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Foresight of Informal Settlements to Increase Resilience against Earthquake

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Original Article

Abstract

INTRODUCTION: Considering the location, the frequency of faults and the probability of earthquake, district 20 is distinguished from other areas as the most dangerous region of Tehran. Due to the uncertainty of the time of the previous destructive earthquake, the probability of activation of these faults is very high.

METHODS: Regarding the exploratory nature of this research, the environmental scanning technique was used, and due to the dominant approach of this research, which is future research, the Delphi technique was used. Structural analysis has been used in MicMac software to analyze data.

FINDINGS: According to the findings of the dispersion of the variables indicate the instability of the system in the studied area, and accordingly, five categories of variables were identified.

CONCLUSION: The results showed that based on the quantitative analysis of the Scenario Wizard software, three golden, static and crisis scenarios were obtained for the 2051 horizon of district 20, which is the most valid scenario related to the static scenario.

Keywords: Resilience; Future research; Scenario; Earthquake; District 20 of Tehran.

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Introduction

The current trend of population growth as well as increasing urbanization has caused many problems in cities and brought many consequences in the world, one of the most important of which is informal settlement. (1-3) Due to the lack of opportunities and suitable options, these settlements suffer from social exclusion and as a result become undesirable urban spots (4) and are considered as one of the biggest challenges of the 21st century, the residents of informal settlements and their residents are highly exposed to possible risks and make these areas prone to natural and human challenges and risks. (5)

The high sensitivity of natural hazards especially earthquake has caused a wide range of activities to be directed to crisis management of urban hazards, and resilience and thinking about it has become an important concept in scientific research and political discourses. (3, 4 & 6)

One of the cities of Iran that faces this problem the most is Tehran, which is very vulnerable to earthquake due to its geographical location, being located among the Alborz mountains, the existence of channels, and being located on many faults. The seismological history of Tehran shows that the return period of strong earthquakes in urban areas is about 150 years and the last relatively strong earthquake (M>7) occurred in 1830. (7)

Another case for intensifying the vulnerability of Tehran is the irregular structures and informal settlements in the heart of this city. Due to their inadequate and limited access, these settlements face difficulties in providing relief to their residents and can cause critical conditions and humanitarian disasters. The location of district 20 in the Tehran-Rey plain distinguishes this area as the most dangerous from other districts due to the operation of several faults as well as, the high urban population, building density, in addition to the concentration of resources in the city of Tehran, increases the

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complexity of crisis management plans during an earthquake. (8)

Mohammadi Serin Dizj and Ahadnejad Roshti (2021) in their research stated that according to the maps obtained from the scenarios, the resilience in the central and southern parts of the Zanjan city is weak and very weak, and as you move towards the north, west and east, the physical resilience of the areas increases. With this result of the resilience images in the scenario maps, no area shows a completely resilient domain, so that in Mercali scenarios 7 and 8, the resilience is placed in the domain lacking resilience and very weak. According to the analyses and maps available in any of the regions, there is no stability in resilience, that is, no region shows resilience in the evaluation of all criteria. (9)

Latifi et al. (2022) have analyzed and stratified the key drivers effective on increasing the physical resilience of Tehran city, with an emphasis on district 10 against earthquake. The results of the research showed that the granulation class driver with the most penetrating power is the infrastructure and the main driver of urban physical resilience, and any action to increase the physical resilience of the studied sample against earthquake requires reforms in this driver. (10)

Joyner and Sasani (2020) investigated about the factors affecting the resilience of buildings against earthquake. Based on their results, the seismic performance of the building plays an important role in strengthening and resilience against earthquake. The seismic performance of the building can also be improved by increasing the strength of the building through strengthening and using resistant materials. (11)

Li and Zhu (2020) in their research, among the factors affecting resilience against earthquake, pointed out the importance of the role of the road network and believe that the road network is one of the most important ways of urban life and its flexibility after an earthquake is very important for fast and safe rescue (12).

Niazi et al. (2021) in their research believed that among the factors affecting resilience against earthquake, it is very important to pay special attention to the performance of healthcare centers after an earthquake to identify how to provide services to patients and identify them. (13)

Bothara et al. (2022) in their research investigated the factors affecting the resilience of indigenously built buildings along the Himalayan arc against earthquake and concluded that the buildings that were built in this area with traditional and local methods, observing all the features of retrofitting, are very resistant and resilient against earthquake. According to them, there should be a proper balance between traditional and modern construction materials and methods in constructions. (14)

The view that has existed so far on incident management and urban management has been the view of confrontation and risk reduction based on the analysis of past trends and its continuation in the future. It should be noted that the changes created in cities, the inability to accurately predict the future, as well as the complexities caused by the ever-increasing changes, have made researchers turn to the capabilities of the emerging science of futurism and include foresight in the planning and forecasting activities. Therefore, in a situation where risk and uncertainty are increasing, resilience is introduced as the concept of facing disruptions, surprises and changes.

However, in this research, in order to manage the crisis in the face of the earthquake, while identifying and evaluating the most important drivers in increasing resilience, investigating the extent and how these factors affect each other, explaining the possible situations of these factors, and finally compiling possible scenarios and identifying possible scenarios effective in improving the level of resilience of district 20 of Tehran metropolis.

In line with the above goal, the main question of the research is raised as follows: what are the possible scenarios of physical resilience against earthquakes with emphasis on the district 20 of Tehran?

Methods

The present applied research is of a descriptive-analytical nature, which was used with the Delphi technique and environmental scanning to identify variables and indicators. In addition, it identifies the most important factors affecting the resilience of informal settlements in district 20 of Tehran with a future research approach and formulates possible scenarios. Next, in the first stage, library sources and existing articles on factors affecting physical resilience against earthquake were used to collect variables.

According to future research studies, 85 primary indicators related to resilience were distributed to 35 experts (20 municipal experts of

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district 20, and 15 professors and PhD students in the field of crisis management) and they were asked to determine the most influential factors of resilience against earthquake. Then, about 44 variables were extracted in 4 dimensions that are effective in increasing the resilience of informal settlements in district 20 of Tehran (Table 1). Afterwards, 44 factors were again provided to the Delphi group in the form of a questionnaire, so that they could give points to the variables in the framework of the Cross Impact Analysis Matrix and on the basis of influence and effectiveness to determine the importance of the factors based on the 3-point Likert scale. Then, the scores were entered in the cross matrix in MicMac software to measure the direct and indirect effectiveness of each of the factors due to the scores of the factors, key drivers were obtained. In the next step, the statistical population was asked to formulate the possible situations of driving factors. In this section, three statuses were defined for each driving factor: desirability, static and critical. Then the matrix of different status of driving factors was designed and completed with a score of +3 to -3. Next, the questionnaire was called to Scenario Wizard software to prepare the scenarios and finally, possible future scenarios were extracted.

Table1. Factors affecting the future resilience of informal settlements against earthquake with an emphasis on the district 20 of Tehran (source: research findings)

Dimension	Variable
Structural- physical	(x1) building density (granulation), (x2) composition of mass and space (ratio of built to unbuilt spaces), (x3) percentage of checkered texture to organic area, (x4) ratio of regular to irregular subdivisions in the area, (x5) the number of building floors, (x6) the quality of residential units (ratio of renovation and demolition parts to the total built area), (x7) the quality of construction and implementation of structures, (x8) the age of the building, (x9) building materials (frame and foundation materials), (x10) occupancy level of residential units, (x11) building density, (x12) distance from fault, (x13) distance from hazardous centers (x14) adjacent to incompatible uses, (x15) development and expansion of population centers on seismic zones, (x16) paying attention to the improvement and renovation of buildings, (x17) geological and lithological condition of district 20.
Roads network and access hierarchy	(x18) the ratio of the average width of the roads to the population density, (x19) urban texture granularity, (x20) the existence of various and numerous access roads with suitable quality to different parts of the city, (x21) the materials and condition of the road floor, (x22) the reliability of network components (roads and bridges), (x23) the percentage of dead-end roads compared to the total area in the region, (x24) roads slope, (x25) road safety.
Statuses of services and infrastructure facilities	(x26) locating specific areas for temporary accommodation, (x27) proper site selection of service centers in times of crisis, (x28) balanced distribution of relief centers, (x29) access to fire stations, (x30) access to medical centers and hospitals, (x31) access to law enforcement centers, (x32) access to the Red Crescent Society centers, (x33) access to emergency services, (x34) access to open and safe space, (x35) securing city infrastructure networks (gas, water, electricity, sewage) against natural disasters with an emphasis on the earthquake, (x36) the existence of communication infrastructure such as messenger lines, (x37) earthquake warning devices.
Socio-economic	(x38) population density, (x39) training of forces in the operational and management departments, (x40) people's ability to use the correct methods to deal with crisis, (x41) training people to deal with possible risks, (x42) government resources for risk management (x43) the existence of an institutional and collaborative culture for self-organization, (x44) preventing the spread of poverty and settling low-income people in high-risk areas.

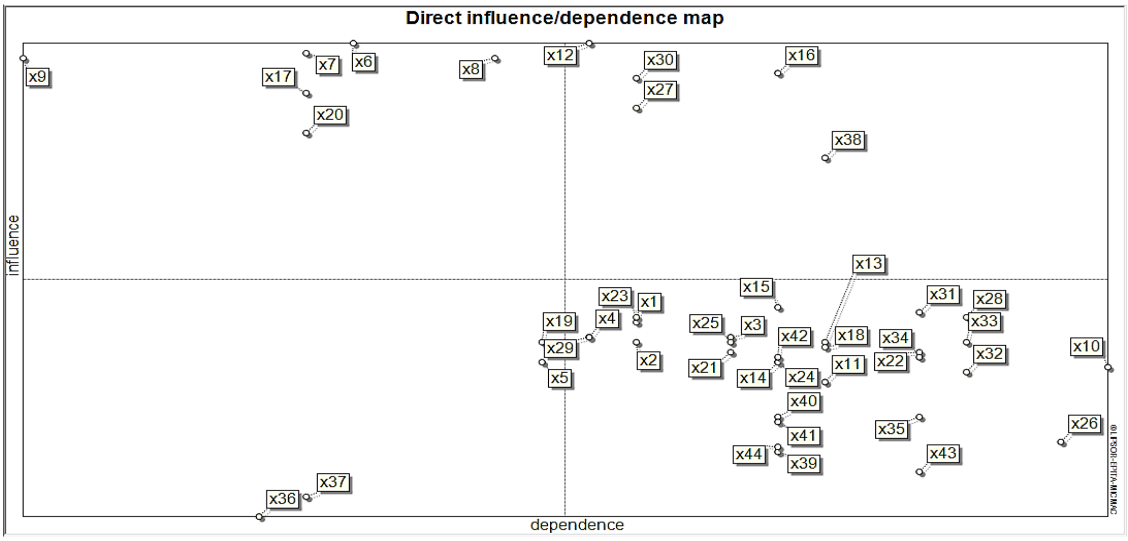

Figure1. Plan of direct influence and effectiveness

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Findings

The district 20 of Tehran is located in the northern land subsidence area of central Iran (Tehran- Rey plain), which due to the operation of several faults such as four physiographic parts such as Tehran plain, Rey land subsidence, South Rey land subsidence, and Kahrizak land subsidence. The maximum length of the South Rey fault and a major part of the North Rey fault are located in the district 20, and the activation of these faults is possible. On the other hand, a large percentage of the land uses in the studied area are among worn out texture, irregular structures and informal settlements. In addition, high building and population densities in some places will increase the vulnerability of the region in the event of an earthquake. According to the surveys, the district 20 of Tehran is more vulnerable than other areas during earthquakes.

Table2. Preliminary data analysis of the mutual effects matrix (source: research findings)

Indicator	No.0	No.1	No.2	No.3	No. of repetitions	Matrix dimensions	Fullness	Plural
Amount	80	712	746	398	2	44	95.86%	1856

The output status of the initial analysis of the Cross Impact Analysis Matrix of the variables in the MicMac software, including factors affecting the future resilience of informal settlements against the earthquake with an emphasis on the district 20 of Tehran metropolis, shows that the index of the matrix is 95.86%, which means that about 96% of the cases have influenced each other (Table 2). This problem reveals the difficulty of deciding on the resilience of the district 20 of Tehran against earthquake, because the high correlation between drivers indicates the need to adopt precise and optimal solutions for different drivers. In fact, due to the relationship between drivers, failure to provide an optimal solution for each driver will necessarily cause the condition of other drivers to decline.

Out of a total of 1856 relations, these values were assigned to the entire matrix: 398 relations, the number three (21.44%), 746 relations, the number two (40.19%), 712 relations the number one (38.36%), and 80 relations the number zero (that is, the factors did not influence each other or each other) (4.31%). These results indicate that the number of relationships with moderate influence (crossing effects 2) is high compared to other relationships. The distribution of variables in the MicMac software determines the stability and instability of the system (Figure 1)

The scatter plot of the variables affecting the resilience of district 20 of Tehran against earthquake shows that most of the variables are spread around the coordinate axis towards the end of the graph and in its areas, which indicates the unstable state of the system and also threatens the lack of influencing variables of the system. Based on this, five types of variables can be identified according to Table 3.

Table3. Distribution of variables based on their classification (Source: research findings)

Classification	Variable
Determining or influencing variables	(x6) the quality of residential units (ratio of renovation and demolition parts to the total built area), (x7) the quality of construction and implementation of structures, (x8) the age of the building, (x9) building materials (frame and foundation materials), (x17) geological and lithological condition of district 20, (x20) the existence of various and numerous access roads with suitable quality to different parts of the city.
Bivariate variables	(x12) distance from fault, (x16) paying attention to the improvement and renovation of buildings, (x27) proper site selection of service centers in times of crisis, (x28) balanced distribution of relief centers, (x30) access to medical centers & hospitals.
Regulatory variables	(x29) access to fire stations, (x4) ratio of regular to irregular subdivisions in the area, (x5) the number of building floors, (x19) urban texture granularity, (x23) the percentage of dead-end roads compared to the total area in the region, (x1) building density (granulation), (x2) composition of mass and space (ratio of built to unbuilt spaces).
Influential variables	(x3) percentage of checkered texture to organic area, (x10) occupancy level of residential units, (x11) building density, (x13) distance from hazardous centers, (x14) adjacent to incompatible uses, (x15) development and expansion of population centers on seismic zones. (x18) the ratio of the average width of the roads to the population density, (x21) the materials and condition of the road floor, (x22) the reliability of network components (roads and bridges), (x24) roads slope, (x25) road safety, (x26) locating specific areas for temporary accommodation, (x31) access to law enforcement centers, (x32) access to the Red Crescent Society centers, (x33) access to emergency services, (x34) access to open and safe space, (x35) securing city infrastructure networks (gas, water, electricity, sewage) against natural disasters with an emphasis on the earthquake, (x38) population density, (x39) training of forces in the operational and management departments, (x40) people's ability to use the correct methods to deal with crisis, (x41) training people to deal with possible risks, (x42) government resources for risk management (x43) the existence of an institutional and collaborative culture for self-organization, (x44) preventing the spread of poverty and settling low-income people in high-risk areas.
Independent variables	(x45) communication infrastructures including messenger lines, (x37) earthquake warning devices.

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Table4. Key factors affecting the resilience of informal settlements against the earthquake with an emphasis on district 20 of Tehran metropolis

Rank	Variable	Indirect Influence	Direct Influence
1	X6	377	379
2	X12	377	379
3	X7	368	373
4	X8	363	370
5	X9	363	370
6	X16	353	361
7	X30	349	359
8	X17	341	350
9	X27	330	341
10	X20	321	326
11	X38	316	311

Table5. Probable statuses of driving factors (source: research findings)

Possible situations	Degree of desirability	Key drivers	Abbreviated name
A1: Increasing the quality of residential units and retrofitting buildings	Desirability	Quality of residential units (ratio of renovation and demolition parts to the total built area)	A
A2: Continuation of the current situation	Intermediate and static		
A3: The increase in repair and demolition parts in district 20 and the subsequent increase in vulnerability to earthquake	Critical		
B1: Preparation and verification of construction standards with special attention to seismic characteristics	Desirability	Quality of construction and implementation of structures	B
B2: Continuation of the current situation	Intermediate and static		
B3:Non-observance of construction regulations and reduction of building safety	Critical		
C1:Use of different methods of stylization of buildings by using new building materials in order to reduce the finished weight of the building	Desirability	Building materials (frame and foundation materials)	C
C2: Continuation of the current situation	Intermediate and static		
C3:Use of inappropriate materials in construction and loose foundation structure of the houses and buildings	Critical		
D1: Preparation of urban planning and restoration plans in worn-out texture and inefficient structures and reducing the vulnerability of buildings against disasters and accidents.	Desirability	Paying attention to the improvement and renovation of buildings	D
D2: Continuation of the current situation	Intermediate and static		
D3:Severe wear and tear of the physical tissue of the neighborhoods of District 20 of Tehran metropolis	Critical		
F1:Compliance with spatial justice of service centers during disasters	Desirability	Proper site selection of service centers in times of crisis	F
D2 :Continuation of the current situation	Intermediate and static		
F3 :Improper distribution of service centers in times of crisis	Critical		

In the next step, the ranking of the desired variables is done in terms of influence and effectiveness (direct and indirect) to extract key factors (Table 4). Since the software multiplies the matrix several times to calculate the indirect effects, the sum of the effects and the indirect effects becomes a multi-digit number and it becomes difficult to compare it with the direct effects. Based on this, the total influence and effectiveness is calculated as 10 thousand and the contribution of each factor from this number indicates its contribution to the whole system.

According to Table 4, about 11 variables such as (x6), (x7), (x8), (x9), (x12), (x16), (x17), (x20), (x27), (x30) and (x38) were obtained as key drivers effective on the resilience of informal settlements against earthquake with an emphasis on district 20 of Tehran metropolis. The variables mentioned in the indirect effect have been repeated without displacement in the indirect effect. The noteworthy point is that all the drivers obtained in some way refer to increasing the resilience of informal settlements in this process. At this stage, in order to develop possible scenarios, the critical uncertainties of the research should be determined first, which according to the results obtained from the analysis and measurement of this index for 11 propositions along with the uncertainty in the physical resilience of region 20 against earthquakes for 5 indicators sentence (x6) is equal to -0.05, (x7) is equal to 0.05, (x9) is equal to 0.08, (x16) is equal

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to 0.12, and (x27) is equal to 0.14 which are very close to zero. In other words, there is no consensus among experts about these five uncertainties and they can be considered as critical uncertainties selected by the consensus index. By identifying critical uncertainties, scenarios can be created (Table 5).

Table 5 shows that 15 possible situations were designed for 5 driving factors and 3 possible situations of each factor were considered. Next, to analyze these scenarios, a 15 x 15 matrix was designed, which was provided to the experts as in the previous step (identification of influencing factors) and they completed the questionnaire with a weight between -3 and -3 by posing this question. They discussed that "If any of the 15 situations occur in the city, what will be the effect on the occurrence or non-occurrence of other situations" and finally determined the effect of each of the scenarios on each other. After collecting the questionnaires, Scenario Wizard software was used to obtain the desired scenarios. Based on the data, the following results are obtained for different scenarios: very strong scenarios: 3 scenarios, weak scenarios: 750 scenarios; and scenarios with high compatibility: 20 scenarios. The nature of this software is to reduce the possible dimensions of scenarios among others to a few possible scenarios with high probability of occurrence. The results of 3 scenarios with a very high score are not among the best and desirable scenarios due to their non-operational and unexpected results. Also, the software shows 750 scenarios with weak probability, which seems to be unreasonable on the one hand to trust the weak scenario, and dealing with 750 scenarios and making policy and planning for them is almost impossible and irrational on the other hand. What seems logical and between strong and weak limited scenarios is to consider scenarios with high compatibility. According to the results obtained from the Scenario Wizard software, 100 situations were determined for 20 scenarios, of which 5 situations (5%) are favorable, 50 situations (50%) are static (maintaining the current situation), and finally 45 (45%) are critical. In general, it can be said that the scenarios facing the driving factors are mostly in a static and critical state, and to increase the physical resilience of the informal settlements district 20 of Tehran, the static and critical state should be improved with coherent planning. In the following, the inductive method was used to compile the scenarios, because it considers all the driving and key factors, and to create and introduce the scenarios, all the factors are involved in each scenario. Based on this method, to create the logic of the scenarios, all 11 key factors obtained should be involved in the development of the scenarios and included and summarized in two dimensions or groups (structural-physical and the status of services and infrastructure facilities) as the holders of different drivers. The difference between these two dimensions is the scale of the factors. In the key factors of the research, the scale of the factors was considered, but here priority was given to the nature and consequence of the factor. This category and these two dimensions can accommodate all driving factors.

Each of these dimensions covers a number of factors such as (x6), (x12), (x7), (x8), (x9), (x16), (x17), (x30), (x27), (x20), and (x38). According to Figure 2, the formation of scenario logic is shown with two structural-physical dimensions and the status of infrastructure services and facilities in the field of physical resilience of district 20 of Tehran.

According to Figure 2, the three golden, static and catastrophic scenarios find their positions in the axis. The golden scenario or improving the physical resilience of informal settlements district 20 of Tehran against earthquake will take place when the condition of the structural-physical factors is facing a favorable trend and the service and infrastructure facilities move in line with the physical resilience of district 20 of Tehran. In fact, in these scenarios, the key factors are more favorable than the critical state or at least maintaining the current state and improving to some extent.

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The disaster scenario will happen exactly opposite to the conditions of the golden scenario. In this group, despite the fact that some key factors are favorable and slightly improving, the critical condition is more dominant. However, the plausible scenario of paying attention to the reduction of vulnerability and neglecting the promotion of resilience is placed in the slightly improving area of services and infrastructural facilities and the decline of structural-physical factors.

Considering the current situation of district 20 in terms of vulnerability to earthquake, in the most optimistic scenario, a static scenario or the continuation of the current situation will be realized in the horizon of 2051, and we may move towards the crisis scenario with the continuation of the current situation, unless we approach in a forward-looking and systemic manner, all driving factors should be included in the planning to improve resilience in district 20 of Tehran. It is possible that with the continuation of the current situation, we will move towards a crisis scenario, unless all driving factors are included in the planning to improve resilience in district 20 with a forward-looking and systemic approach. According to the relationship between these driving factors and their effectiveness, strategic and optimal planning of resilience for the studied area should be done and, in this context, strategies should be presented to improve the situation of the static scenario and prevent the movement towards the crisis scenario.

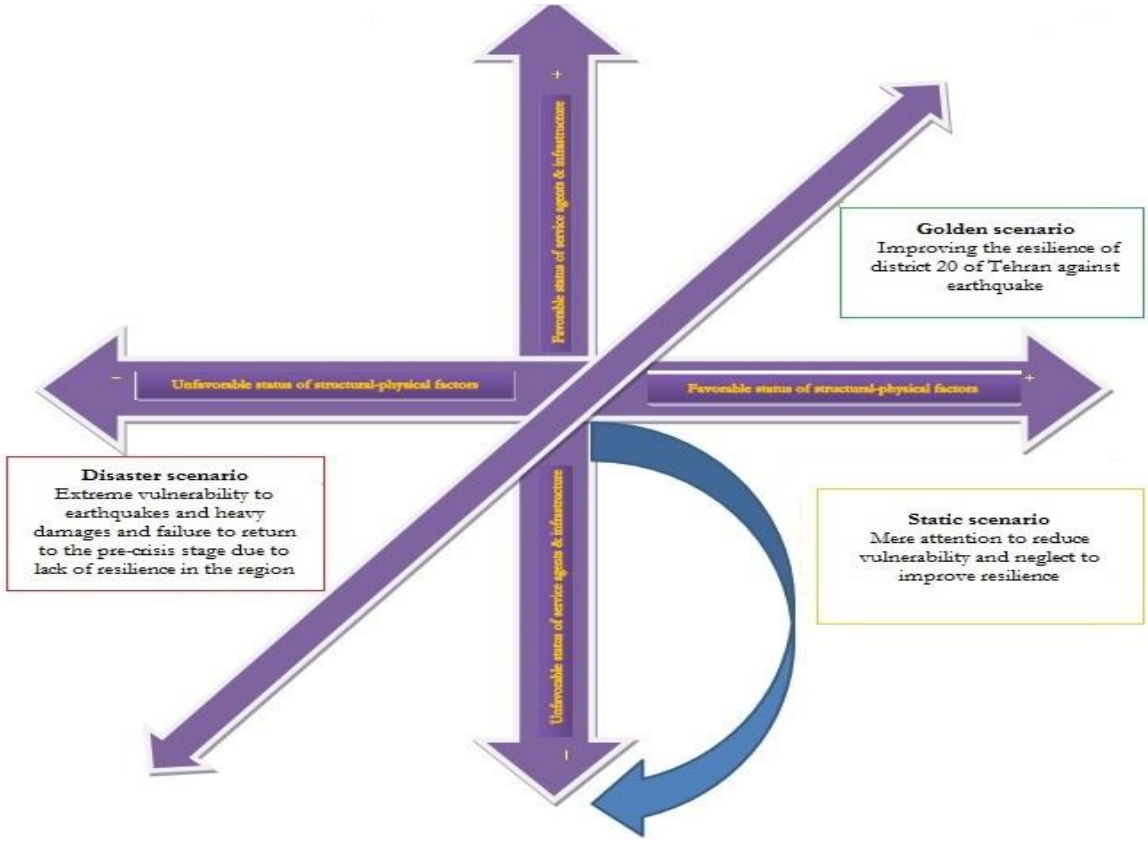

Figure2. The formation of scenario logic with two dimensions in the field of physical resilience of district 20 of Tehran against the earthquake crisis

Discussion and Conclusion

The results obtained from the study of the vulnerability in district 20 make clear the necessity of addressing the issue of resilience in this region with a new planning approach because one of the realities in the city and its problems is the nature of intertwining and complexity as well as its continuous changes. One of the approaches that emerged at the end of the 20th century to overcome the complexity of problems and manage changes is the approach of planning based on future research. Since all the problems and issues in the field of urban planning do not have the same priority and importance, and on the other hand, due to the limitation of resources and facilities, it is not possible to respond to all the problems of the cities, therefore, it is very important to identify the strategic issues and driving factors in the planning process. Considering the internal and external limitations and facilities of the planned system, this approach is based on equipping resources and unifying efforts to achieve long-term goals and missions.

In fact, planning based on future research is a systematic method for managing changes and creating a better future and its ultimate goal is to create sustainable development and improve the quality of life of all citizens. It is also a shell process in which there is no definite and limited time and it includes various steps from recognizing possibilities and limitations to formulating goals and policies, preparing programs, executive management, monitoring, revision and correction, which are repeated again and again. In this regard, the most important factors affecting the resilience of informal settlements against earthquakes were identified, with an emphasis on the district 20 of Tehran.

The results of the research showed that the factors of the structural-physical sector have the highest impact on the future of these settlements. In the next stage, by determining the critical uncertainties, research scenarios and their validity were developed. In the end, it should be mentioned that the issues and problems of informal settlements are multi-faceted and multi-dimensional by their nature and appear in a specific way in each case. The functional and physical disorders of these tissues along with the occurrence of numerous crises and loss of life and money are among the reasons that have forced the policy makers and urban planners to provide new solutions in facing the crises of this region. Therefore, according to the different scenarios obtained, it is necessary to examine all possible states at different levels and make necessary plans in line with each of these effective scenarios.

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None

Conflict of Interests

The authors declare no conflict of interest.

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