

Research Article

Process-Based Improvement of Urban Metabolism in Optimizing the Development Cycle of the Small City Using MIA Method

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In order to maintain the health and stability of the urban ecosystem, humans must undermine the negative effects of improper land use in cities by planning to reduce entropy and regulate urban metabolism, material, and energy cycles, and considering resource capacity when providing the needs of the urban ecosystem population. Subsequently, the general purpose of this study is to explain the process-based pattern of healthy urban metabolism in the development cycle of a small city. The purpose of studying the urban metabolism, which is an integral part of the government from the environment, is to prepare reports and take measures indicating city sustainability. Indeed, the urban metabolism incorporates the relevant information on energy saving, material cycle, and management of waste and infrastructure in the urban systems. The present study employs a descriptive-analytical method. Accordingly, the metabolic impact assessment (MIA) method was utilized to analyze the data and achieve the study results. According to the assessment results in the input part of the urban metabolism process, the water and energy criteria are closer to the ideal status with 64% and 40%, respectively. In total, the performance of the input process is equal to 52%, and after that, the air quality, materials, and output sectors have a performance equal to 35, 31, and 33%, respectively. Moreover, land cover and transport have a performance of 14% and 65%, respectively, revealing that they are in a desirable condition. The above results based on mathematical optimization illustrate that there is no balance between the input and output of the urban metabolism model in the study area, and the main problems are evident in the output sectors and particularly in the recycling of materials and water.

1. Introduction

Metabolism in each city on different aspects includes urban body, urban spatial system, economic, social, and cultural dimensions, and in general, identifying urban issues and sustainable development. There should be some limitations in executive function for every city in the outer and the inner dimension. If the outer dimension, which is the same as the city's privacy, is located on the margins of metropolises and plays the role of attractive and capitalist margins, it will definitely be problematic in marginal practice, and it is logical that measures will be taken by balancing and controlling the losses outside the limits and controlling the attractiveness of keeping urban capital and its orientation towards the center. Urban planners recognize a small town's

performance in determining the status of urban metabolism by mathematical calculations, which is considered an effective step in the optimal realization of urban capital and the study of the entry and exit of renewable and irreversible resources. Today, the most important challenge of urban planning is how to consume energy and resources and how to recycle them; in the first view, the metabolism of restoring urban waste to the reuse cycle is considered, but in a deep view, the reduction of the volume of irreversible capitals, which is the view of prosperity in the path of sustainable development and the creation of the balance in the urban entrance and exit in the metropolis dimension, as well as in the dimension of marginal and small cities, ensures that, unlike the past, metabolism deals with resources and in this regard, metabolism will affect the structure of the city with

the growth of technology and economic, social, and cultural dimensions.

Today, the metropolises have turned into decision-making centers due to the concentration of capital, facilities, and talents that can shape the course of future developments. On the one hand, this issue leads to the rapid growth and development of these metropolises and their suburbs, and on the other hand, poses risks to them in terms of the development mechanism. The area of environmental hazards is naturally the first to be impacted [1, 2], and this is especially evident in the metropolises of the developing countries [3]. In these countries, due to the weak economic structure and the pressure of population needs resulting from widespread migration from other parts of the country in metropolitan areas, irreparable damage is induced to the environment. While this trend is intensifying with the concentration of industries [4], cars, and other environmental pollutants, Iran is not either far from the above trends [5–7]. The city has a life in which the course of changes and development can be evaluated every day, whose complexity should not prevent the consideration of details and proper planning; in fact, managers and experts aim to achieve sustainable development in all dimensions and emphasize reducing urban capital flight on survival and continuation of development.

Sustainable development considers the greatest humanitarian challenge in today's world and has become an essential concept for all people living on the planet [3, 8–16]. In this respect, sustainability includes (a) environmental sustainability that incorporates best practices in the management of the energy, transportation, waste, and pollution, (b) social sustainability related to green business and service activities and promoting the responsibilities of individuals in the community, (c) economic sustainability that includes self-reliance and equality [17, 18]. According to the United Nations' forecast, by 2050, 70% of the world's population is expected to be living in the cities. Accordingly, the high population concentration in the urban areas poses threats to economic, social, and environmental well-being and puts pressure on these systems [19–22].

The urban metabolism considers the city as a living thing and provides a broad framework for analyzing the relationship of input and output sources to the urban system and with the surroundings [23]. The urban metabolism is a model to facilitate the description and analysis of material and energy flows in the cities. Urban metabolism allows researchers to study the interaction of natural and human systems in urban areas with a metaphorical framework. Urban metabolism is studied at different scales, including global, regional, national, urban, and even domestic. By studying it, valuable information about the flow of resources in the urban system is obtained [24–27].

The urban metabolism examines the inputs, outputs, and storage of energy, water, pollutants, food, waste, and raw materials. Moreover, it accounts for the socioeconomic and environmental changes that affect or result from the metabolic balance. Therefore, the urban metabolism contains an integrated review of the sustainability principles that are considered in creating an accurate plan. Precise assessment of energy and material exchanges depends on diverse

physical infrastructure and types of construction. Materials and tools, such as solid waste, air, water pollutants, and water and energy flows, can provide significant insight and help identify sustainable urban structures. It can be argued that understanding the processes of urban metabolism provides the possibility of more sustainable development and management of cities by optimizing the use of available resources and increasing environmental protection [28–35].

The great social challenge of small cities with easy access to large cities, including the capital, population, and the abundance of ethnicity and different cultures, the lack of coherence of which forces urban management to take multiple actions, and the lack of the integrated urban management, have made the urban planning intermittent, and its instability has turned into a problem. The environmental situation in a small town, if it is stratum, is formed by clayey soil (impermeable). The urban effluent causes full-scale pollution of livestock and agriculture in the region, which spreads to a wider area of the region. The problem of municipal waste and lack of proper recycling (mostly by garbage collectors) and the manner of transfer to the landfill in urban management is caused by fluctuations in cleaning the environment and the place of loading, etc., and has disrupted the urban management.

In this study, using the AHP method, the city's input and output criteria, including water, energy, air, materials, ground cover, and weighted transportation, are compared with the ideal situation by MIA metabolic outcomes assessment method. The input and output equilibrium percentage is obtained, and the metabolic status of the city is determined by determining the equilibrium percentage. Finally, the total input process performance is 52%, and the output part has a yield of 33%.

2. Problem Definition

Qarchak city is the result of formation in a periodical process of several decades, which was initially a rural point and suddenly became a population center near the metropolis of Tehran. Environmental studies show that one of the main environmental problems of this city is the existence of many polluting jobs in the city such as tanning workshops, smelting metals (lead), brick factories, directing sewage to the unsuitable environment, recycling workshops, air pollution, lack of municipal wastewater collection and treatment plant, active mines, industrial pollution from fossil fuels (petroleum pollution), and industrial wastes such as wastes containing zinc oxides and aluminum due to the operation of cast iron and aluminum foundry units and production of slag by them, leading to adverse effects on the health of citizens. As a result, this city has a high volume of waste and sewage production. On the other hand, this city's population is growing increasingly, and this issue causes the maximum utilization of the environmental capacities of the city and environmental issues. Thus, the investigation into this small city to improve the process-based pattern of urban metabolism in the development cycle is in line with the research topic. Based on the mentioned problems, this study

seeks to answer this hypothesis. The status of this small city is not considered favorable based on the mathematical operations and assessment of the urban metabolism using the MIA.

3. Definitions, Concepts, and History of Metabolism

Metabolism is derived from the Greek word (Metabol) and has been used in a variety of contexts, including medicine, sports, psychology, politics, society, and architecture. However, its literal meaning in all areas is life-sustaining developments. Since cities could be evaluated as living and dynamic organs with specific inputs-outputs, the term metabolism in the sense of the metabolism of a living organism from biological sciences entered into the urban studies. In the postmetropolitan era, which is still moving towards the globalization of the city and the urbanization of the world, due to the concentration of population in cities and the unbridled use of various mechanical and chemical products and uncontrolled exploitation of natural resources, and due to the phenomenon such as housing crisis, transportation, economy, the coexistence and meaningful interaction between man and his ecosystem is severely threatened, peace and ecological balance are taken away from the ecosystem of the city, and the new city, unlike the stable cities of the past, has indicated an increasing metabolism (energy and resources) on the output (pollutants) and input (energy and resources).

Biologically, the city acts as a living organism using vital resources such as air, water, and food in urban metabolism. The larger the city, the more it demands from its surroundings, thus increasing the risk of environmental degradation. The factors such as urban structure, shape, climate, quality, and age of buildings, urban plant life, and transportation technology affect the rate of metabolism in the city.

Metabolic analysis of the city itself is considered as an indicator to assess the development of urban sustainability because, in the general sense, sustainability can be considered the use of materials and energy, given the ecological tolerance capacity.

In assessing urban sustainability, the three parameters of urban quality, urban flows, and urban patterns must be taken into account. In order to analyze the interactions between urban systems and the environment, the focus could be placed on the trends related to the quality of the environment in cities or their impact on the natural environment. Still, to understand these interactions, it would be necessary to examine the cities' functionality and their spatial structure, urban organization, and the impact of their lifestyles and practices. Urban metabolism is a concept that has taken a special place in urban and environmental studies in recent decades, but unfortunately, it does not have a good position in Iran. The uncontrolled expansion of the urban population and the growth of urbanization in the small cities have increased the consumption of resources and pollution caused by them. On the other hand, the linear pattern of resource consumption in the city, without quantitative and qualitative feedback to the urban system, is indicative of a linear and low-interest succession. This urban growth has

used natural resources to its advantage and has disrupted the environmental system, and consequently, environmental instability has manifested itself in it. Metabolism consists of two main stages. In the first stage, the cells and tissues absorb nutrients and convert them into synthetic chemicals and store them as a part of their protoplasm structure. This stage, in which the combined, analytical, and structural actions occur, is called anabolism, where the living organism's potential energy increases. In the second stage, called catabolism, cells and tissues break down and burn their protoplasmic material and excrete the resulting waste into the environment.

At this stage, some of the reserve force of the living organism becomes a kinetic force, and the reserve force of the living organism is reduced. Historically, the term metabolism was developed in the early 19th century to describe chemical changes within living cells and was widely used in the next 50 years in biology and biochemistry to describe the organ fusion processes within living organisms (at the cellular scale) and between living organisms and their environment. Since then, metabolism in the natural sciences has been dual; it has been used in processes related to the effects of body changes and their reproduction and in more comprehensive concepts in ecosystem connections and relationships [36, 37].

The urban metabolism considers the city as a living thing and provides a broad framework for analyzing the relationship of input and output sources to the urban system and with the surroundings [8]. The urban metabolism is a model to facilitate the description and analysis of material and energy flows in the cities. Urban metabolism allows researchers to study the interaction of natural and human systems in urban areas with a metaphorical framework. Urban metabolism is studied at different scales, including global, regional, national, urban, and even at the domestic level, and by studying it, valuable information about the flow of resources in the urban system is obtained.

The urban metabolism examines the inputs, outputs, and storage of energy, water, pollutants, and food, waste, and raw materials. Moreover, it accounts for the socioeconomic and environmental changes that affect or result from the metabolic balance. Therefore, the urban metabolism contains an integrated review of sustainability principles considered in creating an accurate plan. Precise assessment of energy and material exchanges depends on diverse physical infrastructure and types of construction. Materials and tools, such as solid waste, air and water pollutants, and water and energy flows, can provide significant insight and help to identify sustainable urban structures. It can be argued that understanding the processes of urban metabolism provides the possibility of more sustainable development and management of cities by optimizing the use of available resources and increasing environmental protection [28, 38].

4. Urban Metabolism-related Views

4.1. Theory of Urban Metabolism and Extended Urban Metabolism Model. The concept of urban metabolism that is currently deemed as the main driver of urban environmental

instability was first introduced in the United States in 1965 by Wellman to evaluate the energy, water, materials, and waste cycles in an imaginary city with one million population, which turned into the basis for the sustainable development of cities and communities and was further developed by Newman [39, 40].

Basically, these people consider the city as a biological system and believe that the city as a human system takes resources, processes them, and ultimately removes the waste of this process from the system. The ecosystem metabolism is recognized by ecologists as the production and consumption of organic matter. This concept is typically related to the discussion of energy. A closer look at the similarities between urban metabolism and human biological metabolism leads us to conclude that the processes that take place in the city can have two different outcomes: The first is a positive output when the components of the system play their role well and cause the city liveability. The second deals with the negative output when system components do not play their role properly and lead to the city vulnerability.

In the general view of the city and the city theory as a complex system, it is possible to provide a broad framework for it based on the mathematics, analysis of the relationship of input and output sources to the urban system and their relationship with the biophysical environment around the city. This view is referred to as urban metabolism. This model has features such as goal orientation (increasing viability and reducing waste), empowerment to use statistics and criteria (standards and indicators), represents the basic parts of a habitat (health, transportation, and housing) and has a kind of systematic thinking mechanism.

This model considers the cities and suburbs as the systems that require input from the key sources. These inputs are used in the domestic, industrial, urban, and governmental processes to produce two categories of outputs. The first category of outputs is liveability, the purpose of which is to improve them over time. The second category of outputs is wastes that are desirable to be reduced and eliminated over time.

Liveability in this model means humans need to provide social facilities, health, and welfare in the range of man-made and natural environments. Various consumption sources (data) are entered into the urban system. As a result of the operation of this system (outputs) of the same waste, the information that is often used to indicate the size of the city are population, number of households, size, and distribution of employment; this general information does not provide any indication of the city's impact on the environment. In this regard, Wellman examines only the three major factors of urban metabolism that are problematic in most cities of the world based on population: water, waste, air pollution, etc. In the existing urban systems, data and outputs are minimally related to each other, whereas, in metabolism with a natural cycle, each output is simultaneously considered data for the other part, which gives life and stability to life in nature. Urban spaces can be well represented using the concept of landscape.

The city is represented by the physical infrastructure such as roads, streets, and waterways, and energy and water

routes, on the one hand, and on the other hand by infrastructure such as health, educational, and recreational facilities.

These infrastructures facilitate socioeconomic activities in the process of production, consumption, and connection between the city and the surrounding areas. The urban areas with good infrastructure but a high level of civic participation might have good liveability. On the other hand, the urban areas with old infrastructure might present many problems at the national level. These vulnerable areas are depicted in Figure 1 indicating an urban metabolism. This model has been developed over the past three decades. Figure 1 shows an overview of the ecosystem of cities, which shows the efficiency of the closed sources and loops in which all outputs and inputs are potential, thus having a stronger perspective on achieving sustainability.

As shown in Figure 1, the configuration of the urban metabolism flow is majorly linear. Cities need their interior areas for most matters (ecosystem, water, building materials, and energy). Waste from the consumption of these matters is excreted in solid, liquid, or gaseous forms. Hence, cities are vulnerable due to resource dependence in their current linear metabolism, which puts pressure on the local resources and has a negative impact on the natural environment when extracting resources and disposing of the waste.

An ecosystem metaphor of the cities represents the efficiency of the closed sources and loops in which all outputs and inputs are potential, thus providing a stronger perspective for achieving urban sustainability. Circular metabolism is similar to a natural ecosystem with efficient consumption, recycling, and reuse of resource streams. This issue reduces dependence on the inland areas and other cities. Cities typically design their infrastructure under a linear metabolism. In light of the limitations of planetary resources, the long-term liveability and sustainability of cities rely on a shift from a linear function to a circular metabolism.

In recent years, the idea that urban areas should follow ecosystems has been aligned with the main theories of sustainable urban planning and development. Natural systems are inherently cyclical and efficient in their consumption of matter and energy, while urban systems are seen more as linear, consuming resources and producing waste.

Most studies of matter and urban energy flows encourage the use of urban metabolism as the basis of urban policy and usually conclude with a list of proposed policies. Many researchers also argue that urban metabolism studies can be a tool to identify environmental issues and design more effective urban planning policies in their Toronto-wide neighborhood metabolism studies.

4.2. Research Methodology. This research is applied-developmental in terms of purpose, descriptive-exploratory in terms of method, and in terms of how to collect the required information and data, it is considered as a field and survey research. A questionnaire is also used to collect data, which is distributed among urban specialists (experts). The main research tool is observation and a questionnaire.

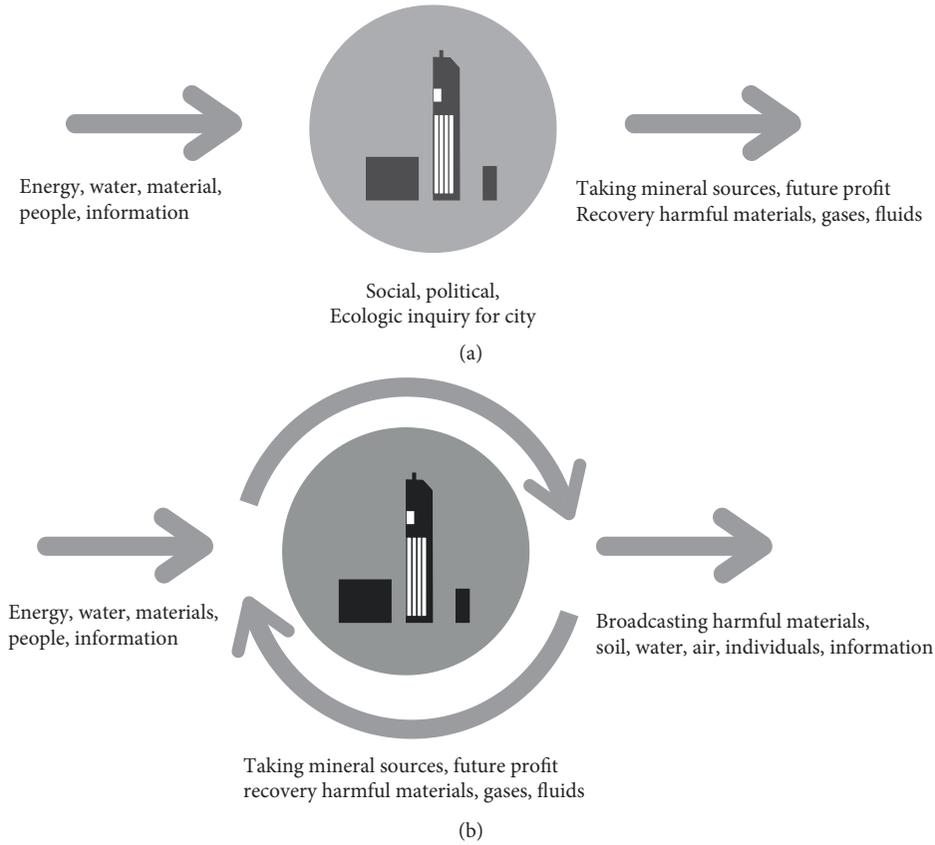


FIGURE 1: Urban Metabolism for Resources [41]. (a) Linear metabolism, instability, deficient, live landscape. (b) Circular metabolism, efficient stability, ecosystem landscape.

The Metabolic Impact Assessment (MIA) method is used to analyze information and achieve research results. In such a way, the data required for analysis and evaluation will be formed based on the indicators obtained from the study of theoretical principles related to the field of urban metabolism and urban patterns and the case study of small cities in relation to these data. In this way, the metabolic analysis of this city will be accomplished to evaluate the sustainability and urban management in relation to urban patterns.

After examining the factors and perspectives affecting the urban metabolism in this study, the criteria selected in Table 1 have been taken to evaluate the metabolism of Qarchak city.

4.3. Research Findings. First, based on the information of various valid sources, the desired status of the indicators is determined for evaluation. It should be noted that indicators without reliable and codified information about their optimal status from reliable sources are removed in the evaluation, which is few in number.

Then, based on the information of the indicators in the current state and the desired situation, the performance of the small city in all indicators and metabolism criteria is assessed. Assessment of the metabolic consequences of Qarchak city is made as follows:

- (i) Analysis of the current and desired states of each indicator
- (ii) Analysis of current and desired states of each criterion based on its indicators and assessment of the impact of each indicator on the criterion's functionality
- (iii) Analysis and assessment of the effectiveness degree of the criteria on the performance of the current state, compared to the desired status
- (iv) Assessment of performance of all criteria of the current state compared to the desired status

In the next step, the indicators are determined using the MIA method.

At this stage, the indicators of different criteria in terms of scale and their unit type become the same, and in fact, scaling operations are applied. The method used in this step is linear scaling so that the indicators can be compared with each other. The following formula has been used to scale the indicators:

$$n_{ij} = \frac{a_{ij}}{\max_i a_{ij}}. \tag{1}$$

According to the information collected from the indicators in the current and desired states, 25 indicators from different criteria are presented for evaluation (Table 2).

TABLE 1: Research criteria.

Criterion	Subcriterion	Indicator	Unit
Land cover	Barren areas	Area of lands in which no buildings or facilities are constructed	Hectare
	Urban reconstructed areas	Area of reconstructed areas	Hectare
	Land use	Green space per capita	Hectare
Visual pollution	Unfavorable view of buildings	#	#
	Inobservance of sanitary principles	#	#
	Crowds and congestion	#	#
	Undesirable design of urban furniture	#	#
Wastewater management	Water consumption	Water consumption per capita	Water consumption per capita
	Wastewater production	Wastewater production per capita	%
Waste management	Wastes	Per capita solid waste collected per year	Ton/person/year
		Per capita waste production per year	Kg/person/year
		Construction waste materials amount	Ton
	Recycling	Per capita construction waste materials	Ton/person/year
		Share of recycled waste	%
	Landfills	Share of buried solid waste	%
Number of waste disposal sites and their capacity		%	
Air pollution	CO ₂ emission	Annual direct emission of CO ₂ , per capita road transport	Per capita ton of CO ₂ emissions per year
		Direct annual CO ₂ emissions from the per capita residential sector	Per capita ton of CO ₂ emissions per year
	Air pollutants	Per capita total amount of air pollutants	Kg/person/year
		Average annual air pollution indicators	To be determined based on each pollutant

Based on the nonscaled values, it can be said that all indicators are less than their desired state. In the scaled data, a lower value means a more unfavorable situation, and since the indicators are measured relative to the unit, the average value of the indicators can be compared as a percentage. According to the information obtained, the average of the unscaled indicator in the current state is equal to 0.420, and based on this, it has 10 indicators above the average and 15 ones below the average. Indicators of construction waste and renewable energy sources have the worst situation compared to the other indicators, and indicators of public transportation use and per capita water consumption have the best performance compared to the other indicators in the desired state.

Second step: Normalizing the indicators in each criterion and analysis of each criterion based on its indicators.

At this step, the indicators of each criterion are assessed based on the average of the indicators and are also normalized. Performance analysis of a criterion states that its indicators based on the normalized relationship allow the relative evaluation of indicators with each other.

$$d_j = \frac{x_j}{\sum_{j=1}^n x_j} \times 100. \quad (2)$$

Third step: weighted scoring of the criteria, metabolic analysis, and assessment of the area based on the criterion. At this step, based on the values obtained from the total values of the indicators of each criterion, assessment is made between the criteria, and finally, all the criteria of the current and desired states are evaluated to determine the overall

metabolic status of the study area compared to its optimal status. In order to more accurately assess the current state of the urban metabolism, the coefficient of significance (weight) is determined for each criterion, and then the weight of the criteria is affected by the values obtained from them. The importance of the criteria has been determined based on studies of theoretical principles. One future direction in this aspect can be the application of machine learning models [42–48], decision-making approaches [8, 49, 50], enhanced deep learning models [51–55], machine learning-based tools [56, 57], deep learning methods [58], optimized prediction tasks [59–63], optimization algorithms [64–68], and intelligent systems and hybrid feature selection methods [69–90] for weighting the importance of the criteria.

To score weights for the criteria, they are compared two by two. The comparison results are given in Table 3. For equal importance, score 1; for a little more importance, score 3; for more importance, score 5; 7 points for much more importance; and for absolute importance, a score of 9 is given. Scores 6, 4, 2, 8 are also compared for intermediate values. A 5×5 matrix is used for the two-by-two comparisons. To calculate the importance factor of the criteria, first, the geometric mean of the rows of the matrix is derived, and then the results are normalized.

After determining the importance factor of the criteria, the sum of the values obtained from the indicators of each criterion obtained in the previous step is considered as the value of each criterion, and these values are normalized to their desired state in each criterion. Then, the weight of the

TABLE 2: Value of indicators in the current and desired state and linear unscaling operation on the indicators.

Criterion	Subcriterion	Indicator	Unit	Value of indicator based on the main unit		Value of unitless unscaled indicator	
				Current state	Desired state	Current state	Desired state
Land cover	Urban area	Total value of the constructed area	Hectare	11925597	1232547	0.10	1
	Reconstructed urban areas	Area of constructed lands	Hectare	15	100	0.15	1
	Land use	Green space per capita	Hectare	2	11	0.19	1
Water	Water consumption	Water consumption per capita	Liter/number/day	190	187	0.98	1
		Water consumption per capita by residential sector	Liter/number/day	160	113	0.70	1
		Water consumption share by residential sector	Liter/number/day	80	50	0.62	1
	Wastewater production	Wastewater production per capita	%	150	120	0.80	1
		Population connected to the domestic sewage network	%	10	100	0.10	1
Materials	Waste materials	Per capita of solid waste collected per year	M ³ /person/year	1	1	0.62	1
		Per capita of waste production per year	Kg/person/year	850	150	0.17	1
		Volume of construction waste materials	ton	670	55	0.08	1
	Recycling	Share of recycled waste materials	%	4	28	0.14	1
		Share of buried solid wastes	%	78	45	0.57	1
Air quality	Annual average of air pollutants	Suspended particles less than 10 microns	Micrograms	114	20	0.17	1
		Suspended particles less than 2.5 microns	Micrograms	36	10	0.28	1
		SO ₂	ppb	13	7	0.54	1
		NiO ₂	ppb	50	21	0.42	1
Energy		Energy consumption per capita	KWh	17055	5840	0.34	1
		Energy consumption per constructed area	KWh	450	85	0.18	1
		Ratio of renewable energy sources, to total energy consumption	%	1	16	0.06	1
		Use of public transport	%	70	75	0.93	1
		Access to the public transport	%	60	100	0.60	1
		Share of passenger transport modes- bus	%	10	25	0.39	1
		Number of parking lots	Number of parking lots per each 1000 citizens	2	5	0.44	1
		Share of passenger transport modes- private car	%	11	25	0.44	1
	Number of taxis	Number of cars per each 1000 citizens	91	426	0.21	1	

criteria is multiplied by their normalized value, and the final score of each criterion is obtained in the current and desired state. Finally, the total score of the criteria shows the result of the metabolic status of Qarchak city. In addition, by normalizing the final score of the criteria, it is possible to evaluate each criterion and the extent of its impact on the metabolic performance of the range. In Table 4, the related values are presented, and in Figure 2, metabolic assessment factors are shown.

According to the calculations performed and the results obtained from the evaluation criteria, it can be said that the final score of the study area in the current state is 29.61. In contrast, the final score of the desired state is equal to 60.64. In fact, the current state of the area has gained about 45% scores compared to the desired situation, indicating that the study area's metabolic performance has gained on a score basis and indicates that based on the information obtained, the metabolic status of the study area is poor. In general, if

TABLE 3: Comparison matrix of the criteria and determination of their significance coefficient.

Criterion	Land cover	Water	Materials	Air quality	Energy	Importance factor	Normalization factor
Land cover	1	4	1	4	2	2.10	0.1924
Water	4	1	5	3	4	2.92	0.2711
Materials	1	5	1	1.2	1.4	1.53	0.1223
Air quality	4	3	1.2	1	3	2.12	0.2220
Energy	2	4	1.4	3	1	2.10	0.1922

TABLE 4: Metabolic assessment of the area based on the criteria.

Criterion	Value of criterion		Weight of criterion	Normalized criterion		Final scope of the criterion		Relative comparison
	Current state	Desired state		Current state	Desired state	Current state	Desired state	
Land cover	0.44	3	0.1924	15.18	41.42	2.92	7.96	13.20
Water	3.20	5	0.2711	40.50	59.25	10.97	16.06	33.33
Materials	1.58	5	0.1223	22.34	70.34	2.73	8.60	8.60
Air quality	1.41	4	0.2220	19.26	72.23	4.72	16.03	31.57
Energy	3.59	9	0.1922	45.4	62.41	8.72	11.99	14.04
Sum	10.23	26	1.0000	139.68	306.15	29.61	60.64	100
Total performance	****	****	****	****	****	45.125	100	100

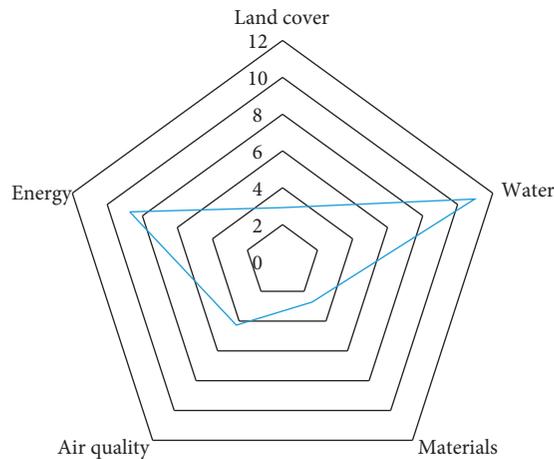


FIGURE 2: Metabolic assessment factors.

any criterion or optimal condition is compared, it can be concluded that the water criterion of 64% and the energy criterion of the transportation sector are 40% closest to the ideal conditions. After these two, air quality, materials, and

land cover stand, respectively. The result of the assessment circular urban metabolism around the study is shown in Figure 3. Moreover, the comparison of the ideal and current situation is illustrated in Figure 4.

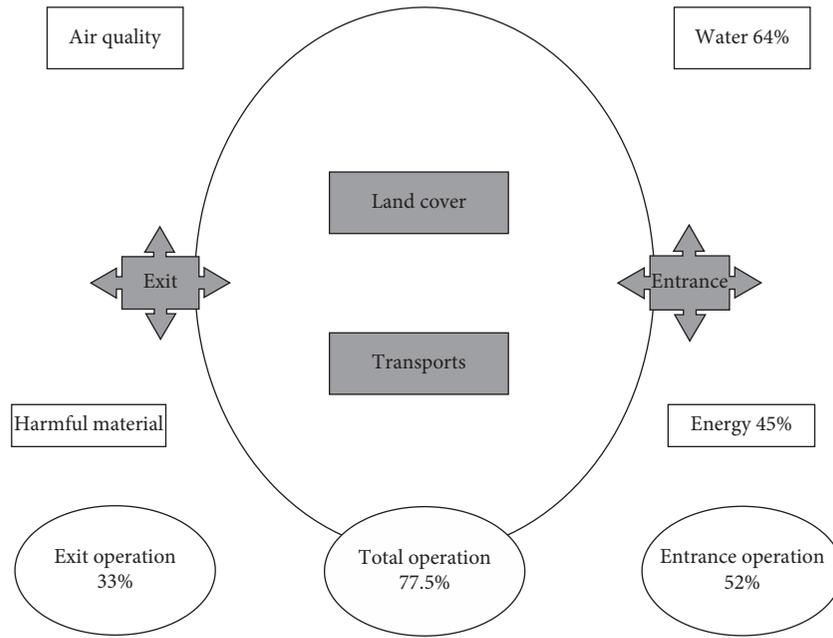


FIGURE 3: Result of assessment circular.

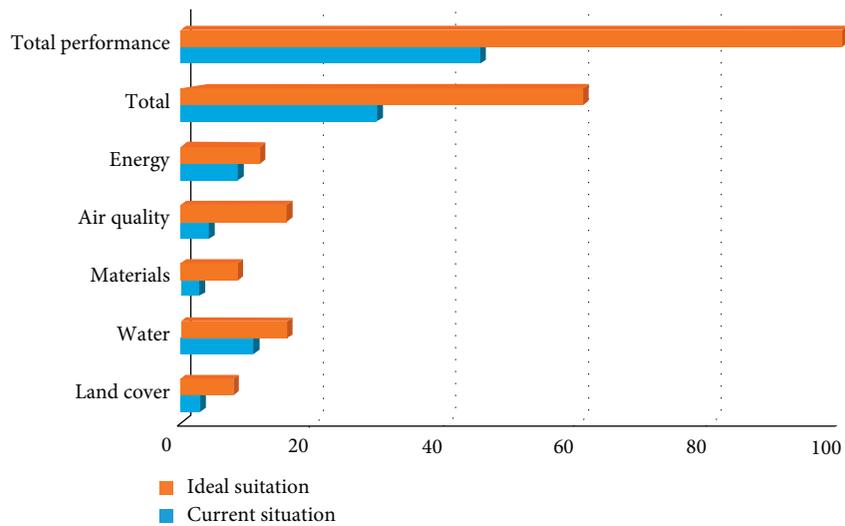


FIGURE 4: Comparison of the ideal and current situation.

5. Conclusion and Future Directions

Qarchak city is one of the metropolises of Iran that has had great physical growth in the last two decades due to its innumerable immigration, and this uneven growth and population density and special geographical location have caused environmental challenges in this city.

The environmental issues of Qarchak city, which are caused by internal and external factors, have a wide impact on health, mental health, economic, social, and urban environmental health, and if they are not controlled in a strategic urban development plan, the consequences and effects will remain not only for the present generation but also for future generations.

As previously stated in the study of theoretical principles, the cycle of urban metabolism has inputs and outputs whose interactions occur in the urban system, which herein is limited to urban structures, patterns, and forms. In order to achieve greater stability, it is necessary that linear metabolism, which includes the input of resources, their consumption, and the output of waste materials, be converted into the cyclic metabolism, and in fact, the processes of material recycling and its conversion into reusable materials and energy production. According to the assessment results in the input sector of the urban metabolism process, the water criterion of 64% and the energy criterion of the transportation sector have 40% of the closest distance to the ideal conditions. In total, the performance of the input

process is 52%, and after that, air quality, materials, and output sectors have a performance of 35, 31, and 33%, respectively. In addition, land cover and transport have the performance of 14 and 65%, compared to the desired state.

The above results reveal that there is no balance between input and output of the urban metabolism model in the study area, and the main problems are evident in the output sectors, especially in the material and water recycling sector. This issue affects the sustainability of the study area because, in the broad model of the urban metabolism, the goal of urban sustainability is to reduce the use of natural resources and decrease waste production to improve its livability and not only the consumption of natural materials in the area in terms of energy, water, and food, but also the amount of waste and not returning it to the reuse cycle is very problematic and critical.

Sustainability is created if urban development is such that the rate of resource utilization is not more than the rate of their rehabilitation; if based on the results expressed in the study area, the opposite has happened. In order to achieve stability in the cycle of urban metabolism, it is necessary to establish a balance between its input and output, and also, it is required to achieve this balance by paying attention to the proper functioning of the urban systems.

Finally, the general measures that can be taken to improve the metabolism of Qarchak city could be expressed. These measures are as follows:

- (i) Optimizing energy consumption, maximizing energy efficiency, maximizing the share of renewable energy sources, and using clean energy in the public transportation
- (ii) Development of green spaces and paying attention to their extent and distribution in the area, renovation of old structures, and nondestruction of buildings until they are completely out of service
- (iii) Changing the industrial uses to green uses and mixed residential-commercial areas
- (iv) Minimizing water consumption, minimizing damage to the natural water cycle, optimizing water recycling, and reuse
- (v) Minimizing waste production, optimizing material recycling, proper use of recycled materials for consumption and energy production, and minimizing landfilling

Data Availability

Request for data, 4 months after publication of this article, will be considered by the corresponding author.

Conflicts of Interest

The authors declare no conflicts of interest.

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