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Deep Excavation Hazard Assessment Zoning in District 1 in Shiraz Municipality Using Geographic Information System (GIS)

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Abstract

This research presents a geotechnical zoning map of district 1 in Shiraz municipality with a focus on municipal deep excavation hazard assessment on data from 160 boreholes. For this purpose, the mechanical properties are determined according to the results of direct shear, uniaxial, and SPT tests and then excavation hazard assessment with depths of 3, 6 and 9 m, in situations where the excavation depth of the neighbor foundation is below 0 and 0 to 20 meters have been calculated. Finally, using ArcGIS software, the assessment hazard excavation for 6 different modes was zoned and the zoning map of the assessment hazard excavation with the normal, high and very high hazard index is provided. The zoning maps show that with increasing depth of excavation, the danger is increased so that in maps whit depth of excavation of 9 meters, more than 90 percent of points havea high hazard index.

Keywords: *Geotechnical zoning, Excavation hazard assessment, Geographic information system, districts1 in Shiraz municipality*

1. Introduction

With the growth of population and the development of societies, the need for construction is increasing, which is not possible except with the development of civil infrastructure. On the other, lack of land with suitable mechanical properties for construction in populous cities as well as expensive land in some areas has caused the buildings to expand in depths below the ground level.

Obviously, in order to prevent accidents leading to life-threatening hazards, damage to adjacent buildings and urban spaces, and determining the strategy for choosing a possible sustainability method, awareness of the danger of excavation is necessary. Therefore, Arc GIS software is used to determine the high hazard areas in order to plan and provide effective solutions for the employers or the owners in reducing the hazards of excavation on the one hand, and on the other hand, designing an appropriate urban development plan for planners and urban developers in organizations in charge. The design and implementation of proper excavations require accurate and comprehensive information about the land under study, which is only possible by obtaining geotechnical information from drilled boreholes and site investigation. Nowadays, considering the software developed based on the Geographic Information System (GIS) and using the data from drilled boreholes, geotechnical parameters of the borehole data can be zoned in the urban areas, and thus for each area, according to the zoning, the excavation hazards assessment can be provided as a preliminary warning to the design engineers of the retaining walls. The hazards of excavation are, in fact, an appropriate criterion for identifying the stability of excavation before the construction of a retaining wall which can be determined based on rock or earth parameters, the depth of excavation, the depth from the level of the neighboring foundation and a load of structures or adjacent passages. Geotechnical zoning maps are a type of geological engineering map with specific objectives such as determining the foundations bearing capacity, land settlement, liquefaction hazards, excavation hazards and so on. The earth parameters are determined by field and laboratory tests such as plate loading, standard penetration,

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cone penetration, direct shear, uniaxial and triaxial shear. Geotechnical zoning enables engineers, designers and operators of urban development and construction projects to obtain a general picture of surface and sub-surface geological and geotechnical features of the project area, identify the location of hazardous phenomena and make appropriate decisions about their plans based on this information [1], [2] and [3].

Nadi et al. studied different methods for interpolating the monthly and annual precipitation data of Khuzestan province in which seven different methods of interpolation including general Kriging, co- Kriging, Kriging with the external trend, Kriging regression, distance map weight, spline, and three-dimensional linear gradients are compared. By comparing the interpolation methods, the Kriging regression method has been identified as the most appropriate interpolation method [4].

So far, numerous studies have been done on the zoning of geotechnical issues. Andrus et al. (1999), Sharma & Chetia (2016), Sana and Nath (2016), Rao and Satyam (2014), Lodi et al. (2015), Singh and Jawaid (2016) Rakesh et al. (2016) and Zarei and Boushehrian (2017) zoned the hazards of liquefaction for different cities in the world [5-13].

El May et al. (2010) studied the geological zoning of Tunis city using ArcGis software. El may et al. have divided the region of Tunis into four different areas for seismic zonation by ArcGis software. These areas were: (1) a high region with the potential risk of superficial perturbation; (2) a low and flat zone with flooding risk; (3) a low zone with flooding and probability of sliding risk; (4) a region with mud levels and settlement risk. [14].

Wan- Mohamad and Abdul- Ghani studied the application of GIS in the processing and provision of geotechnical data which was a case study conducted in Malaysia. Geotechnical data were processed in GIS and the output soil description and resistance maps are provided in different depths based on SPT results [15].

Labib and Nashed (2012) zoned the geotechnical features of the expansive soil in the Tashaki region in Egypt using the Geographic Information System. This map is based on information from 53 soil samples of the region. Considering the problem of expansive soils and increasing their volume by increasing moisture content, the GIS can be used in visualization and analysis of the results of empirical studies, to prevent potential problems before any new project [16].

Considering the increasing expansion of commercial and official buildings in the city of Shiraz as the economic and medical center of the south of Iran, in one side and the lack of urban space, the high value of land especially in the district 1 of municipality of Shiraz, 160 sample data have been selected from executive governmental organizations and private consultation companies for zoning the excavation hazards assessment in district 1 of Shiraz Municipality.

2. Geographical Location

Shiraz is the capital of Fars province. The city is located at 30 degrees and 25 minutes' latitude and 37 degrees and 29 minutes' longitude. Its height from the sea level is 1590 meters.

The city area is 12,990 square kilometers, with a length of 90 and a width of 20-30 km. The district 1 in Shiraz Municipality has been established in 1980. The current area of the region is 4235 hectares, having 1869001 inhabitants. This area is adjacent to district 6 from the south, district 4 from the east and districts 8, 2 and 3 from the northwest. The boundary of the area is surrounded from the south to the streets of Hang and the Pasdaran Blvd., the Gas Junction and the southern Iman from the west to the border of Jebel Derak to the Ehsan square and Ma'ali Abad from the east to Hor Street, Saadi Street, part of the street of Zand and the Enghelab street to Baskol Nader and from North is limited to the service area of the 74 detailed plan. This district has the most valuable lands and buildings of Shiraz.

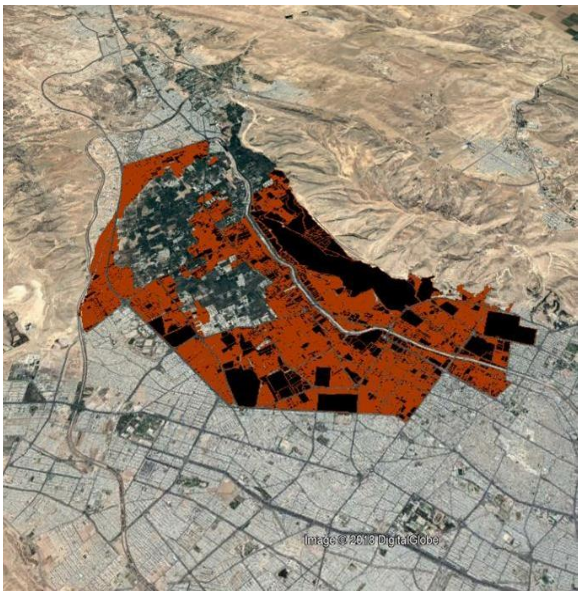


Figure1. Location of the study area on a satellite image (Google Earth)

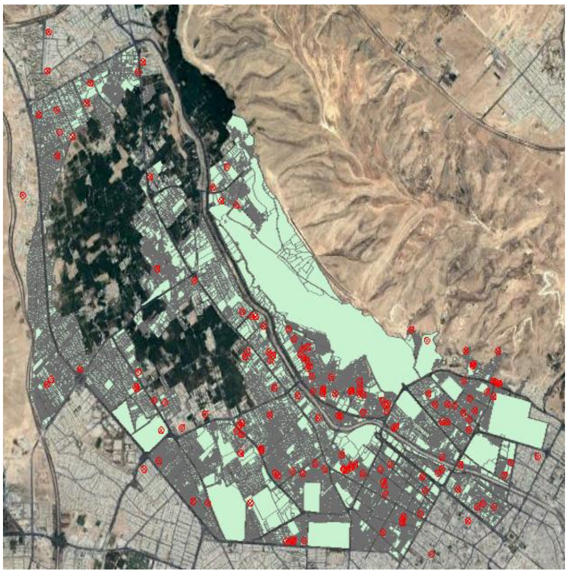


Figure2. Location of research data on the map of the area and satellite image (Google Earth)

3. Research Methodology

To be meaningful, data should be converted to information after being collected. Data and information are used in many cases instead of each other, while they are not synonymous. Data includes facts and forms that are meaningless to the user, but the information is processed data or data with meaning. Data are raw facts that turn into information when they are processed efficiently [17].

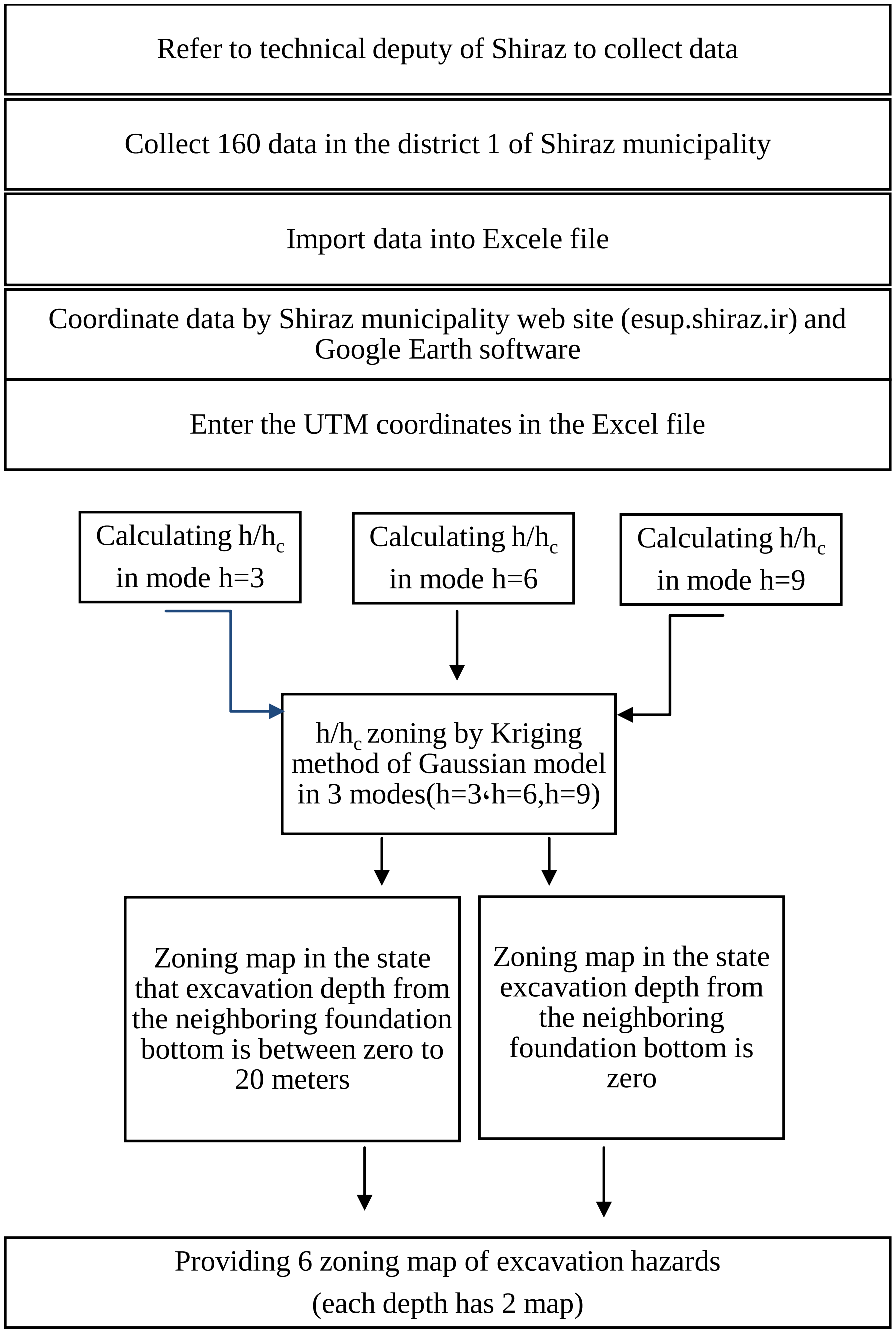
The raw data of this research include soil cohesion, soil friction angle, soil specific gravity, elastic modulus, location of properties, registration number and in some cases, renovation code. These raw data are derived from geotechnical investigation reports, which should be converted into information to be used.

The first step in this research is to enter data into the Excel environment and coordinate this data to export to the ArcGis software in the next steps. The number of data is 160.

Coordinate the points with the renovation code are obtained by entering this code into the Shiraz municipality website (esup.shiraz.ir). Firstly, the renovation code is entered and then the location of the site and the coordinates are shown. In cases where the data do not have a renovation code, the property location is found in Google Earth using the address, and the coordinate process is carried out.

After obtaining the coordinates of the points and entering the coordinates in Excel, the excavation hazards assessment calculations are done using the formulas in the geotechnical references. Table 1 shows the sequence steps of this research.

Table1. Sequence steps of the research program



4. Excavation Hazards Assessment Calculations

Due to the fact that urban excavation is usually done vertically because of space and ground constraints, in this research, the excavation hazards assessment is done based on the vertical retaining wall. The excavation hazards assessment is calculated for depths of 3, 6 and 9 meters. In each of these states, it is assumed that the depth of excavation from the bottom level of the neighboring foundation is zero and 6.

The relationship used for assessing the hazards of excavation has been extracted from the seventh chapter of the National Building Regulations (foundationand foundation construction) [18]. In order to assess the vertical excavation hazards, all three conditions set out in Table 3 must be met.

Table2. Excavation hazards assessment based on the vertical wall [18]

Amount of h/h_c	**Excavation depth from Zero level**	**Excavation depth from the bottom of the neighboring foundation**	**Excavation hazards**
Less than 0.5	Less than 6 meters	Zero	Normal
Between 0.5 to 2	Between 6 to 20 meters	Between 6 to 20 meters	High
More than 2	More than 20 meters	More than 20 meters	Very High

Where h is the depth of excavation and hc is the critical depth which is calculated by preliminary estimation of c and Φ from Eq. 1 as shown below.

$$h_c = \frac{2c}{\gamma\sqrt{k_a}} - \frac{q}{\gamma} \quad (1)$$

Wherehe is the critical depth of excavation in meters, c soil cohesion in kPa, γ is the soil unit weight in kN/m3 ka the coefficient of active lateral earth pressure and q is the overburden pressure of surrounded building and passes in kPa.

Due to the fact that the depth of excavation from zero level and also from the bottom of the neighboring foundation is different for each project and depends on the criteria of the municipality and the owner's request, in different situations, the hazards of excavation has been examined and for each depth, several zonings of excavation hazards was developed. Only by identifying the excavation depth from zero levels and also from the bottom of the neighboring foundation, the owner is able to figure out the excavation hazards in his/her project.

5. Excavation Hazard Assessment Using of GIS

Arc GIS software is a geographic information system that is used for the preparation, analysis and general management of geospatial maps and data in the form of the databases. This software is used in various sciences, including soil mechanics.

Spatial analysis is in the form of definitive methods and statistical methods. In definitive methods, interpolation only uses mathematical functions [19].

Land-based interpolation is based on the theory of regional variables and relies on math and statistics functions. It uses the variogram model to describe the spatial continuity of input data and estimate the number of unobserved locations [20].

The issues which can affect the results of interpolation are the sequence and order of interpolation processes [21].

Two interpolation methods were mostly studied by many scientists. Interpolate- then- calculate(IC) and the Calculate- Then- Interpolate (CI) methodology. Zhao et al., in 2005 used the IC method for mapping the spatial distribution of reference crop evapotranspiration (ET0)[22]. Zhang et al. concluded that the IC method is appropriate for areas with separate meteorological stations [23]. On the other hand, Mardikis et al. (2005) and Ashraf et al., reported little difference between the two methods. [21, 24]. Also, Phillips and Marks (1996) and Bechini et al. mentioned that for IC method error is more likely expected to be higher because in this method the interpolation error of all input data affects interpolation [25, 26].

Accordingly, in this research, the CI method has been used for zoning the excavation hazard assessment, in such a way that firstly the calculations and then interpolation operations are performed.

In this research, ArcGis software version 10.3.1 was used. First, an Excel file containing 160 coordinate points with specific excavation hazard assessment was imported into the ArcGis software, and then, after comparing different methods, the Kriging method which has the least error is used for the zoning of excavation hazard assessment in

3 different depths and 2 different levels from the neighboring foundation bottom.Finally, 6 zoning maps have been prepared. After zoning, the classification of the maps has been done which reduced the number of classes up to 3. The Natural Breaks method is used to classify the results. The owner, depending on the excavation depth from zero levels and also from the bottom of the neighboring foundation, will look at the zoning maps and take his/her project excavation hazard assessment.

5.1. Kriging method

The Kriging method is the best unbiased linear estimator with the least variance. It is necessary to explain that for the normal Kriging method, the data must have a normal distribution. Otherwise, nonlinear Kriging should be used, or, first, by converting the distribution of the variable into a normal distribution and then using linear Kriging [27]. Kriging is an estimation method based on the weighted moving average logic.

In this study, due to the non-normalization of the data, the Gaussian non-linear kriging method is used which has the least error.

The efficiency level of each interpolation method, or in other words, the accuracy of estimates, is evaluated by comparing the deviation of estimates from the measured data by cross-validation [28].

In this method, a comparison is made between the measured points and the estimated values by the methods used. So that a point is deleted and using other points and the interpolation method estimation is done for this point. Then this point is returned to its location, and the next point is deleted and similarly, for all points, the estimation is done, so that at the end of the two columns there are observable values and estimated values that can evaluate error and deviation of the method. In Table3 and 4, the comparison between the different methods of interpolation and the statistical ground is presented.

Mean is the error mean, Root-Mean-Square (root mean square of error), Mean standardized (standardized mean of error) and Root-Mean-Square standardized (the second root of standardized error mean). By comparing different methods of interpolation, the normal Kriging method with the Gaussian model has been considered as the most accurate method in this zoning and has been used in this research.
According to (Creutin and Obled, 1982, Isaaks and Srivastava 1989, Weber and England, 1994, Martinez-Cob, 1996, Caruso and Quarta 1998, Nalder and Wein, 1998), the difference among interpolation methods mostly depends on the variable nature under study, variable values and selected criteria for data interpolation than the method used for interpolation [29- 34].

Table 3. The comparison of error rate in Kriging models

Error / Model	**Mean**	**Root-Mean Square**	**Average Standard Error**	**Mean standardized**	**Root-Mean-Square standardized**
Gaussian	0.03652518	2.978508	3.030446	0.002041315	0.9322142
Spherical	0.05682064	2.994799	3.057392	0.01255532	0.9561587
Circular	0.06318994	2.995206	3.049382	0.01381335	0.9652013
Exponential	0.03997302	3.029529	3.125081	0.008996881	0.9834832

Table 4. The comparison of error rate in different models

Error / Method	**Mean**	**Root-Mean-Square**
Kriging Gaussian	0.03652518	2.978508
Idw	0.04452969	3.196107
RBF	0.0547957	3.083547

6. Results

The results of the presented research are as follows:

Figures 2 to 7 show the zoning of excavation hazards at depths of 3, 6 and 9 meters in different situations, which are classified according to Table 1 to three hazard levels of normal, high and very high. It should be noted that due to the diversity and plurality of neighboring structures and adjacent passages, the corresponding overheads in all situations are considered to be equivalent to a single story old building in order to synchronize the results. According to the maps below, the excavation hazards is increased by increasing the depth, and in general, the excavation hazards is at its lowest in eastern areas.

Zoning maps 2 and 3 show the excavation hazards with a depth of 3 meters for two different levels of excavation depth relative to the foundation bottom of the adjacent building.

In the case that excavation depth is at the level of neighboring foundation bottom, the excavation hazard in the eastern areas including Chugia and part of Chamran Boulevard is normal and high. The reason for the normal excavation hazard in parts of these areas is the presence of limestone with relatively high sear strength parameters (Fig. 2). In the northern areas, including Ma'ali Abad Street, due to the presence of coarse-grained soil at low depths, excavation hazard is high, and in the south and west, it is very high.

Zoning maps 3 and 4 show the excavation hazards assessment with a depth of 6 meters for two different levels of excavation depth relative to the foundation bottom of the adjacent building.

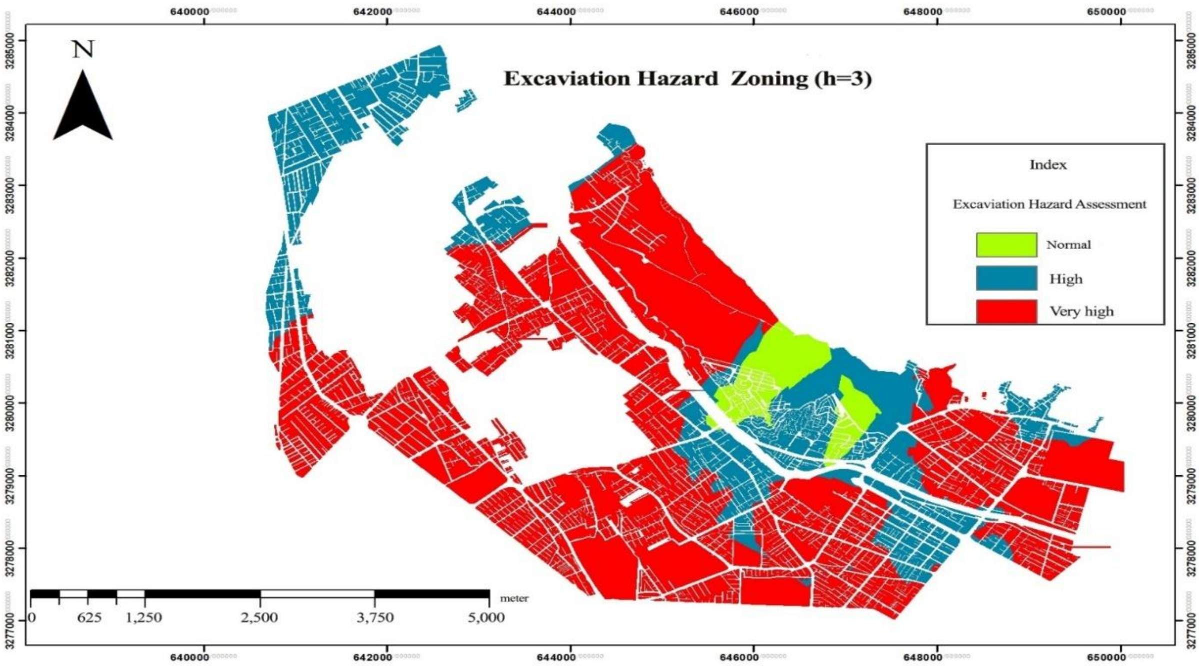


Figure 3. Zoning of excavation hazards (the depth of excavation from the neighboring foundation bottom is zero)

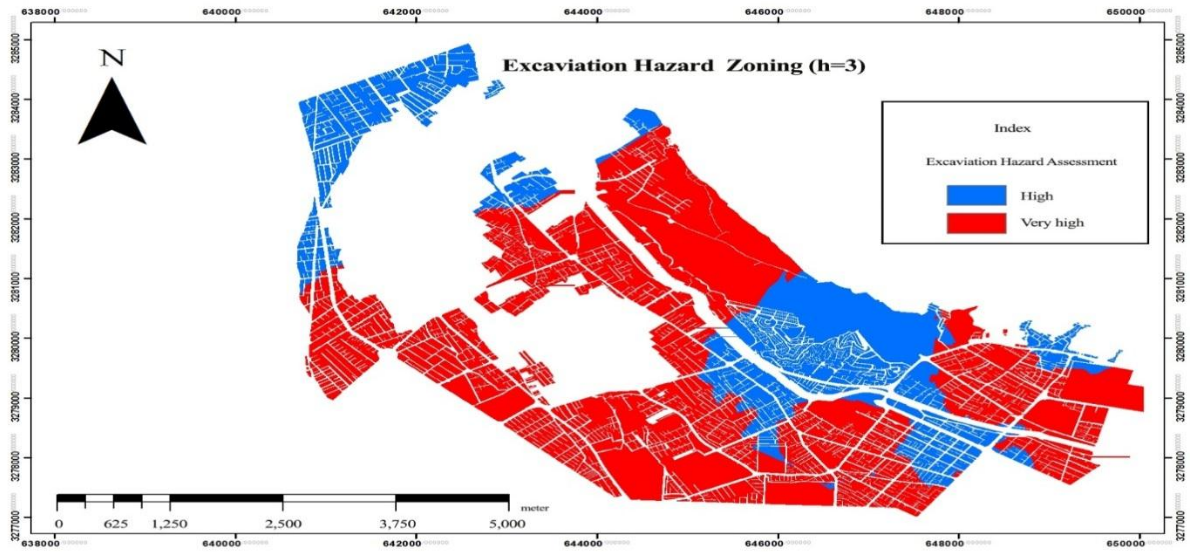


Figure 4. Zoning of excavation hazards (the depth of excavation from the neighboring foundation bottom is between zero to 20 meters)

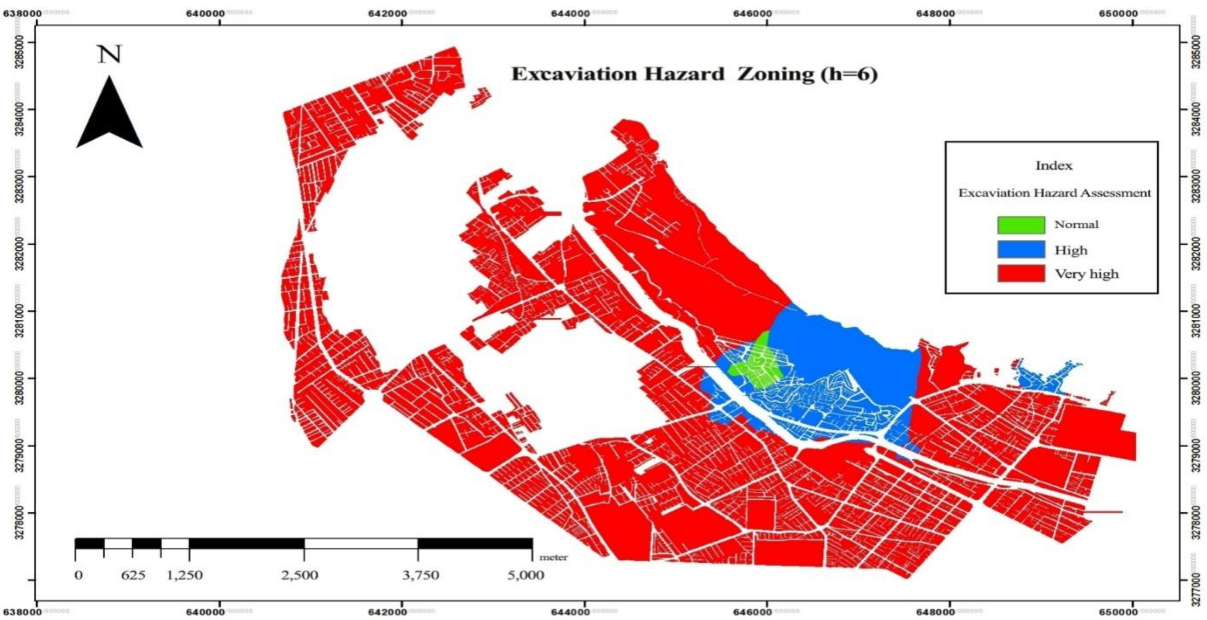


Figure 5. Zoning of excavation hazards (the depth of excavation from the neighboring foundation bottom is zero)

According to Figure 4, in the case that excavation depth is below the neighboring foundation level, the excavation hazard in the eastern areas including Chugia and part of Chamran Boulevard is normal and high and in the north, south and western areas excavation hazard is very high. According to Figure 5, in the case that excavation depth from the base of the neighboring foundation is between zero and 20 meters, the excavation hazard in the eastern areas including Chugia and part of Chamran Boulevard is high and in the northern, southern and western areas excavation hazard is very high.

Zoning maps 6 and 7 show the excavation hazards assessment with a depth of 9 meters for two different levels of excavation depth relative to the foundation bottom of the adjacent building.

In the case that excavation bottom level is the same as the neighboring foundation level, the excavation hazard in the eastern areas including Chugia and part of Chamran Boulevard is high and in north, south, and west excavation hazard is very high.

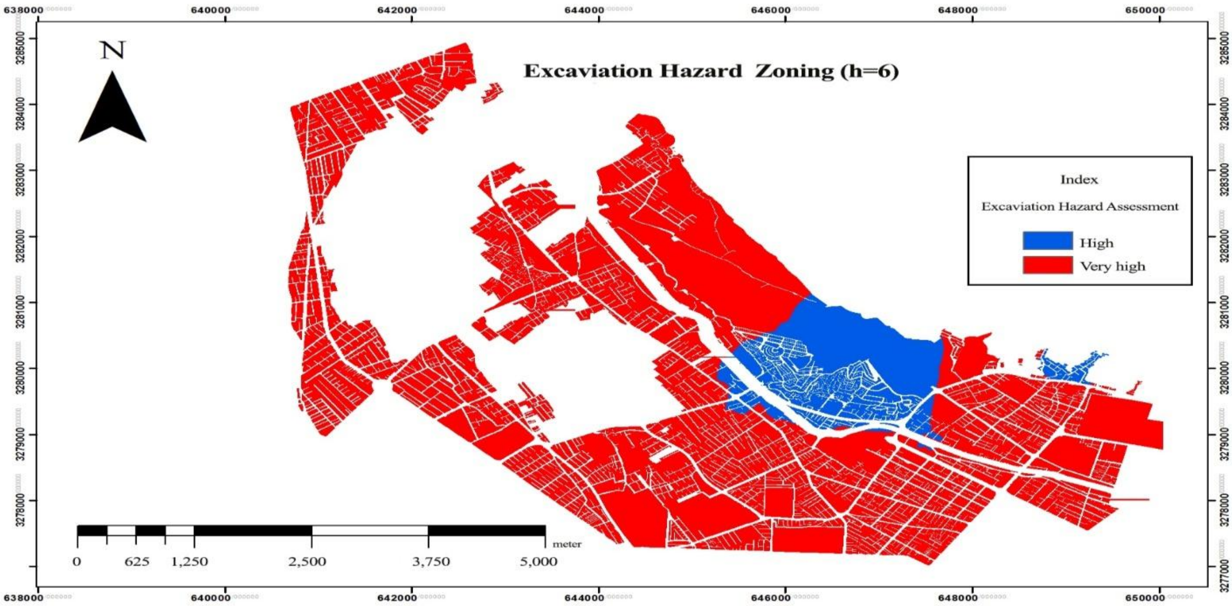


Figure 6. Zoning of excavation hazards (the depth of excavation from the neighboring foundation bottom is between zero to 20 meters)

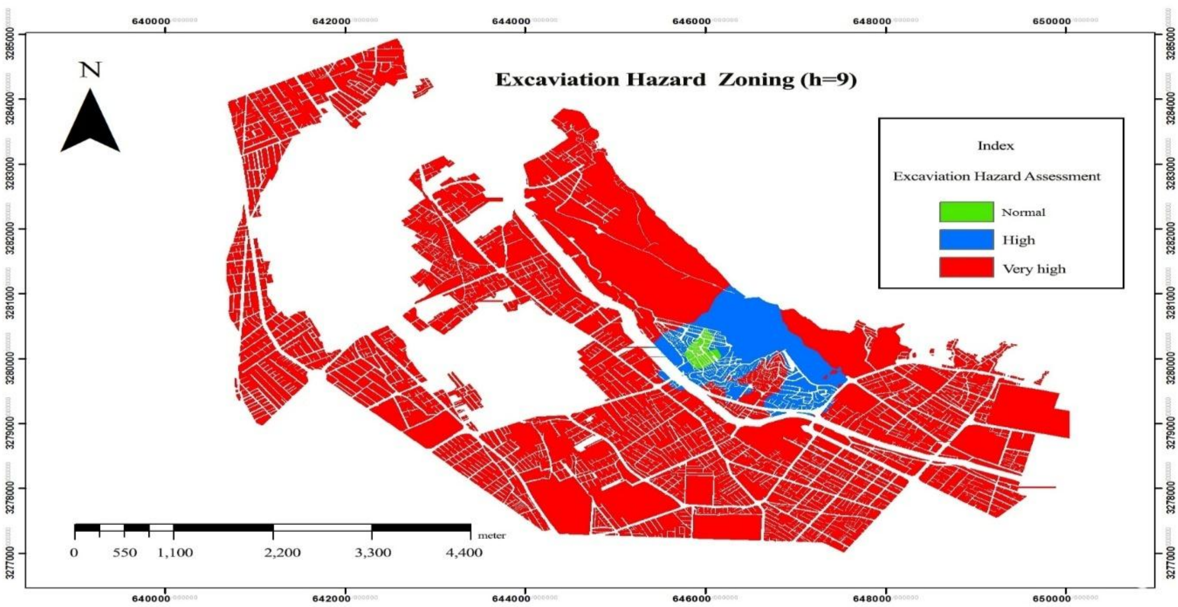


Figure 7. Zoning of excavation hazards
(the depth of excavation from the neighboring foundation bottom is zero)

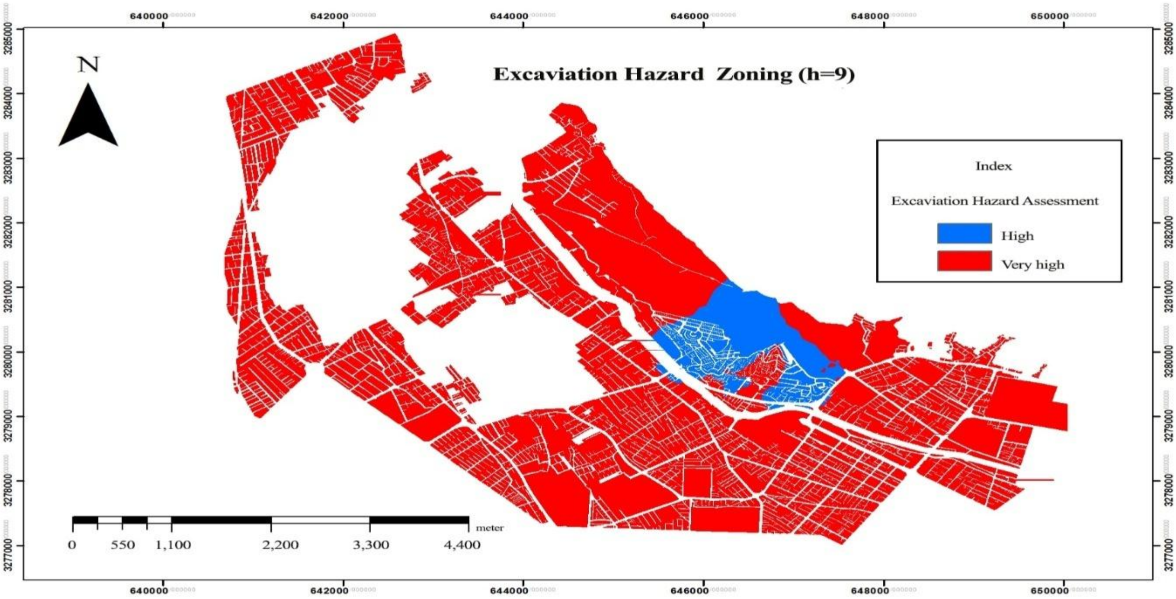


Figure 8. Zoning of excavation hazards (the depth of excavation from the neighboring foundation bottom is between zero to 20 meters)

According to Figure 7 and considering that the depth of excavation from the base of the neighboring foundation is between zero to 20 meters, the excavation hazard in eastern areas including Chugia and part of Chamran Boulevard is high and in north, south and west excavation hazard is very high.

7. Discussion and Conclusion

After comparing different interpolation methods, it was found that the Kriging method with the Gaussian model is the most appropriate method in terms of precision for excavation hazard zoning. A GIS helps tremendously in organizing data. In addition, GIS can provide accurate and fast access to data in a large volume and makes it possible to conduct analysis, processing, queries and spatial requirements needed. On the other hand, GIS prepares the ability to deliver results in the form of a map, report, chart and Table. It also paves the way for the identification and introduction of multiple capabilities and potentials of different geographic regions. While GIS can at the same time identifying the study gaps of these areas.

The excavation is one of the most dangerous construction operations; therefore the soil properties and the excavation hazard must be examined before its design and feasibility assessments.

The Excavation hazard zoning map is developed for 3 different depths of 3, 6 and 9 meters in different situations. In cases where the depth of excavation was 3 meters and also the cases where the depth of excavation from the bottom of the neighboring foundation was zero, then the zoning map had the lowest hazard.

In the excavation hazard maps, as the depth of excavation increases, the excavation hazard is increased so that in maps with a depth of 9 meters, more than 90 percent of the points are at a very high hazard.

Given the fact that the depth of excavation from the zero level and the depth from the bottom of neighboring foundation for each project is different and depends on the criteria of the municipality and the choice of owners and investors, in different situations, the excavation hazard has been examined and several zonings for excavation hazard was developed for each depth. Only by identifying the excavation depth from zero levels and also the depth from the bottom of the neighboring foundation, the investor is able to figure out the excavation hazards in his project.

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