the data table had a different unit, the comparison was made by unscaling the data with the help of the equations for unscaling the data with a positive dimension (Equation (2)) and unscaling the data with a negative dimension (Equation (3)) as below.

$$r_{ij} = \frac{x_{ij} - x_i^{min}}{x_i^{max} - x_j^{min}} \quad (2)$$

$$r_{ij} = \frac{x_j^{max} - x_{ij}}{x_j^{max} - x_j^{min}} \quad (3)$$

where, X_{ij} indicates the value of ith, X^{min} represents the minimum ith, and X^{max} is the maximum ith indicator, X_{ij} indicates the value of ith, and x_j^{min} represents the minimum ith.

5. Callcuating the barometer of sustainability

Calculating the barometer of sustainability is regarded as one of the most important steps in analyzing the indicators, as shown in Figure 7. The mean of primary indicators (basic indicators from 1 to 53) and the mean of secondary indicators (($E_{1,1,1}$), ($E_{1,1,2}$), ($E_{1,1,3}$), ($H_{1,1,1}$), ($H_{1,1,2}$), ($H_{1,1,3}$), ($H_{1,2.,1}$), and ($H_{1,2.,2}$)) were calculated to determine the degree of sustainability of each dimension. The calculated means were derived from the mean of environmental sustainability, ecosystem well-being, and socioeconomic and cultural environments of the sustainability of human well-being. The egg white was obtained from the mean sustainability data of ecosystem well-being and the egg yolk was derived from the mean of human sustainability data. Finally, based on the Prescott-Allen ranking presented in Table 4, the diagram of barometer of sustainability was obtained (Figure 7). Overall sustainability was calculated using the mean of sustainable data of ecosystem well-being and human well-being.

Table 4. Sustainability classification from Prescott-Allen's perspective 1997.

Sector	Range
Unsustainable	0–0/2
Almost unsustainable	0/2–0/4
Medium	0/4–0/6
Almost sustainable	0/6–0/8
Sustainable	0/8–1

2.3.4. Sustainability Radar Tool

Sustainability radar is a graphic tool that can help to understand sustainability in different fields by combining and displaying the value of sustainability indicators. In fact, this radar can integrate a set of different and diverse indicators; it includes a polygon with an axis perpendicular to its center extending from each side. Each index has a side and an axis in this model, and the measured performance and conditions associated with each index are specified on the axes. Finally, the points related to the indices will be connected. In this tool, the indicators rotate around the circular diameters like a regular branch, and there is also a standard basis on which other indicators are evaluated. This basis shows the optimal value of achieving sustainability conditions from 0 to 1. In each axis, the value of the desired index must be consistent with this basis to achieve stability conditions. It means that the closer we get to the center of the graph, which is 0, indicates instability, and the closer we get to the top of the graph, which is 1, shows stability. This model is used to better display the stability of indicators.

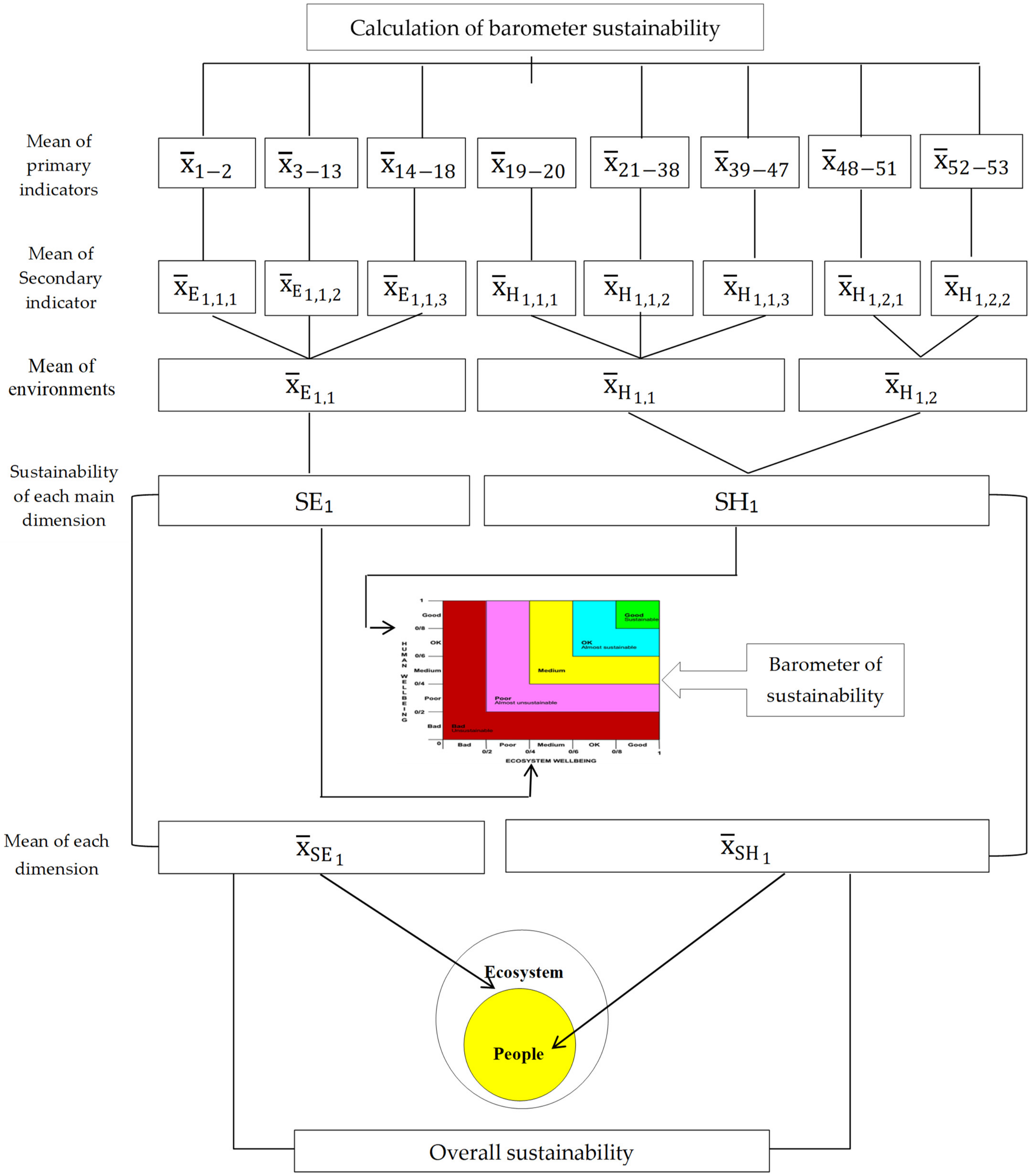


Figure 7. Hierarchical framework for the process of barometer of sustainability.

3. Results and Discussion

According to the data already presented in Table 2, urban sustainability levels in 9 regions of District 4 of Tehran were investigated based on the barometric and sustainability radar methods covering three classic dimensions of sustainability under two broad dimensions of ecosystem well-being and human well-being. In this section, it was attempted to discuss the environmental, socioeconomic, and cultural environments, and finally, the sustainability of all regions was determined using the results of urban sustainability based on two broad dimensions.

3.1. Urban Sustainability of the 9 Regions Based on Three Dimensions of Sustainability

3.1.1. Evaluation of Environmental Dimension

The environmental sustainability of 9 regions of District 4 of Tehran was assessed based on 18 primary indicators and 3 secondary indicators of $E_{1,1,1}$, $E_{1,1,2}$, and $E_{1,1,3}$, illustrated in Figure 8. As can be seen in Figure 8, among the 9 regions, region 8 has a better condition in terms of transportation and energy approved by initial indicators 14–18 in Table 2. However, region 2 has a more acceptable condition in terms of health and environmental quality approved by the indicators in Table 2 (number of parks and green spaces, number of plant species, satisfaction with collecting garbage, cleanliness of streets and urban spaces and electricity consumption, etc.). In contrast, regions 8 and 9 are in poor conditions due to poor green space per capita, high environmental pollution, and a limited number of recycling pats. Finally, in terms of land use capability presented by indicators 1 and 2, regions 5 and 6 are in better condition compared to other regions, especially 9 and 1. According to the sustainability classification of Prescott-Allen, the environmental sustainability of the regions indicates that region 2 is at medium sustainability level with a score of 0.457 and region 9 is under potential unsustainability with a score of 0.279

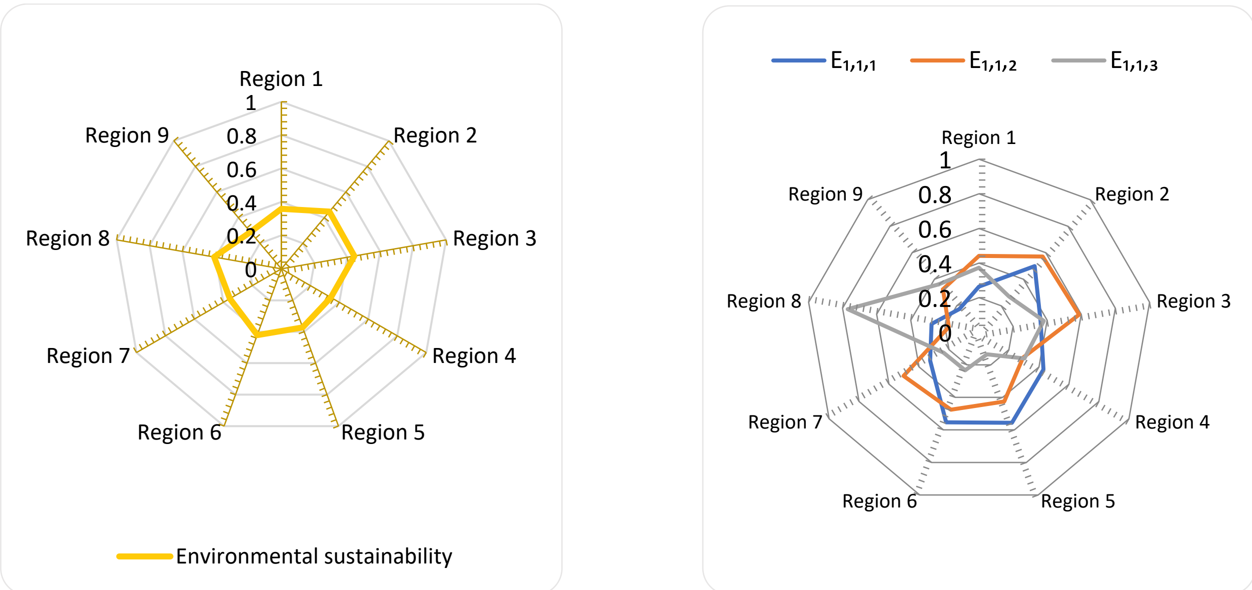


Figure 8. Assessment of environmental sustainability in the 9 regions: land use capability ($E_{1,1,1}$), health and environmental quality ($E_{1,1,2}$), and energy consumption and transportation ($E_{1,1,3}$).

The results obtained from the environmental conditions of the regions reveal the necessity of some interventions such as application of green management approach and development of existing solar power plants which are effective in improving consumption patterns and energy supply.

3.1.2. Evaluation of Socioeconomic Dimension

Figure 9 shows the sustainability level in the study area based on the economic and social indicators explained in Table 2. This sustainability radar indicates that regions 1, 9, 3, 4 and 6 are in similar conditions in terms of the $H_{1,1,1}$ indicator, and regions 2 and 5 are in most favorable and unfavorable conditions in terms of indicators 19 and 20, respectively. Furthermore, according to the secondary indicators ($H_{1,1,2}$), regions 6, 2, 5, 9 and 3 are in medium sustainability level since they have almost similar performances in terms of indicators 21–38. Regions 7, 4, and 1 are in potentially unstable conditions because the life quality of residents and their dependency burden are neglected there. It should be noted that all the regions suffer from a poor life quality and house trading state, which require the close attention of the mayor and authorities. Region 3 has a better condition due to better services and infrastructure provided by an acceptable number of hospitals, banks, petrol stations, and fire stations. However, region 4 is not in an acceptable condition because of the problems in accessing the services and facilities. As shown in Figure 9, in terms of economic and social sustainability, only regions 2 and 3 are in potential stability according to the Prescott-Allen ranking, and regions 4 and 5 are potentially unsustainable. It should be noted that in a similar study conducted by the Tehran Municipality Studies Centre [83], regions 2 and 3 of District 4 were reported to be in better conditions in terms of comparable economic and social sustainability.

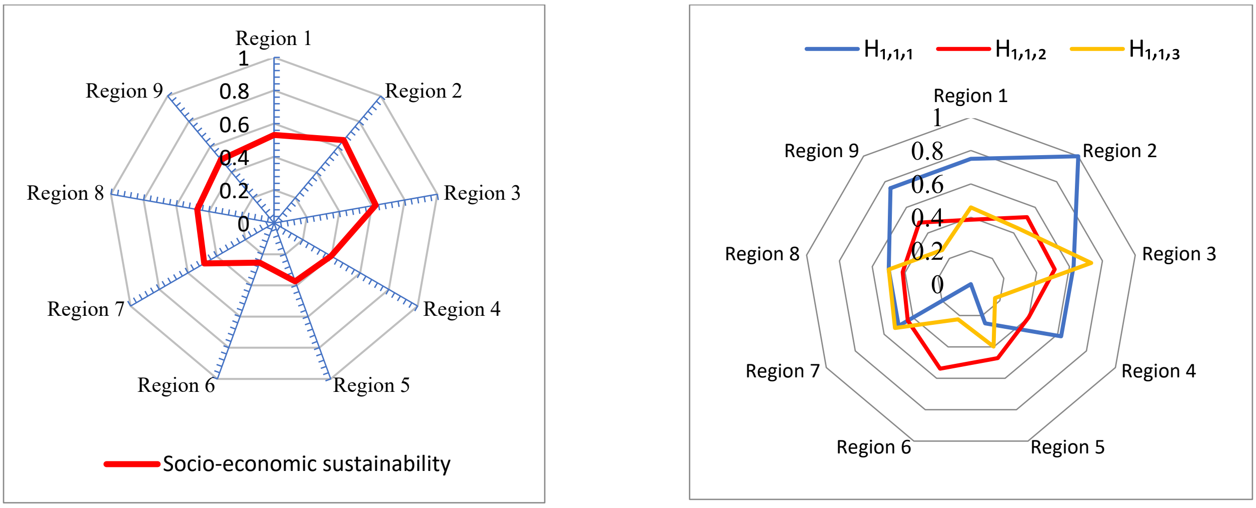
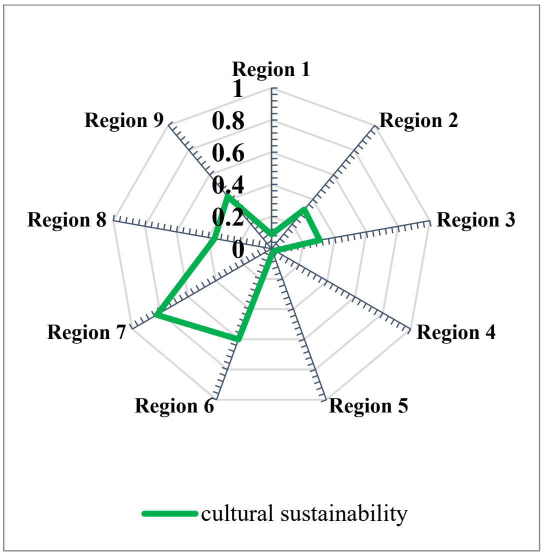


Figure 9. Socioeconomic evaluation of the 9 regions: $H_{1,1,1}$ (safety and security), $H_{1,1,2}$ (demographic characteristics and social welfare), and $H_{1,1,3}$ (infrastructure and urban Services).

In order to improve the current situation, it is recommended to increase the number of police stations, patrols, highway lights and surveillance cameras throughout the study area. In addition, more attention should be paid to spatial distribution of utilities, unemployment rates, and decentralization of immigration to the region which has a significant share and direct impact on the quality of life.

3.1.3. Evaluation of Cultural Dimension

Six primary indicators given in Table 2 were used to evaluate the cultural environment of the district as illustrated in Figure 10. According to indicators 48–53, it is obvious that most of the regions in this district lack recreational facilities. However, region 7 has a better condition in terms of the number of cultural corporations, cinemas, and tourist attractions which are classified as $H_{1,2,1}$. The results indicate that regions 3, 9 and 6 have similar conditions and are in medium sustainability level since they have a similar problem according to indicators 48 and 5. According to $H_{1,2,2}$ indicators which include religious centres and mosques, regions 7 and 6 have a potential sustainability. Considering sustainability radar ranking, which is similar to the Prescott Allen ranking, regions 1, 3, 4, and 5 are unsustainable. In fact, unsustainability occurs by nearing the center and the zero point of the diagram, and sustainability appears by nearing the vertex 1. Based on the results presented in Figure 10, the regions in District 4 do not show a favorable cultural sustainability since only regions 7 and 6 have sustainability and potential sustainability, respectively, and the remaining regions are not in a satisfactory condition. Therefore, close attention should be paid to the new locations or proper placement of religious and recreational places in order to promote cultural sustainability in District 4.



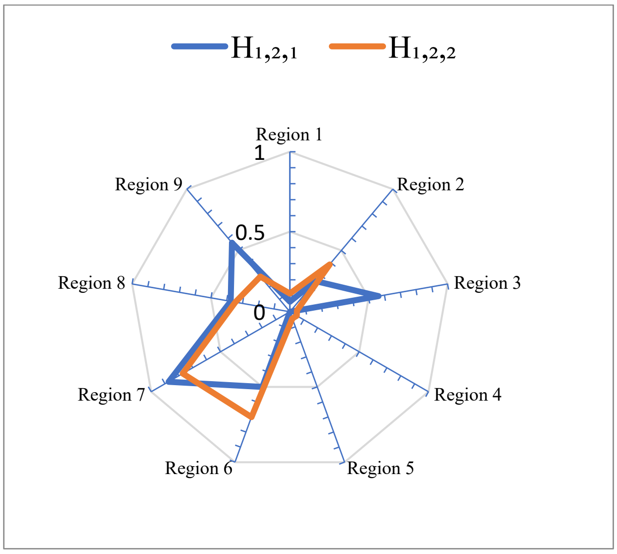


Figure 10. Cultural evaluation of the 9 regions: $H_{1,2,1}$ (Cultural places = 48–51), $H_{1,2,2}$ (Religious places = 52–53).

3.2. Assessment of Urban Sustainability in District 4 Based on Two Broad Dimensions

3.2.1. Sustainability of Ecosystem Well-Being

The ecosystem well-being in District 4 was considered based on the results of evaluating the environmental sustainability dimension, as shown in Figure 11. In fact, none of the regions are in a satisfactory condition based on the Prescott-Allen ranking already presented in Table 4, and urgent arrangements are necessary to improve the ecosystem in this district. The scores obtained for each region indicate the existence of many problems in them. Regions 2, 3, 6, and 8 are in a medium sustainability level with the scores of 0.457, 0.442, 0.438 and 0.408, respectively, although they are close to potential unsustainability. However, regions 5, 4, 1, 7, and 9 with the Prescott-Allen ranking of 0.2–0.4 show a potential unsustainability, and region 9 is the most unsustainable region in terms of ecosystem well-being sustainability.

The egg white of 0.38 obtained using the mean sustainability of ecosystem well-being (Figure 4) indicates the potential unsustainability of the region. This emphasizes the adverse conditions of the region in terms of ecosystem well-being.

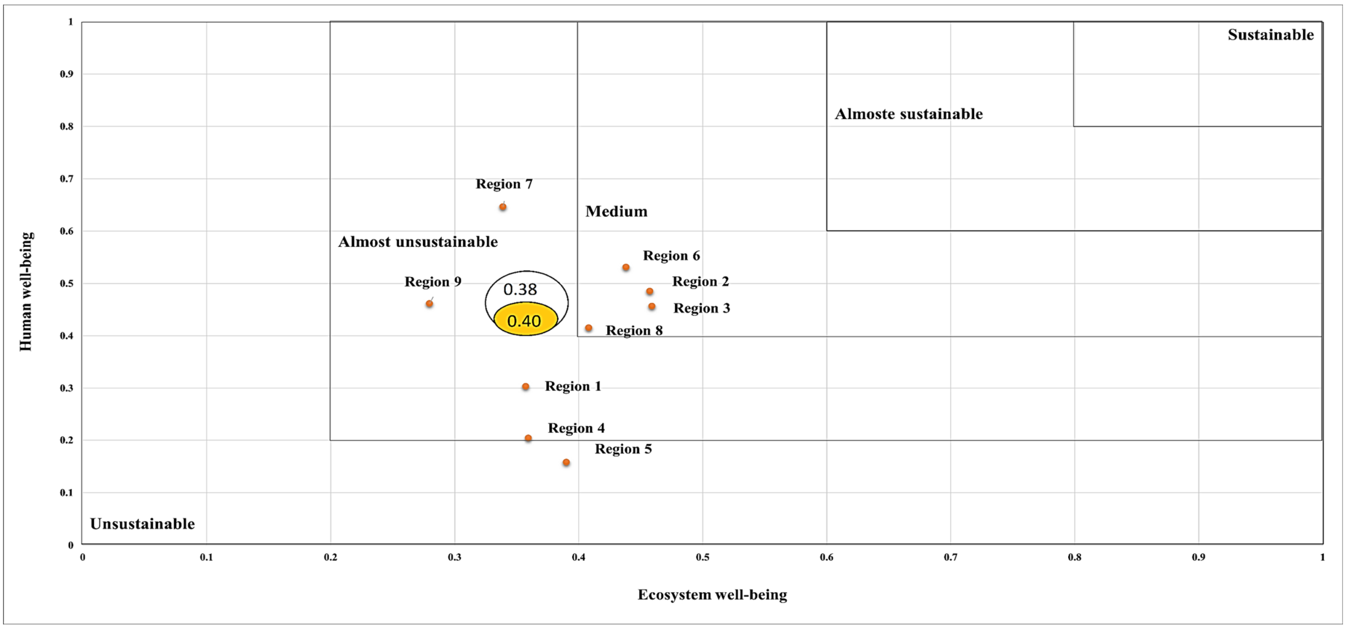


Figure 11. Barometer of sustainability.

3.2.2. Human Well-Being Sustainability

According to the pattern introduced by the barometer method, human well-being was obtained using the mean of socioeconomic and cultural environments, as shown in Figure 11. The obtained results indicate that the population in region 7, with the score of 0.646, has the highest human well-being in District 4, as it shows more acceptable conditions in terms of spatial distribution of cultural and religious centers. However, human well-being sustainability in region 5, with a very low score of 0.157, is in an unsustainable condition according to the Prescott-Allen ranking due to poor recreational, religious and security facilities. Among the remaining regions, the scores of regions 6, 9, 3, 2, and 8 were in the range of 0.4–0.6, showing a medium sustainability (Table 4). Regions 1 and 4, with the scores of 0.303 and 0.203 respectively, had a potential unsustainability.

Health egg yolk, which represents people's condition, was obtained as 0.40 based on human well-being sustainability. The obtained value, which is at the border of medium sustainability and potential unsustainability, implies a reduced risk to the welfare of the people due to the unfavorable condition in District 4. Based on the results, special attention should be paid to cultural issues and recreational facilities through strengthening civil and cultural institutions in this district.

3.3. Overall Sustainability

As already presented in Figure 7, the overall sustainability was obtained from the mean of sustainability of the broad dimensions of ecosystem well-being and human well-being. According to Figure 12 and Table 4, the 9 regions fall within two categories: regions 9, 1, 4, and 5 with potential unsustainability (0.2–0.4), and regions 7, 6, 2, 3, and 8 with medium sustainability (0.4–0.6). Calculation of the overall sustainability shows that none of the regions are at a high level of sustainability. Figure 13 shows that most regions scored 0.4, which is at the border between potential unsustainability and medium sustainability.

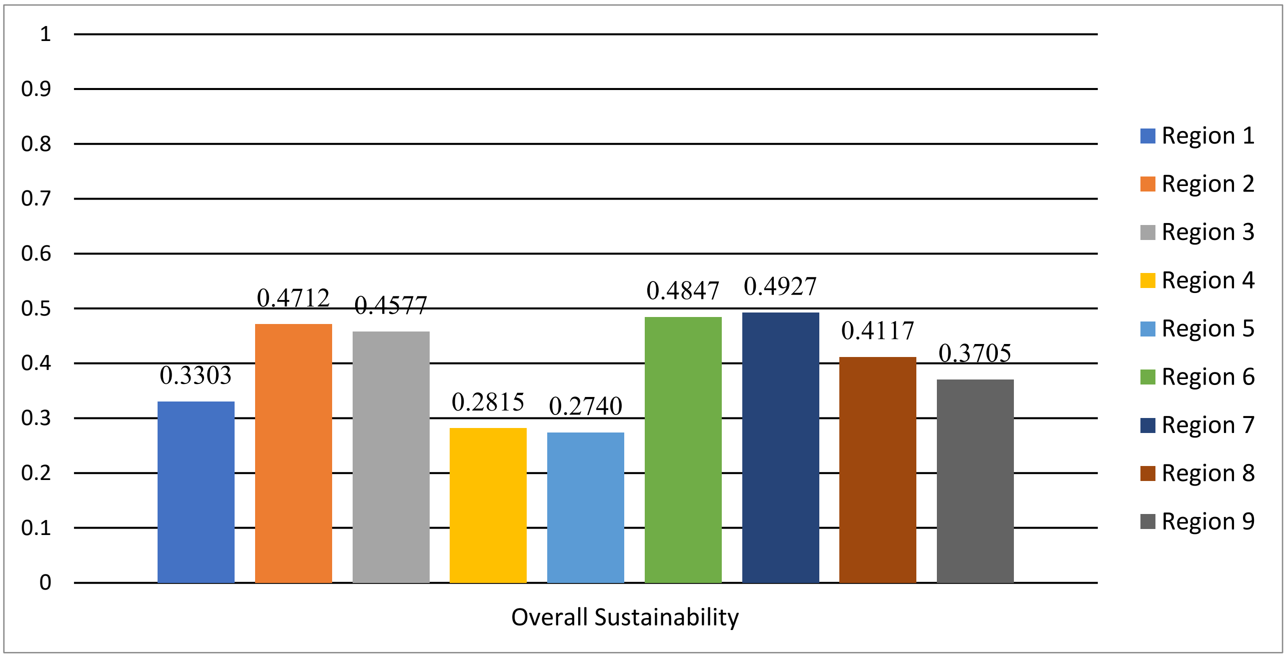


Figure 12. The overall sustainability of the 9 regions.

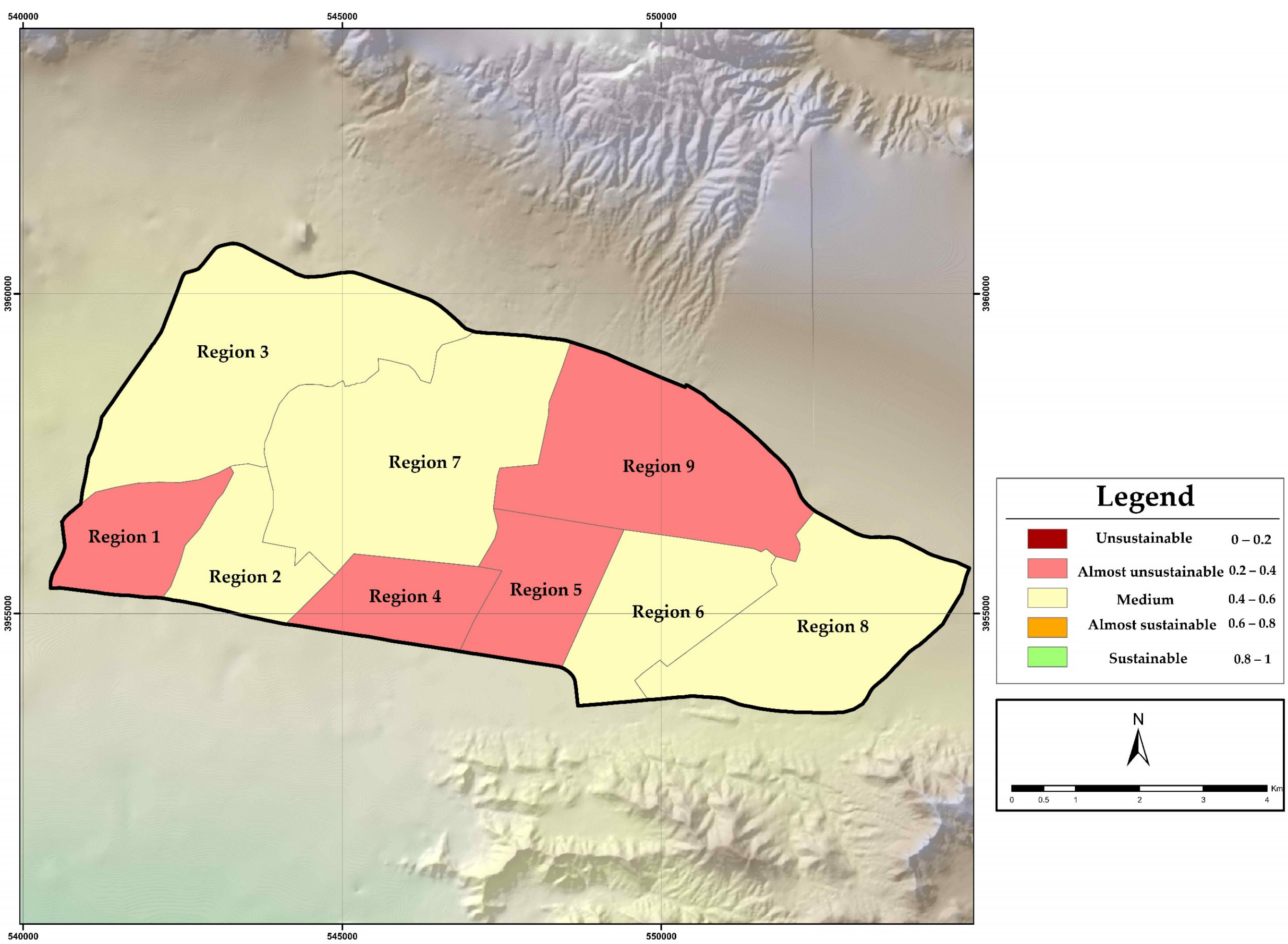


Figure 13. Sustainability map of 9 regions of District 4.

The results showed that the barometer method used in this study might help more precisely recognize the social, economic, cultural, and environmental situations of Tehran District 4 since the sustainability barometer model can reflect an explicit condition of the existing situation by measuring the interaction between human well-being and ecosystem well-being. This urban area has been assessed for the first time considering all sustainability dimensions in a comprehensive framework according to the barometer method. However, the main limitation of this work is the unavailability of data since some indicators have been surveyed for the first time, such as the satisfaction rate with collecting garbage, mean time to reach the bus stop and subway stations, accessibility to the fire station, police station and health centers, hospitals in minutes. In a similar study that was carried out in Tehran, a systems approach was adopted to develop a composite index called SUQCI (Sustainable Urban Quality Composite Index) in order to assess the urban environmental quality of the Tehran megacity. The index comprises 10 components containing a total number of 16 indicators. The result showed that this megacity is unsustainable [53]. In another study done by the Studies and Planning Centre of Tehran Municipality entitled "Sustainability Assessment of Tehran Metropolitan" [58], FANP and factor analysis methods were used and the cultural dimension was not considered, and some indicators are different for this reason at the district level, as overall sustainability region 4 differs from the present study but gives a close result in the socioeconomic dimension. The level of sustainability of Ribeirão Preto, Brazil, was assessed based on sustainability indicators using the barometer of sustainability. The results showed that Ribeirão Preto is on the intermediate level concerning sustainability [28]. However, social, economic, and environmental sustainability did not collaboratively display.

The barometer model used for assessing sustainability in Tabriz of Iran by Mofarah Bonab et al [29]; used 53 physical, environmental, social, and economic indicators in this paper. It should be noted that, in this study, the mentioned method has not been fully implemented based on the seven stages mentioned in the International Union for Conservation of Nature (IUCN). Also, Guidolini et al. [31] employed the barometer approach to assessing the water sustainability conditions of the River Grande Basin (BHRG). Thresholds corresponding to values ranged from 0 to 100; the result indicated that the BHRG was in an "almost unsustainable" condition and under high environmental stress. The Shazand Watershed sustainability was assessed with the help of an initiative barometer developed based on different dimensions of social, economic, environmental, and policy, with 18 criteria reporting that the social dimension had high effectiveness across different sub-watersheds, and the policy dimension had a poor result in effectiveness [33]. In recent research done by Nazmfar et al. [99], the barometer and ANP methods were applied to assess 10 counties of Ardebil province's sustainability with 50 indicators. According to the results, the city of Ardebil reached an almost sustainable level; however, each county achieved a different level of sustainability considering the studied dimensions. It is noticeable that none of the mentioned studies presented the egg of sustainability and most of the researchers applied the sustainability radar tool for displaying the situation better.

4. Conclusions

Different tools and methods have been designed to measure the progress toward sustainable development. In an attempt to propose an efficient method, the sustainability barometer method was used to assess the sustainability of 9 regions in District 4 of Tehran metropolitan. In total, 53 indicators were selected based on the criteria mentioned by the international organizations, and three environmental, socioeconomic and cultural dimensions were investigated using two broad dimensions of ecosystem well-being sustainability and human well-being sustainability.

The health egg confirmed that the whole district was not in a good condition. The results indicated various challenges such as environmental pollution, especially in regions 2 and 4, and transportation and energy problems. Study of the welfare of the residents by 35 indicators revealed that the study area is affected by housing costs, lack of security, and inadequate distribution of urban services and cultural-religious facilities. Regions 7 and 6 proved to be better than other regions in terms of human well-being. Finally, the 9 regions were found to be between moderate sustainability and potential unsustainability, implying that their conditions were getting worse. According to the results, the barometric model was found to be helpful in identifying the socioeconomic, cultural, and environmental health conditions in the study area more accurately.

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Appendix A

Questionnaire forum

The questionnaire was designed to test the relevance of 98 indicators selected according to the three core dimensions of sustainability. In this questionnaire, 384 participants were asked to specify their opinion regarding the importance of each indicator in the format (very important 5, important 4, medium importance 3, low importance 2, and not important 1). Due to the large number of indicators, only part of the questionnaire (8 indicators of the cultural dimension) is presented below as an example. The number of people who have declared their opinion for each indicator is included in the table. For example, 276 participants (71% of the total) considered the number of cultural institutions to be very important. In this study, we chose to use indicators whose level of importance was considered by the participants to be "very important 5" and "important 4" and above 50%. In this respect, six indices were chosen in the example shown, based on the answers obtained.

Table A1. Questionnaire.

No.	Basic Indicators	Importance Rate				
		Very Important 5	Important 4	Moderate 3	Less Important 2	Not Important 1
1	Number of cultural corporations	276 [71%]				
2	Number of cinemas		228 [59%]			
3	Number of libraries	288 [75%]				
4	Number of tourist attractions		192 [50%]			
5	Number of religious centers	312 [81%]				
6	Number of mosques	252 [65%]				
7	Number of museums				276 [71%]	
8	Number of theaters				204 [53%]	

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