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Evaluating Geomorphological Hazards of Urban Development in District 15 of Tehran for Hazard Management

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Abstract:- This study aimed to determine the geomorphological hazards caused by the urban development of District 15 of Tehran and to provide solutions to reduce risks in the region. In this study, Data required were obtained using 1:25000 topographic maps, satellite photos, and aerial images. Sample excavation points were surveyed by using GPS, and elevation map differences of the years 1965 and 2020 were provided via ArcGIS spatial analyst. The hydrology tool in the GIS was used to extract waterways to analyze waterway network changes. A geomorphological hazard map of the region was extracted by considering the criteria of distance from excavation points, distance from points where elevation decreases, distance from natural waterways, slope, and land use using AHP and Fuzzy models. Results indicated that hazards from excavation, floods, waterway network changes, and foot slope changes threaten society and human activities. Excavation and embankment caused by construction and road construction activities changed the local elevation of the zone in the region, consequently causing changes to the local slope and natural morphology. Foot slope and elevation changes were found to disrupt the compatibility of the regional morphology with the natural topographic state to cause floods in this region. The most notorious hazards in this region can be urban floods, which may affect various areas.

Keywords*: Hazards, Geomorphology, Development, Urban Management, Tehran*

1. Introduction

The growing size of cities, affected by rising population and migration, has led to unplanned construction and many changes within the urban spatial structure, especially the physical development of cities in inappropriate natural places (Saberifar, 2012). Since Iran is a developing country, urban development, migration, and a rising urban population can negatively affect the occurrence of environmental crises in cities (Sepehr and Kavian-Ahangar, 2014). Global surveys of damages caused by natural hazards indicate that in 2001, 700 identified natural incidents claimed the lives of 25000 people and incurred 36 bln $ in economic losses and 11.5 bln $ in insurance costs (Sasanpour et al., 2017). Also, six percent of the casualties caused by unprecedented incidents in the world relate to Iran, which ranks sixth among the world's vulnerable countries and fourth in Asia (Kavusi et al., 2018). Therefore, natural hazards, especially geomorphological ones, incur many financial, life, and environmental losses, so taking precautionary and protective measures are critical (Jafari, 2015).

Geomorphology is one of the most practically dynamic geographical disciplines, and geomorphological studies involve the relationship between environmental factors and earth landforms (Jafari and Shah-Zaidi, 2018). Predicting future geomorphological changes caused by urban development requires studying the past and perceiving the current time and future capacities (Moghimi, 2012). Geomorphological strategies aim to reduce both human and natural vulnerabilities and seek to identify internal and external ground processes to provide methods to predict natural incidents (Karami, 2015). In a study, "Applications in Geomorphology," Edward Keller et al. (2020) introduce geomorphology knowledge as a practical science aiming to meet the needs of society. Consistent with the findings of Keiler and Fuchs (2016), Geomorphological and social processes are related together through a diverse set of relations and feedback and One of the most important of these relations is the effect of hazardous geomorphological processes on society, which cause economic and life damage. Prokos et al. (2016) also investigated the practical geomorphological hazards in the Tétouan City of Morocco.

District 15, a suburban area of Tehran City, served as one of the main entries for travelers since it enjoyed many gateways. This area saw its highest urban and population expansion in the early years of the revolution. This area expanded with the Islamic Revolution and the introduction of the 25-year Master Plan of the city of Tehran in 1979, with most of its vacant land occupied by residential units just recently [2020-12-01](https://region15.tehran.ir). The imbalanced expansion and physical development of this region based on vacant land policies, compounded with the immediate decision and disregard of urban development rules and regulations, caused a variety of problems for residents of this region, as the majority of residents are not satisfied with their residence and has to live there for some reasons. The spatial development of this region without regard for environmental capacities could leave undesirable impacts and cause irreparable damage to the metropolis of Tehran (Mirzaei, 2012). The present study aimed to evaluate the morphological hazards of the urban development of District 15 of Tehran City to manage those hazards. For this, the researcher aims to respond to the following three questions:

1) Which geomorphological hazards threaten Tehran's District 15?
2) What is the priority of the existing hazards, and what are their effects?
3) What are the appropriate methods to deter, control, and reduce these hazards?

2. Studied Region Hazards

2.1. Hazards from Excavation

Excavation of different depths for constructing high-rise buildings is inevitable. This issue is also important in urban areas, especially in their downtowns, considering the presence of buildings and installations around the excavation sites. Inaccurate design and calculation and improper execution of excavation could lead to irreparable life and financial losses (Maleki et al., 2010). When deep excavation is performed, soil balance is disrupted, and soil tensions change, too. Also, as a result of excavation, soil undergoes deformation. Each of these states can cause soil cohesion to disrupt or rupture, thus unbalancing and destabilizing structures adjacent to excavation sites (Pezeshki and Ahmadi-Masineh, 2013).

2.2. Waterway and Flood Hazards

In cities, floods do not just cause hazards; population concentration, economy, and artificial crafts add to the subject's significance. Flooding in cities falls under two categories: urban territory flooding occurs under conditions where rivers outburst, while the second type occurs due to an overflowing collecting network of urban flooding, usually caused by torrents across cities (Hosseinzadeh, 2010). In integrated flood management, water and ground resource development in a watershed basin is planned in the form of integrated water resource management. To implement integrated management, it is required to consider the components of river watershed basins in an integrated form. In this connection, social-economic activities, land use patterns, hydro-morphological processes, etc., should be recognized as system-constituting components, as a master plan and an integrated program can be used for various measures (Naqshbandi, 2017).

2.3. Foot Slope Change Hazards

When roads and buildings are constructed on foothills, sewage canals, water pipes, and electricity cables are buried under foothills, the pressures applied to the material inside the foothills change. These changes can cause the mass movement of material on the foothills in different forms (Rustayee and Jabbari, 2012). Foothill instabilities are a particular ground-morphological hazard in semi-arid mountains with rocky foothills. These phenomena that are considered natural outcomes within these areas are aggravated by human interventions and threaten most human facilities, especially mountainous roads, thus, incurring many costs on governments and residents (Rustayee et al., 2015).

3. Characteristics of the Studied Area

District 15 of Tehran is located between latitude 35° and 36’ to 35° and 40’ northern and longitude 51° and 26’ to 51° and 30’ eastern. This district is situated in southeastern Tehran, bordered by Ghasr-e-Firouzeh Barracks, 45-m Ahang, Khavaran St. and Shush-e-Sharghi to the north, by Fedaiyan Islam to the west, and by Dolat Abad St. Bibi Shahrbanu Mt. and Cement Factory to the south, and by eastern mountains of Tehran and the eastern limits of Afsariyeh to the east (Figure 1).

The 25-year legal-range area of the region covers a land of 28.5 sq km, as according to the latest regional urban development studies and changes made to the legal territories, the legal-range area of the region will exceed 35 sq km. Tehran’s area of city exclusion under the municipality’s administrative responsibilities covers a land of 16500 hectares, accounting for 14.6% of the total area of Tehran’s city exclusion. The zone of this territory lies within the national division framework under the administrative responsibilities of two cities of Tehran and Rey.

The district 15 municipality has divided its service territories into eight areas, with the territories of six areas being within the territories approved of by Tehran’s Master Plan and the territories of two areas (i.e., Khavarshahr and Ghiam Dasht) being outside the territories and within the city exclusion, detached from the district [2020-12-01](https://region15.tehran.ir).

A large part of the district has formed in the alluvial plain of southern Tehran. A small district area on the eastern side has volcanic bedrock, with a small part of the northeast formed of D formation deposited in the form of young fan alluvial (Mirzaei, 2012). Because district 15 is located in low-altitude areas, it enjoys a relatively hot and dry climate.

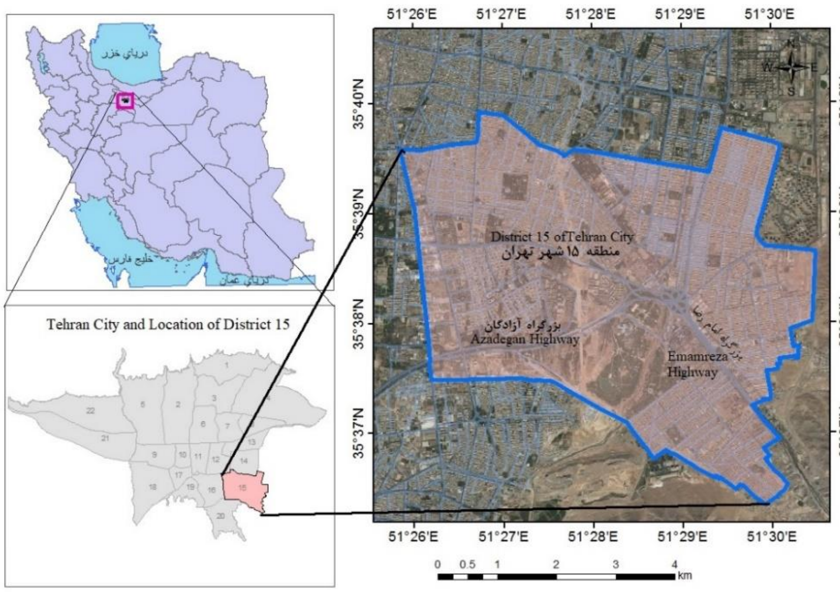

Fig. 1. Location of the studied area

Underground water levels in the region vary from 5-10m, indicating higher underground water levels. This level of water has also caused numerous environmental problems. Pollutions caused by well drain and house sewage, as well as the lack of appropriate sewage facilities in the district, have affected the quality of air, and caused spread of diseases among residents there (Mirzaei, 2012). In district 15 there are 14 aqueducts, all of which flow at the depth of 15m below the ground levels.

The only aqueduct that has a free flow and is located upstream is the Mostowfi aqueduct flowing separately alongside the Barut Kobi canal. The only river that passes through the region is the one that gathers sewage and surface waters over its route from north and northern Tehran; after the adjoining of the Sorkhe Hesar route at the

Abuzar Boulevard, it flows freely from the fourth bridge of the boulevard down into the territories of District 15 (Mirzaei, 2012). The average height of this region from the sea level is 1100 m.

In the south lay the Bibi Shahrbanu Mountains, which form the regional southern perspective ad serve as delimiting factors. To the east lay various highlands, including Turkmen Mt., which not only shape the eastern perspectives of the region but also seriously affect the general slope changes of the region and increase natural ground terrains (Mirkhani, 2007). As stated, a large part of the district is situated on the alluvial plains of southeastern Tehran; the general north-to-south ground slope is around 1-3% (Mirkhani, 2007).

Some of the factors that affected the physical development of the district were the presence of large-scale communication networks. For example, a first-class arterial road (Khavaran St.) leads, on the one hand, to the areas inside the district and, on the other hand, leads to the Khorasan Road, thus indicating its intra- and inter-city importance (Mirzaei, 2012). District 15 of Tehran has 583896 meters of passageways and 699682 meters of first-, second-, three-, and fourth-class canals (Bayat, 2016). Recently, this district has experienced many changes due to the passage of the Imam Ali Highway (Bayat, 2016). In sum, residential areas have seen an eastern-western direction, with two classes of barren land and industrial areas being reduced to the benefit of two classes of residential territories and commercial and green-space regions.

4. Material and methods

This study gathered data by visiting the Internet and reviewing library sources better to understand the background of the subject under study. Data required were obtained using 1:25000 topographic maps, satellite photos, and aerial images. This connection used Google Earth and GIS software to obtain sample excavation points using GPS and field surveys. This study pinpointed excavation ranges from the images and specified their locations. Then, GPS excavation points in District 15 were recorded using GPS and entered the ArcGIS software based on latitude and longitude features. ArcGIS spatial analyst software was used to analyze excavation hazards to provide elevation difference maps of 1965 and 2020. Also, topographic maps of 1965 and 2020 were used to analyze foot slope changes. To analyze waterway network changes, the hydrology tool of the GIS software was used to extract the waterways. Waterway networks of 1965 and 2020 were provided, and their range changes were determined based on topological rules in the GIS. In the end, considering such criteria as the distance from excavation points, distance from points where elevation decreases, and distance from natural waterways, slope, and land use, the geomorphological hazards map of the region was extracted using AHP and Fuzzy models.

5. Results

Elevation and waterway change analyses from 1965 to 2020 were performed based on aerial photos, satellite images, large-scale maps, and field surveys. A comparison of elevation and waterway changes with human activities in the region can provide insight into the effects of urban activities on the local morphology of the region.

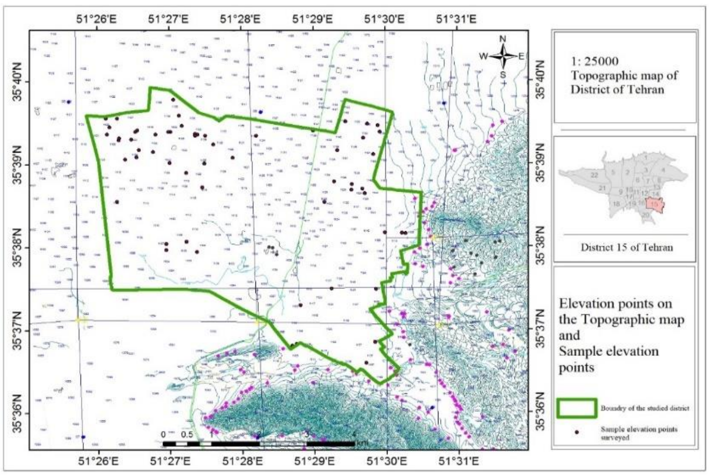

Fig. 2. Map of sample points surveyed

It is noteworthy that data were revised before entering the analysis stage. Elevation and drainage network data errors were corrected using topological rules in the ArcGIS and generated DEM layers were changed into UTM coordinates. The hydrology tool in the ArcGIS10.7 spatial analyst (waterway class) was used to provide a drainage network layer. Below data preparation stages are described:

1) The 1965 topographic layers were extracted from the same year's aerial photos using Stereo pair and photogrammetric techniques, then turned into Digital Elevation Model using Spatial Analysis in the GIS.
2) The 2020 topographic layers were provided based on the updated 1:25000 topographic map by the Mapping and Field Survey Organization of sample points in the region using Spatial Analysis in the GIS (Figure 2).
3) The hydrology tool of ArcGIS 10.7 (waterway class) was used to provide the drainage network layer. Then, the waterway network was revised using topological rules for later analyses.
4) Using a GPS device, sample excavation points were collected via field surveys in two stages.

5.1. Elevation Changes

The ArcGIS spatial analyst provided elevation map differences of the years 1965 and 2020. Elevation changes results indicate that parts of district 15 of Tehran City had, at the time intervals, experienced rising and falling elevation rates due to excavation and preparations for urbanization and construction projects.

According to the 1965 aerial photos, the region had a natural drainage network, mainly formed by run-offs caused by precipitations based on topographic and a soil bed. However, the 2020 drainage network indicates that the network has a synthetic form, mainly developed in the direction of constructed canals and passageway networks. These results suggest that the 1965 network had a natural state, but in 2020, the network took a synthetic form due to the construction of canals and street leveling, thus, causing natural classes to disappear due to street networks.

Results from elevation map differences in 1965 and 2020 indicate that some regions have experienced increasing and decreasing local elevation rates. Consistent with the results, decreased elevation zones were mainly affected by construction work, while increased elevation rates were due to road and infrastructure construction and regional highway projects.

According to Table 1, in 1965, Area 6, at 1158m above sea level, held the highest average elevation rate among the six areas, whereas Area 4, at 1120m above sea level, held the lowest elevation. In 2020, Area 6, 1159m from the sea level, held the highest average rate, whereas Area 4, with minor elevation changes, held the lowest average rate. Also, Area 6 held the highest changes from a spatial perspective; in other words, the difference between the highest and the lowest elevation in this area in both time intervals is 85m. Changes in standard deviation indicate that Area 4 held the highest standard deviation in pixel values, thus experiencing the highest elevation changes and roughness from a spatial perspective.

Table 1

Elevation parameters of six areas of the studied district in 1965 and 2020.

Year	Area	Area of each area	Min. elevation	Max. elevation	Foothill	Average of each area	S.D.
1965	Area 1	4432175	1107.36	1142.12	37.44	1127.61	7.90
	Area 2	4853625	1112.10	1144.68	32.58	1128.13	7.56
	Area 3	6511125	1089.59	1123.08	33.49	1104.82	7.63

Year	Area	Area of each area	Min. elevation	Max. elevation	Foothill	Average of each area	S.D.
	Area 4	6492525	1091.07	1163.41	72.34	1120.65	18.35
	Area 5	2840625	1118.25	1172.62	54.37	1143.99	13.95
	Area 6	3325175	1115.25	1197.99	82.74	1158.87	16.67
	Average	4742542	1105.60	1157.32	51.72	1130.68	12.01
2020	Area 1	4432175	1109.60	1139.02	29.41	1125.09	6.47
	Area 2	4853625	1112.67	1146.25	33.58	1127.37	6.02
	Area 3	6511125	1091.40	1126.35	34.95	1106.81	7.18
	Area 4	6492525	1086.97	1166.69	79.71	1120.03	20.67
	Area 5	2840625	1120.47	1179.35	58.88	1143.98	14.14
	Area 6	3325175	1119.74	1204.81	85.08	1159.59	17.66
	Average	4742542	1106.81	1160.41	53.60	1130.48	12.02

Elevation changes from 1965 to 2020 indicate that the highest average elevation reduction of the region pertained to Area 1, with 2.52m of the sea level compared to 1965, which is probably due to the excavation activities for the road and subway station project construction there. The highest elevation from 1965 to 2020 pertained to Area 3 with around 2m from the sea level, which is most probably due to the region's embankment and highway construction projects, including Azadegan and Be'sat highways, and urban developmental the Kian-Shahr neighborhood (Table 2).

Table 2

Elevation changes from 1965 to 2020 in the six areas of District 15 of Tehran (elevation in meters above sea level).

	Area	Min. elevation	Max. elevation	Foothill	Average of each area	S.D.
Changes in the two-time intervals	Area 1	2.24	-3.11	-5.35	-2.52	-1.43
	Area 2	0.57	1.57	1.00	-0.77	-1.54
	Area 3	1.81	3.27	1.45	1.99	-0.45
	Area 4	-4.09	3.27	7.37	-0.62	2.32
	Area 5	2.22	6.74	4.51	-0.01	0.19
	Area 6	4.49	6.82	2.33	0.72	0.99
	Average	1.21	3.09	1.89	-0.20	0.01

Elevation changes of points with the most increases or decreases are extracted. These points indicate the effects of road construction and highway and street projects on the increasing elevation and the effects of construction excavation on the decreasing elevation (Table 3).

Table 3

Elevation decrease and increase changes in the region based on proximity to communication arteries and excavation points (elevation in meters from sea level).

Elevation decrease			**Elevation increase**		
Row	**Distance from maim arteries**	**Distance from sample excavation points**	**Row**	**Distance from maim arteries**	**Distance from sample excavation points**
1	37.81	59.44	37	85.96	363.96
2	96.31	179.77	38	5.09	711.52
3	58.25	406.84	39	49.45	444.81
3	561.33	120.22	40	32.86	690.76
5	176.37	120.87	41	59.69	997.79
6	245.82	143.44	42	41.35	370.96
7	46.01	161.56	43	140.39	586.68
8	124.52	455.80	44	122.82	462.85
9	137.42	389.76	45	16.78	160.68
10	160.43	374.51	46	48.93	906.63
11	81.38	719.46	47	33.32	480.03
12	26.52	402.49	48	47.02	404.00
13	2.84	459.22	49	356.96	285.79
14	65.28	546.88	50	42.38	981.19
15	170.51	748.80	51	15.35	1177.85
16	188.84	133.59	52	13.34	656.48
17	134.49	193.85	53	1.65	758.59
18	180.62	356.03	54	4.85	938.17
19	43.60	500.40	55	5.99	558.48
20	47.49	469.32	56	19.13	451.31
21	83.75	156.17	57	55.04	360.65
22	77.47	61.23	58	95.68	301.89
23	214.39	347.94	59	779.22	344.06
24	479.80	93.41	60	242.03	813.90
25	727.00	142.99	61	962.09	353.87
26	25.41	326.46	62	26.62	212.10
27	282.52	105.14	63	215.68	328.42

Elevation decrease			**Elevation increase**		
28	218.74	714.88	64	54.63	862.75
29	85.04	531.88	65	76.16	482.47
30	319.19	717.45	66	46.24	317.90
31	102.26	690.68	67	177.99	123.79
32	249.68	199.72	68	25.73	89.50
33	109.12	173.50	69	5.99	482.44
34	179.33	333.82	70	0.44	750.62
35	225.30	433.58	71	3.99	473.13
36	246.57	214.42	72	29.24	1464.78
Average	172.54	338.49		109.45	559.73

Road construction excavation and urban territory levelling for urban development were more effective than construction excavation in creating elevation changes (Figure 3). Although the highest average elevation decrease was caused by Area 4 excavation, the highest or maximum elevation decrease of around 8m pertained to Area 1, which may be due to the construction of Imam Ali Highway on the outskirts of this area and the development of subway tunnels, as well as the expansion of urban water canals. The highest increase in elevation is also noted in the intersection of Azadegan and Imam Ali Highways and the intersection of Azadegan, Be'sat, Basij, and Imam Reza Highways.

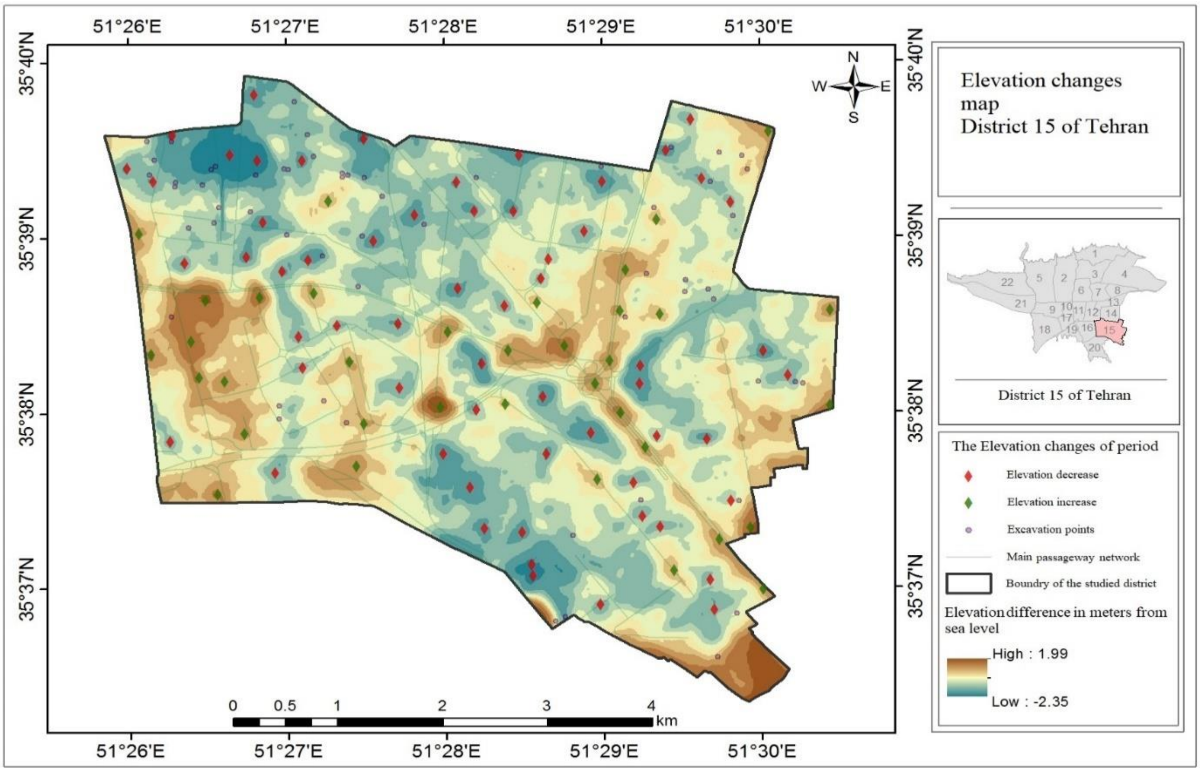

Fig. 3. Map of elevation changes based on the proximity of elevation change points to road terrains and excavations

5.2. Waterway Network Changes

The hydrology tool in ArcGIS was used to calculate waterway changes. Therefore, calculating elevation changes in this study by the hydrology tool using DEM elevation layers of each year under study significantly contributes to answering the study questions. Analysis results from regional waterway changes from 1965 to 2020 indicate that the construction of artificial water canals causes considerable changes to waterway network distribution models.

Table 4

Relationship between waterway changes and changes in the local topography of the region.

Elevation decrease			**Elevation increase**		
Row	**Distance from waterway (1965)**	**Distance from waterway (2020)**	**Row**	**Distance from waterway (1965)**	**Distance from waterway (2020)**
1	140.86	447.38	37	57.32	303.83
2	59.99	51.84	38	84.89	202.68
3	279.49	463.93	39	57.04	145.62
4	199.68	420.43	40	65.18	8.01
5	166.00	115.83	41	6.58	185.12
6	132.73	84.04	42	37.60	374.05
7	183.14	77.96	43	11.52	191.21
8	168.77	75.24	44	17.52	484.72
9	133.93	41.44	45	37.10	326.17
10	143.23	15.54	46	13.07	177.62
11	128.18	147.68	47	22.06	259.04
12	136.86	14.98	48	94.54	242.39
13	118.10	155.91	49	22.56	196.57
14	190.01	125.18	50	57.10	279.93
15	124.86	7.91	51	22.94	218.03
16	161.13	203.93	52	106.46	207.31
17	39.81	9.75	53	91.48	142.36
18	159.93	237.80	54	1.57	246.78
19	170.99	106.40	55	41.18	333.60
20	280.01	568.37	56	204.96	752.68
21	130.83	115.77	57	135.77	699.69
22	86.28	118.07	58	461.88	887.32
23	130.42	230.12	59	372.57	936.88

Elevation decrease			Elevation increase		
Row	**Distance from waterway (1965)**	**Distance from waterway (2020)**	**Row**	**Distance from waterway (1965)**	**Distance from waterway (2020)**
24	10.67	10.55	60	252.80	766.68
25	81.96	347.39	61	166.69	458.97
26	157.03	86.65	62	48.72	153.50
27	98.20	429.44	63	29.17	131.18
28	98.52	29.91	64	27.60	127.33
29	79.84	119.77	65	76.32	446.92
30	157.44	368.24	66	38.90	321.10
31	160.02	338.31	67	42.18	36.02
32	223.96	36.82	68	70.77	145.72
33	66.02	396.65	69	6.81	193.05
34	18.26	474.60	70	72.77	621.85
35	276.98	612.36	71	60.07	5.07
36	213.62	319.20	72	97.54	309.49
Average	144.66	205.71		83.70	319.96

Table 4 indicates that at points where elevation has decreased, the distance from waterways was 145m in 1965, while at points where elevation has increased, the distance from waterways was 84m in the same year. This suggests that at points where elevation has been experienced, positive changes were the same ranges within the canals in the past, which may be due to human and embankment activities. In other words, elevation increase was more significant near older canals. According to this table, at points where elevation has decreased, the distance from new waterways was around 206m, while at points where elevation has increased, the distance rate was 320 m. This indicates that the points with negative elevation changes are nearer to current networks, while points with positive elevation changes are more distant from current networks. In other words, constructing new canals and developing new waterways indicate a decrease in elevation in the adjacency of artificial canals. As stated above, waterway changes transformed from regional morphology-compatible natural waterways into regional morphology-incompatible artificial waterways can cause incidents by the time of flooding.

To analyze and obtain the geomorphological hazards map of the region, criteria were weighted and then combined after being normalized. These effective criteria were the distance from points where elevation decreases, distance from natural waterways, distance from excavation sites, distance from open spaces, slope, and land use (Table 5). These criteria affect regional geomorphological hazards. The criterion of distance from excavation points affects excavation hazards; the criterion of distance from points where elevation decreases affect elevation change hazards; the criterion of distance from natural waterways affects the natural waterway change hazards; the criterion of slop affects urban flooding hazards, and the criterion of land use affects all four hazards, and mainly flooding hazards. All these criteria also affect each other, and for this, a final map of regional geomorphological hazards is extracted (Table 6).

Table 5

Pairwise comparison of the criteria and their preference (the ratio of criteria weighting direction and obtaining of each criterion weight are combined).

	Distance from points where elevation decreases	Distance from natural waterway	Distance from excavation	Slope	Distance from open spaces	Land use
Distance from points where elevation decreases	1	3	4	3	5	6
Distance from natural waterway	1.3	1	3	2	3	4
Distance from excavation	1.4	1.3	1	2	6	5
Slope	1.3	1.2	1.2	1	2	2
Distance from open spaces	1.5	1.3	1.6	1.2	1	2
Land use	1.6	1.4	1.5	1.2	1.2	1
Total	2.28	5.42	8.87	9	17.5	20

Table 6

Combining criteria and extracting the weight of each criterion (unit of comparative ratio numbers).

	Distance from points where elevation decreases	Distance from natural waterway	Distance from excavatio n	Slop e	Distance from open spaces	Land use	AH P weig ht	CA
Distance from points where elevation decreases	0.44	0.55	0.45	0.33	0.29	0.30	0.39	0.9
Distance from natural waterway	0.15	0.18	0.34	0.22	0.17	0.20	0.21	1.14
Distance from excavation	0.11	0.06	0.11	0.22	0.34	0.25	0.18	1.62
Slope	0.15	0.09	0.06	0.11	0.11	0.10	0.1	0.93
Distance from open spaces	0.09	0.06	0.02	0.06	0.06	0.10	0.06	1.11
Land use	0.07	0.06	0.02	0.06	0.03	0.05	0.05	0.92

Table 7 indicates that the CI coefficient and general compatibility were calculated to measure the compatibility of the criteria and the accuracy of the AHP mode.

Table 7

CI coefficient value and general compatibility degree.

Lambda	CI	CI/RI	Randomness Index, RI
6.622	0.124	0.101	1.24

Given that the model's compatibility degree was appropriate, the obtained weights will be multiplied in the next stage by each criterion or each corresponding raster layer. Later, the maps of criteria affecting regional geomorphological hazards and their combination will be analyzed (Figures 4-9). The Fuzzy Logic Theory refers to attention to spatial objects on a map as members of a set. According to the Classic Set Theory, an object is a member of a set if it has a membership value of 1, or it is not a member of a set if it has a membership value of zero. In the Fuzzy Set Theory, membership can involve any value between 0 and 1, suggesting a confidence rate of membership (Qanavati and Alijani, 2011).

Fig. 4. Map of the criterion of distance from points where elevation decreases with fuzzy membership

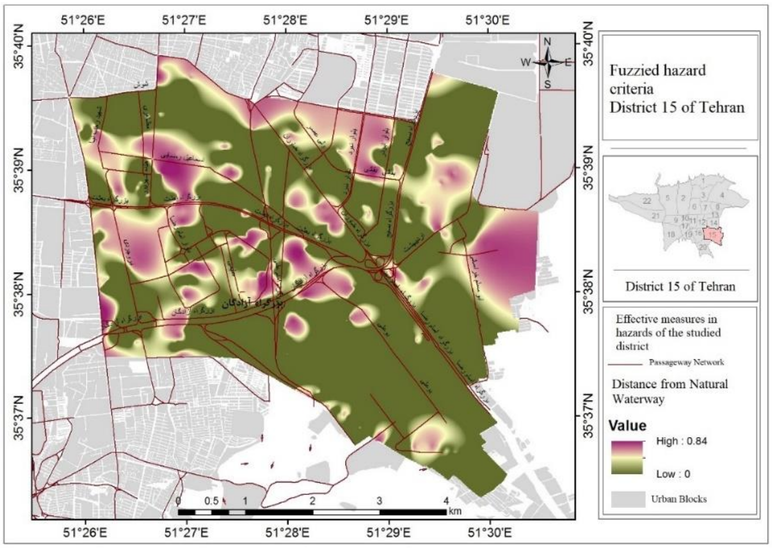

Fig. 5. Map of the criterion of distance from natural waterway with fuzzy membership

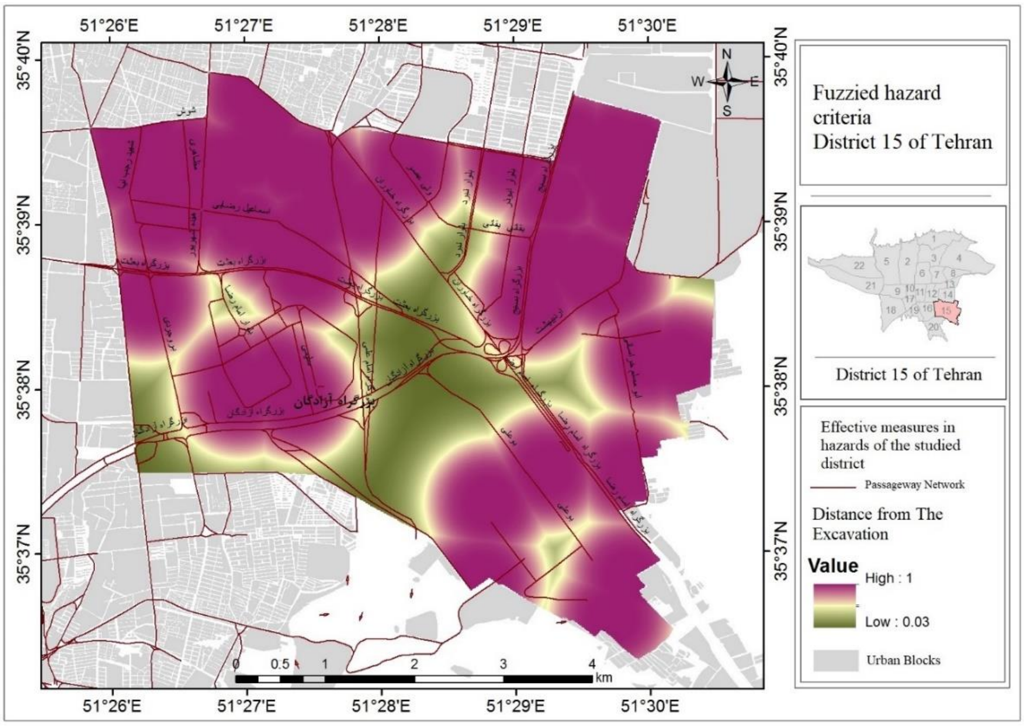

Fig. 6. Map of the criterion of distance from the excavation with fuzzy membership

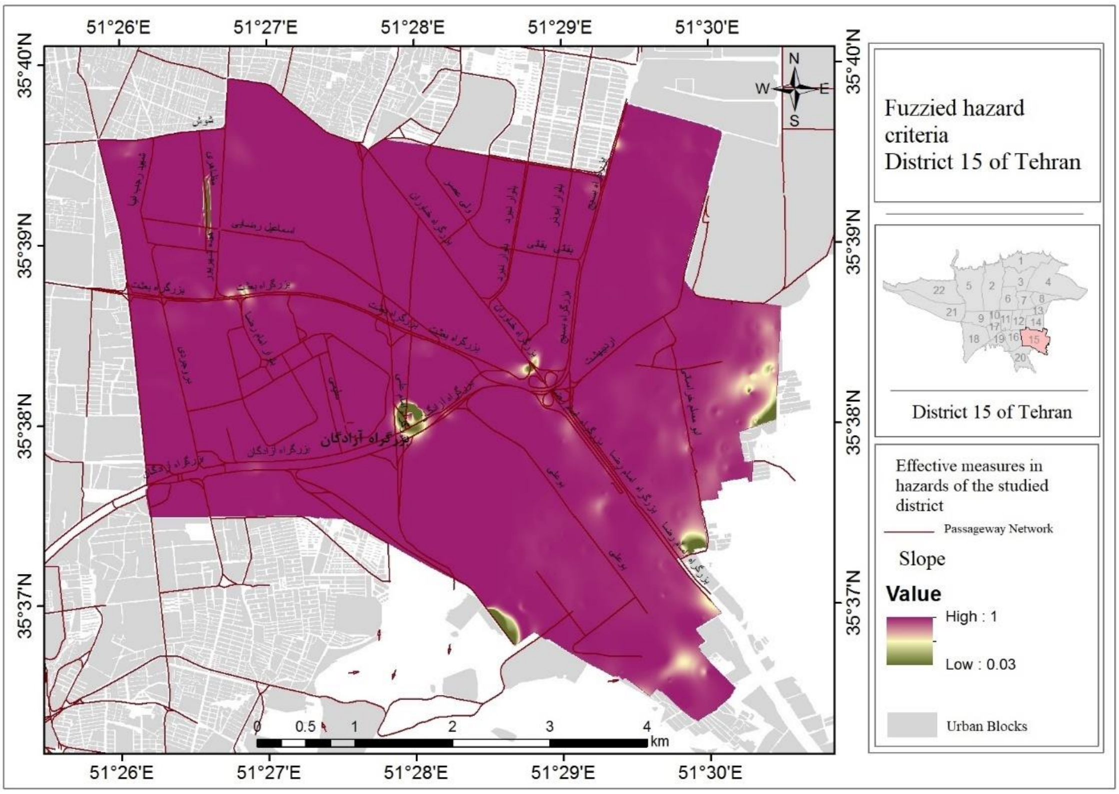

Figure 7. Map of the criterion of the slope with fuzzy membership

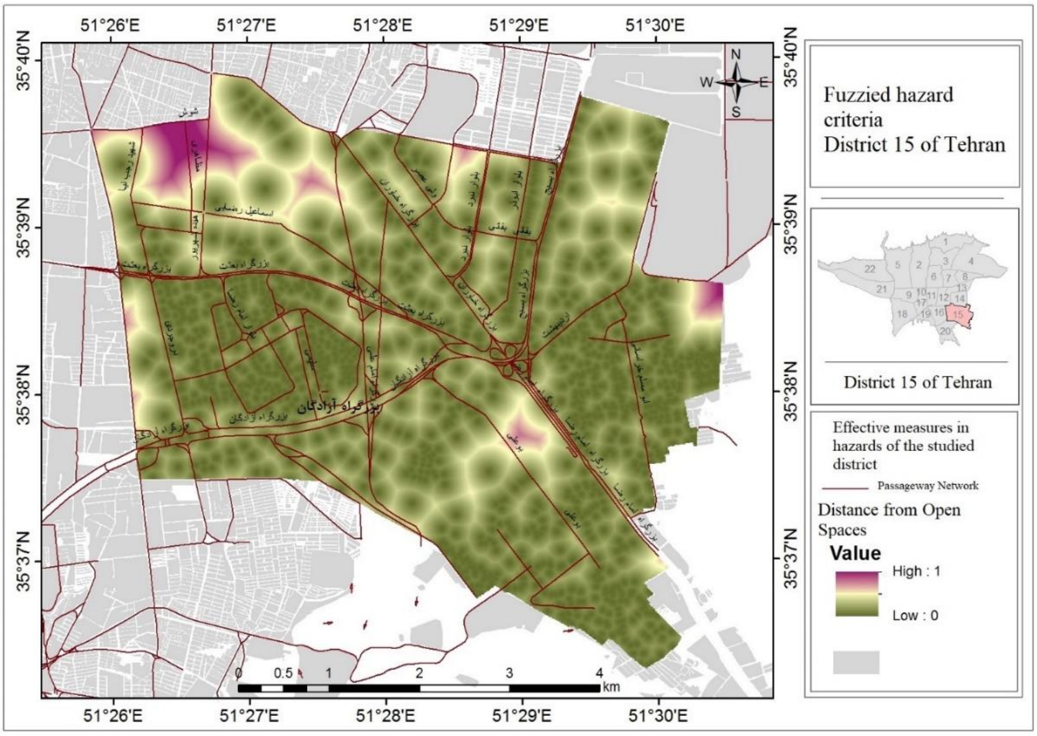

Figure 8. Map of the criterion of distance from open spaces with fuzzy membership

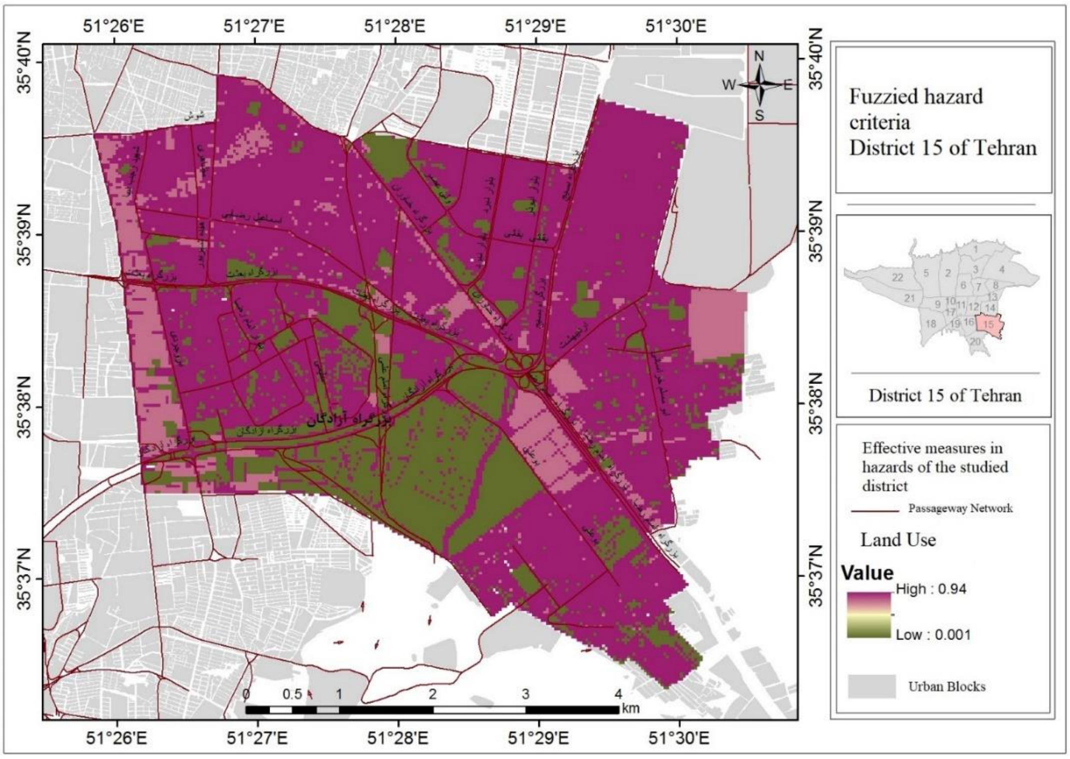

Fig. 9. Map of the criterion of land use with fuzzy membership

Combining layers, the final map of urban infrastructure vulnerability was derived based on these six criteria. This map is illustrated in Figure 10.

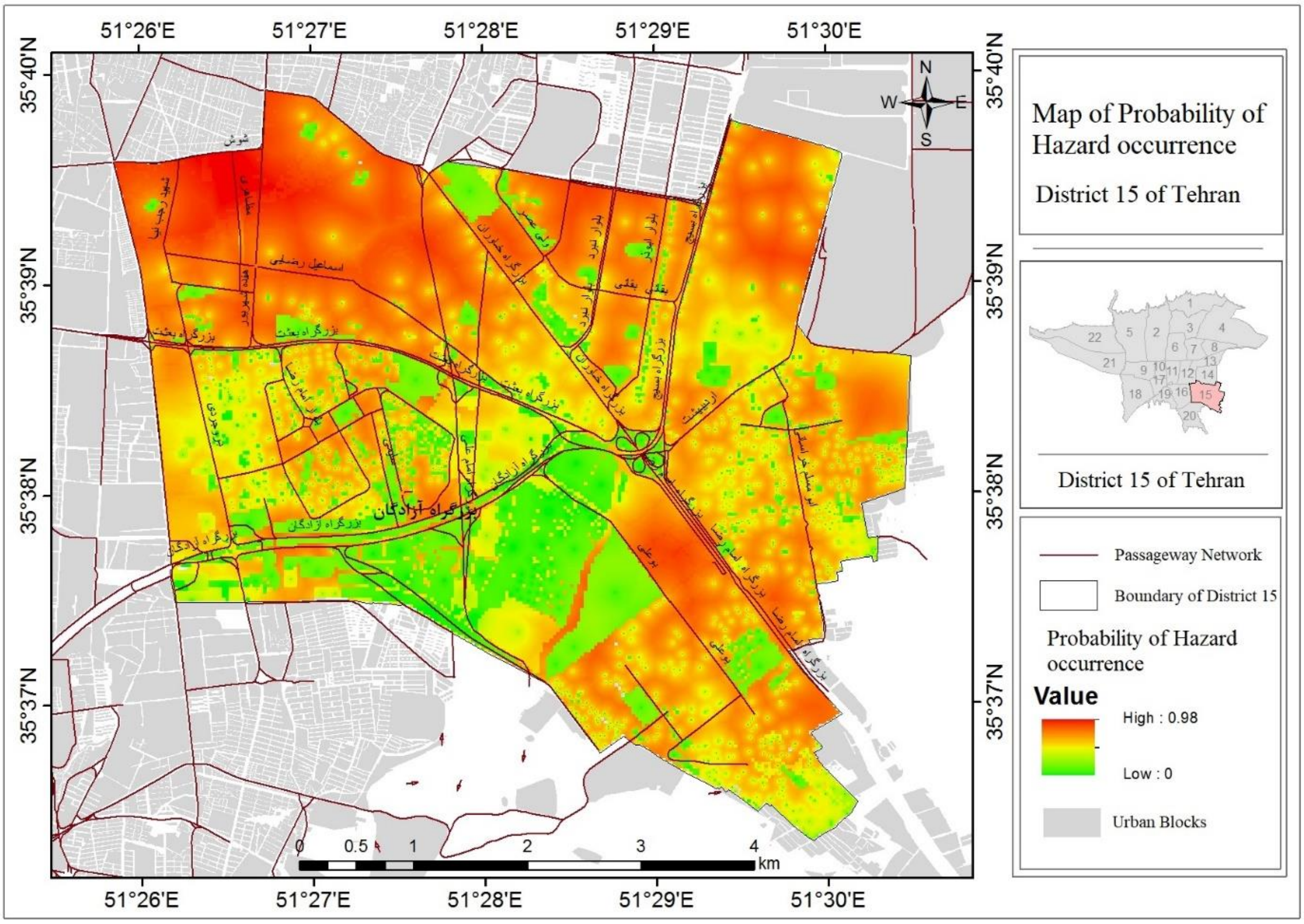

Fig. 10. The final map by combining fuzzified criteria of geomorphological hazards

The outcome of this combination indicates the ranges of regional geomorphological hazards. Therefore, as illustrated above, which is the final map of the probability of the geomorphological hazards, red-colored ranges with higher fuzzy membership degrees suggest a greater probability of geomorphological hazard occurrence.

6. Conclusions

Geomorphological hazards can be considered factors that damage human-made infrastructure; this phenomenon is caused by unstable ground properties, which expedite the effects of form changes and predominant ground processes relative to natural conditions. For this, it is essential to investigate the situation and values of damaged human environments against geomorphological hazards. Natural hazards, especially geomorphological hazards, could cause many financial and life losses.

According to the results, types of hazards, including excavation, floods, waterway network changes, foot slope changes, etc., can threaten society and human activities in regions under study. Excavation and embankment caused by construction and road construction activities changed the elevation of district 15 of Tehran, consequently causing changes to the region's local slope and natural morphology. Foot slope and elevation changes can disrupt the compatibility of the regional morphology with the natural topographic state to cause floods in this region. The most notorious hazards in this region can be urban floods, which may affect various areas.

To answer the first question, types of geomorphological hazards, including excavation, flood, waterway network changes, and slope changes, can affect the region. According to analyses done in this region, the effects of three types of hazards of excavation, floods, waterway network changes, and foot slope changes are confirmed.

To answer the second question about the priority of the hazards, the analysis of the maps found that since the effects of the hazards of excavation, elevation changes, and foot slope changes are confirmed in the region, each of which can cause flooding or aggravate this phenomenon in the region, with each of the hazards may affect the other. Thus, the hazard of flood assumes higher importance.

To answer the third question on optimal methods to deter, control, and reduce hazards, managing floods in District 15 and controlling changes caused by the embankment and slope changes can be a good way to reduce regional hazards. Since it was determined that the main factor of the three hazards of excavation, flood and waterway network changes, and foot slope changes is the excavation activities caused by constructing highways and construction sites, controlling the activities or implementing them by observing regional geomorphological considerations could better control the hazards. In sum, it is suggested to provide hazard-reduction plans and urban planning policies, create flood warning systems, organize regional water canals by protecting river paths and controlling deposit and erosion, use slope sustainability studies when constructing structures, avoid urban development plans in areas of high risks, train people, and provide appropriate facilities for optimal construction and renovation projects.

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