Geotechnical Zoning of Municipal Districts 4 and 22 of Great Tehran

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Abstract
With increasing the growth of population and urbanization the importance of developing zoning maps and geological engineering maps becomes further clear. Due to the development of construction in cities and inadequate attention to geological and geotechnical issues, many technical and engineering problems were occurred in events such as earthquakes. The first step to understanding the environmental phenomena is collecting data about them and on next steps it is possible to expand knowledge about that phenomenon by data processing. In this paper an attempt is made to achieve a clear vision and comprehensive understanding of underground condition of municipal districts 4 and 22 of Great Tehran and an effort was made to draw practical geotechnical geological maps of these districts. Results indicate that subsurface soils of districts 4 and 22 have low Liquid Limit (LL) and Plastic Limit (PL) and they are non-swelling materials. With regards to the coarse-grained soil of these districts there is no possibility of liquefaction in the earthquake.

Keywords: Geotechnical zoning, Geotechnical parameters, Geophysics, GIS

1. Introduction

With increasing the growth of population and urbanization the importance of developing zoning maps and geological engineering maps becomes further clear. Due to the development of construction in cities and inadequate attention to geological and geotechnical issues, many technical and engineering problems were occurred in events such as earthquakes.

Geophysical methods are not able to provide comprehensive data from the site singly and have much turbulence in urban areas. As well as use of these methods in urban centers is practically impossible. Aerial photographs and satellite images can't supply detailed information of technical ground conditions, too. Hence, the best way to evaluate and interpret of geotechnical properties of a special place in urban areas is the usage of the geotechnical boreholes data. These boreholes usually are drilled for different purposes and various tests are performed on soils from different depths. Results of these tests can be provided usable data for geotechnical zoning maps.

Geotechnical zoning maps are a kind of geological engineering maps that are provided for special evaluations such as: geotechnical properties, bearing capacity, surface settlement, hazard of liquefaction and etc. In these maps physical and mechanical properties of soil in specified depth are shown. The most important uses of geotechnical zoning maps are the estimation of allowable bearing capacity and estimation of volume and type of earthworks.

Extensive geotechnical studies were done by many researchers around the world for geotechnical zoning of cities. Amini and Labib (2013) according to subsurface data and experimental results studied the properties of soils and rocks in Toshka area of Egypt to provide geotechnical maps in order to construction of structures and Sheikh-Zaied canal. In order to prepare geotechnical zoning maps of Guwahati, the major city in the north eastern region of India, Sharma and Rahman (2013) used information obtained from boreholes. Moises et al. (2011) used GIS and data obtained from boreholes to geotechnical mapping of Mexico City. In a similar study Al-Saoudi and Kadhim (2013) provided geotechnical maps of Basra in Iraq.

In Iran, a lot of studies were done to geotechnical mapping of cities, too. Hasanzadeh et al. (2006) investigated geotechnical and geological properties of Kerman. Parizadeh (2003) studied small-scale geotechnical exploration and provided hazard maps of west province of Iran by satellite images. Pourazin (1997), Farajpour (2002), Shirodi (2002), Maleki (2002) Khamechian et al. (2003) and Behro (2008) studied geomorphogical, geological and geotechnical properties of Tehran using GIS and geotechnical and geophysical data.

Due to the high seismic risk of Tehran and the constraints of resource and facilities in face of crisis, it is necessary to apply measures to reduce risks. Because of the increase in population in the eastern and western regions of Tehran in recent decades (municipal districts 4 and 22), and the need to better understanding of technical properties of the earth in these areas for safe constructions, geotechnical zoning of mentioned areas is done in this paper.

2. Study area

Tehran is the capital of Iran and it is in the southern part of Alborz Mountains. Its latitude is between 35˚ 35´ N to 35˚ 50´ and its longitude is between 51˚ 15´ E to 51˚ 35´ E. Tehran is formed 22 municipal districts as shown in Figure 1 that in this study the main focus is on the districts 4 and 22.

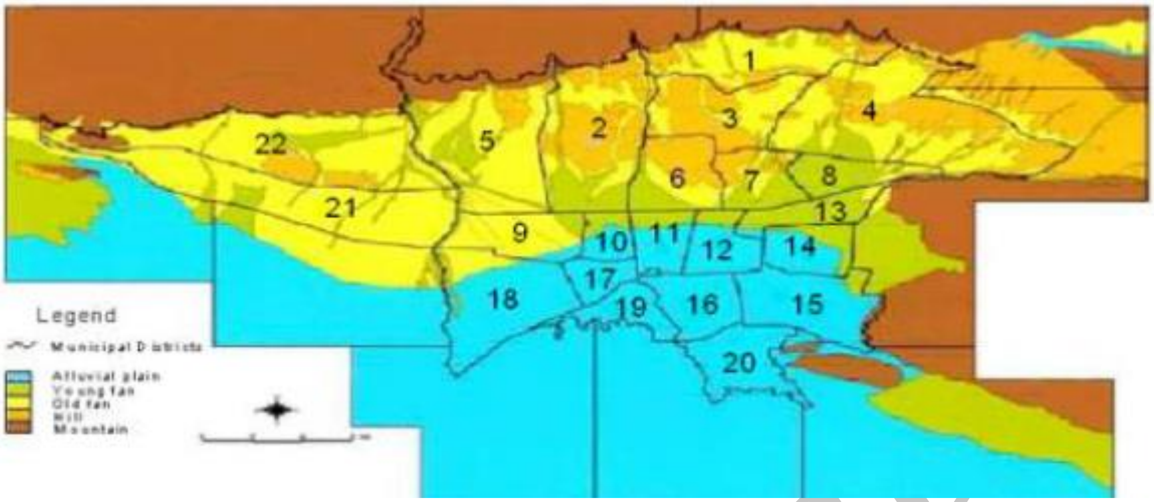

Figure 1. Geological map and municipal districts of Tehran (Behro, 2008)

3. Geology of the area

Tehran has developed on recent sediment and quaternary. Geological maps confirm that quaternary and Pliocene alluviums and moraine deposit have developed in Tehran desert.

Bed rock. The bed rock of Tehran is the Tertiary formations, mostly Eocene lava, showing in the mountainous areas in the north of the city. The younger sediment have formed on this bed rock. The bed rock of the eastern heights in Sehpayeh and Bibi Shahrbanoo mountains have been formed from the dolomite limestone from Triassic and Cretaceous ages.

Hezardarreh formation. The name of the formation, literally “Bad land morphology” has been inspired by the geomorphologic properties of its surface and the existence of the multitude of its erosional valleys of great density. This formation widens and rises and increases in bulk at Ghoochak defile in the northeast of the city. Its alluvial substances mainly consist of alluvial sediment and alluvial talus and volcanic rocks from Eocene age.

- Young alluvial fans. This formation includes deposits of conglomeratic young alluviums. The stones of this formation consist of homogenous conglomerates made of sand and Grave land pebble size class. The outcrop of the young Alluvial Fans of Tehran is expanded towards the southern half of the city. A great part of Tehran has been built on this formation. The maximum thickness of the alluvial Fans is estimated to be 60 meters. These alluvial Fans are highly penetrable; they form the greater part of the aquifers of the north of Tehran.

- Tehran’s river alluviums and alluvial plain. This formation is the youngest stratigraphical unit of Tehran formed as alluviums and river deposits. This formation is divided into two different stratigraphical alluvial plain units:

A) Khorramabad alluvial formation. This formation has covered the formation of the older alluvial fans in the south of Tehran, forming a fairly smooth plain. In the northern and eastern parts, the sand is richer. The southwest of the plain is dominated by fine grain material such as clay and silt.

B) River alluviums unit. The most recent alluviums of alluvial levels in Tehran are formed by the deposits of the flood plain of rivers consisting Grave land pebble size clasts. These materials have an alluvial origin and are not very hard. Many parts of municipal districts 4 and 22 consist of this type alluvial.

4. Geotechnical zoning of districts 4 and 22

The first step to understanding the environmental phenomena is collecting data about them. And on next steps it is possible to expand knowledge about that phenomenon by data processing. In this section an attempt is made to achieve a clear vision and comprehensive understanding of underground condition of municipal districts 4 and 22 of Great Tehran and it is tried to draw practical geotechnical geological maps of these districts.

According to geotechnical date of each district, percentage of earth materials is determined (cf. Figure2), required parameters to design are specified, and the geotechnical maps are provided by ArcGIS software. As well as, in order to do statistical calculations and to draw graphs, SPSS software was used.

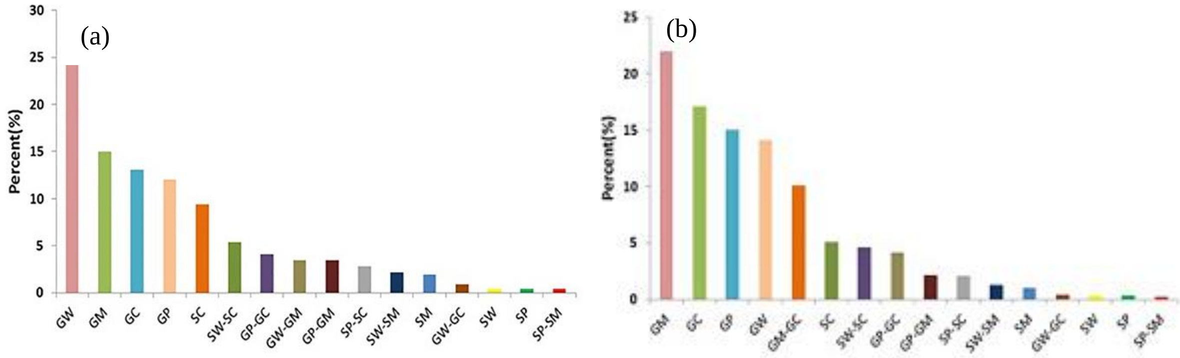

Figure 2. Histogram of percentage of earth materials in a) district 4 and b) district 22

4.1. Atterberg Limits

According to obtained data from boreholes in districts 4 and 22 the geotechnical zoning maps were provided. These maps show changing a geotechnical parameter with depth. As an example, zoning maps of Atterberg Limits at depth of 2 m are shown in Figure 3 to Figure 5. According to Table 1, in district 4, LL and PI ranges are 0-34% and 0-14 respectively. Dominant LL is 20-30 % and Dominant PI is 4-7%. In district 22, PI ranges are listed in Table 2 and Dominant LL and PI are 20-36% and 4-7%, respectively.

Table 1. LL and PI ranges in district 4

Depth (m)	2	4	10	16	26	32
LL (%)	0-34	0-36	0-34	0-32	0-34	0-34
PI (%)	0-14	0-13	0-13	0-11	0-11	0-11

Table 2. LL and PI ranges in district 22

Depth (m)	2	10	20	40	60	70
LL (%)	0-35	0-36	0-34	0-33	0-36	0-34
PI (%)	0-14	0-13	0-13	0-11	0-13	0-11

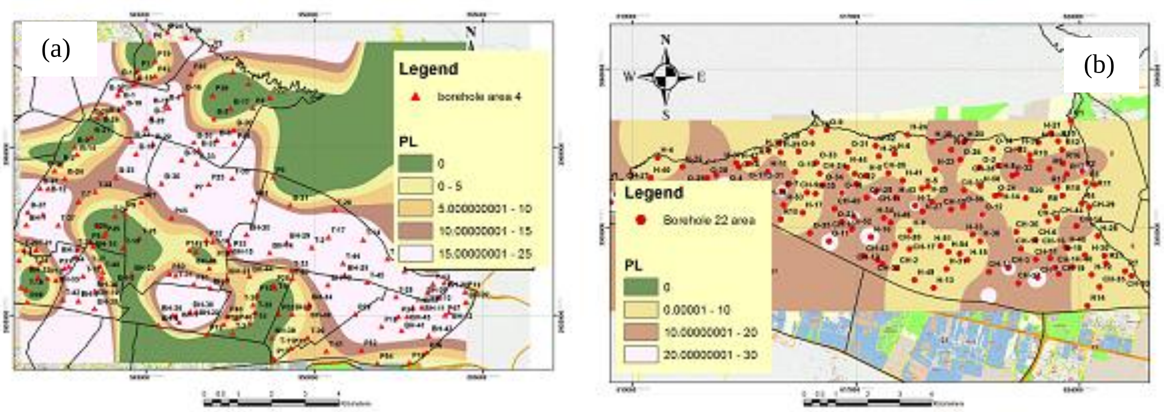

Figure 3. PL zoning map of a) district 4 and b) district 22 at depth 2m

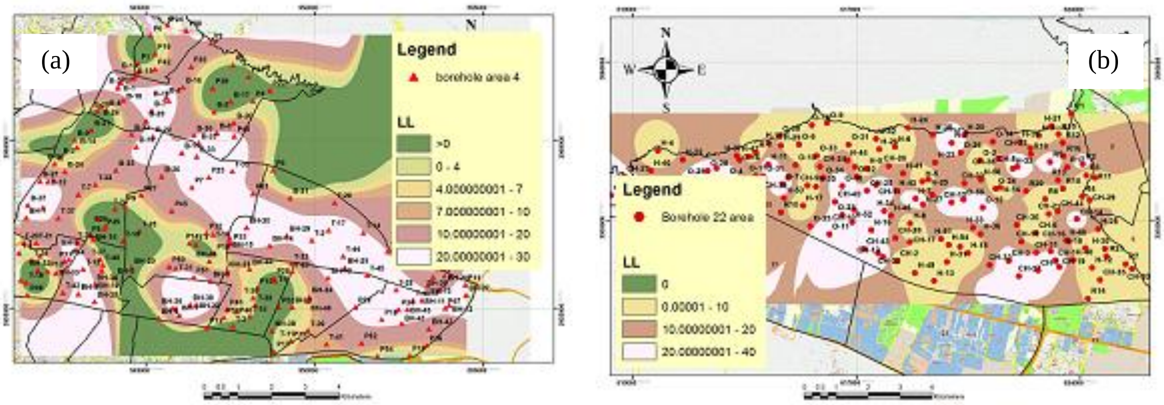

Figure 4. LL zoning map of a) district 4 and b) district 22 at depth 2m

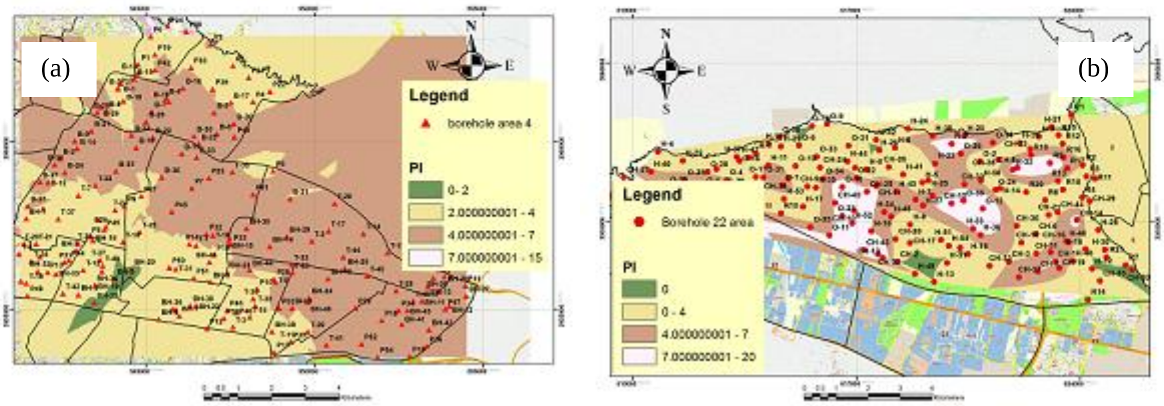

Figure 5. PI zoning map of a) district 4 and b) district 22 at depth 2m

4.2. Dry density (γ_d)

Figure 6 shows the change of dry density, γ_d, at depth 2 m in districts 4 and 22. Summary of γ_d at different depths are in Table 3 and Table 4. Dominant γ_d is greater than 2.00 g/cm^3 for district 4 and it is 1.90-2.05 g/cm^3 for district 22.

Table 3. Dry density ranges in district 4

Depth (m)	2	4	10	16	26	32
γ_d (g/cm^3)	1.86-2.03	1.86-2.03	1.87-2.02	1.91-2.02	1.93-2.04	1.91-2.04

Table 4. Dry density ranges in district 22

Depth (m)	2	10	20	40	60	70
γ_d **(g/cm^3)**	1.86-2.03	1.90-2.05	1.88-2.02	1.91-2.03	1.90-2.02	1.91-2.04

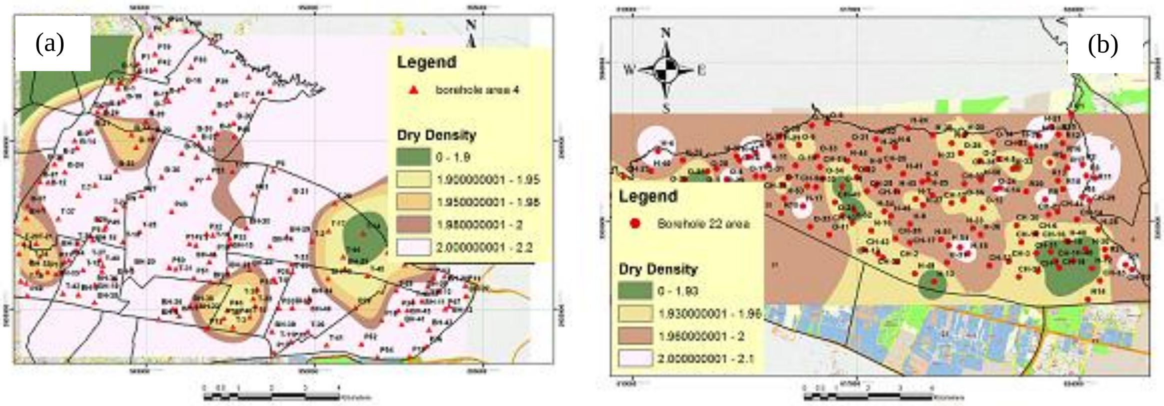

Figure 6. Dry density zoning map of a) district 4 and b) district 22 at depth 2m

4.3. Shear strength parameters (C, φ)

Shear strength parameters (C, φ) were obtained from in situ shear tests. In Figure 7 and Figure 8 changes of cohesion, C, and internal friction angle, φ at depth 2 m are shown. Dominant ranges of C In districts 4 and 22 are 10-30 kPa and 0-20 kPa, respectively. φ don't have great changes and dominant ranges of φ in both districts is 33-34˚.

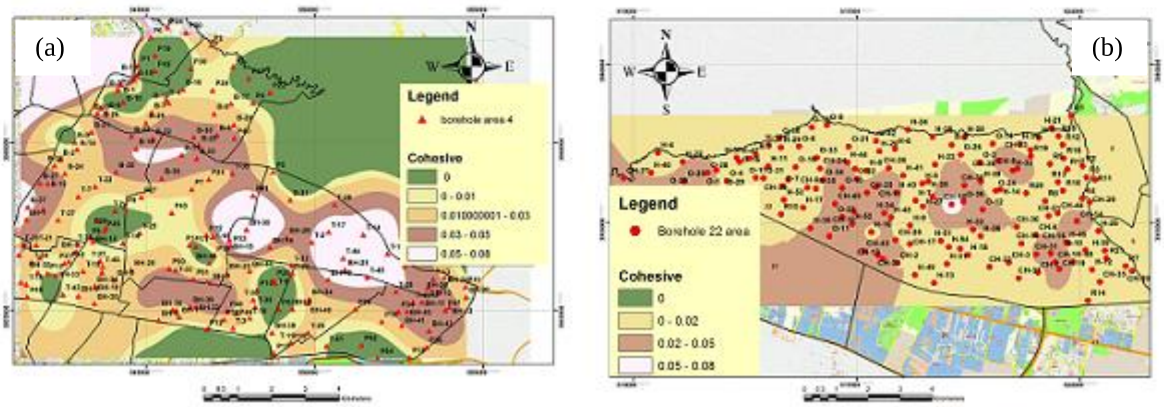

Figure 7. Cohesiveness zoning map of a) district 4 and b) district 22 at depth 2m

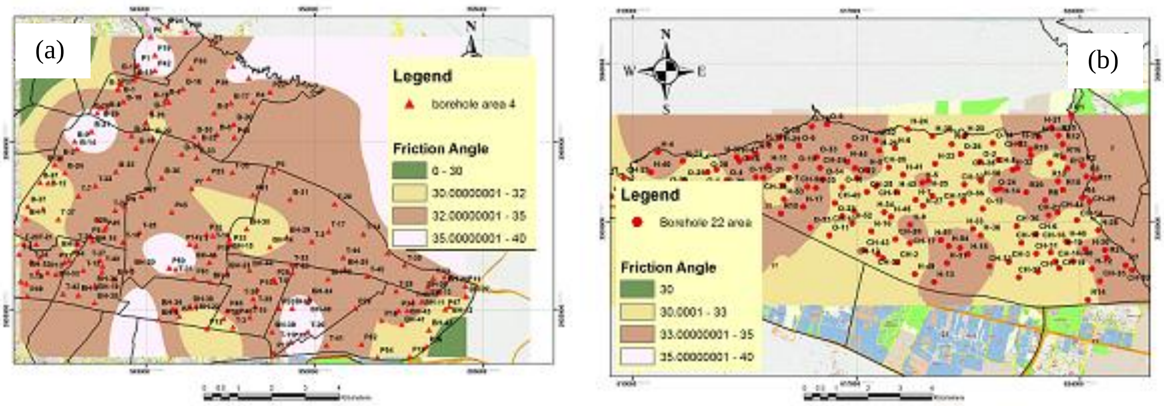

Figure 8. Internal friction angle zoning map of a) district 4 and b) district 22 at depth 2m

Table 5. Shear strength parameters in district 4

Depth (m)	2	4	10	16	26	32
***C* (kPa)**	0-70	0-70	0-60	0-70	0-60	0-60
φ (°)	30-35	31-35.5	30-35.8	30-36.7	30-36.3	30-35.5

Table 6. Shear strength parameters in district 22

Depth (m)	2	10	20	40	60	70
***C* (kPa)**	0-70	0-70	0-70	0-70	0-70	0-70
φ (°)	30-35	31-35.5	28.9-36	30.5-36.4	30-37.6	30-35.6

4.4. Elastic modulus, *E*

Results of elasticity modulus, E, were obtained from plate load tests. The zoning maps of E are shown in Figure 9 for districts 4 and 22 at depth 2 m. As well as, the ranges of E at different depths of discrete 4 and 22 are presented in Table 7 and Table 8. It is evident that *E* increases with depth because of overload pressure.

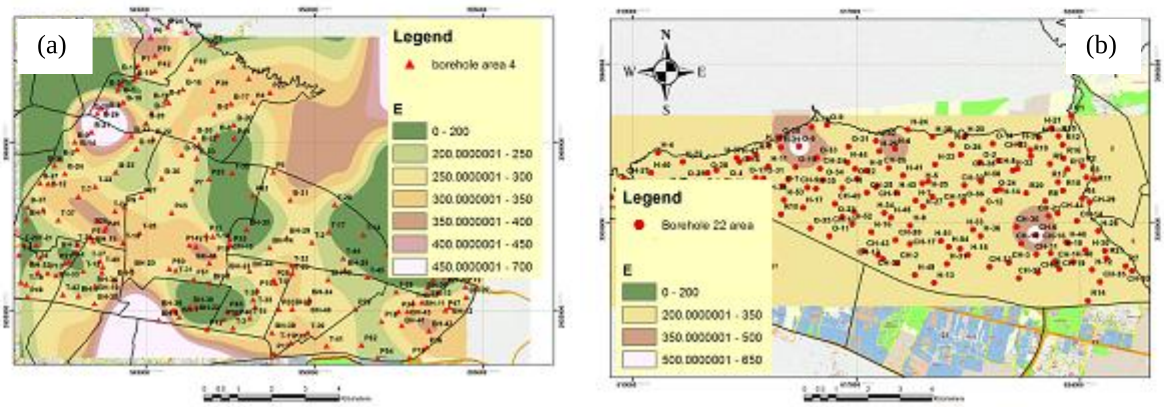

Figure 9. Elastic modulus zoning map of a) district 4 and b) district 22 at depth 2m

Table 7. Dry density ranges in district 4

Depth (m)	2	4	10	16	26	32
***E*(MPa)**	18-60	20-60	25-65	25-70	32-75	30-75

Table 8. Dry density ranges in district 22

Depth (m)	2	10	20	40	60	70
***E*(MPa)**	18-60	20-60	25-65	25-70	32-75	35-45

4.5. Poisson's ratio, υ

Poisson's ratio maps of districts 4 and 22 at depth 2 m are shown in Figure 10. υ don’t have great changes with depth and its range is 0.30-0.35 in both districts.

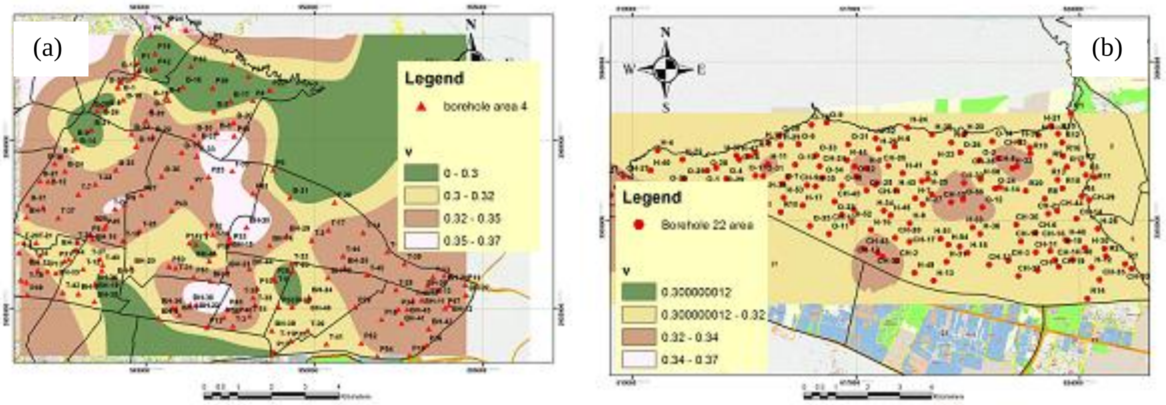

Figure 10. Poisson's ratio zoning map of a) district 4 and b) district 22 at depth 2m

4.6. Longitudinal and shear wave velocity

Longitudinal and shear wave velocity maps of districts 4 and 22 at depth 2 m are shown in Figure 11 and 12. The results of longitudinal and shear wave velocity in these districts at different depths are summarized in Table 9 and 10. Longitudinal and Shear wave velocity increase with depth because of increase in stiffness of ground with depth.

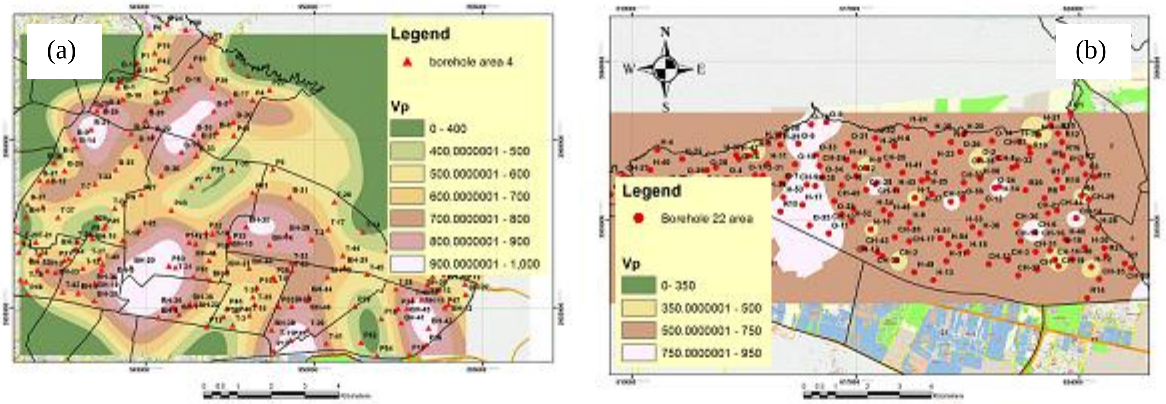

Figure 11. Longitudinal wave velocity zoning map of a) district 4 and b) district 22 at depth 2m

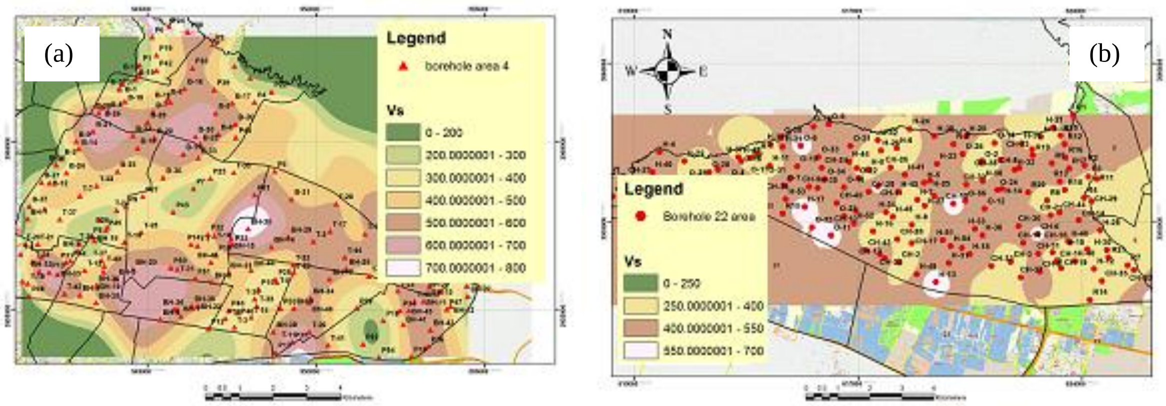

Figure 12. Shear wave velocity zoning map of a) district 4 and b) district 22 at depth 2m

Table 9. Dry density ranges in district 4

Depth (m)	2	4	10	16	26	32
Longitudinal wave velocity (m/s)	330-900	330-1130	700-1520	700-1730	950-1730	950-1730
Shear wave velocity (m/s)	220-655	230-750	300-990	300-990	600-990	600-990

Table 10. Dry density ranges in district 22

Depth (m)	2	10	20	40	60	70
Longitudinal wave velocity (m/s)	330-900	330-1300	630-1710	700-1710	900-1750	900-1750
Shear wave velocity (m/s)	220-655	230-800	300-990	300-990	600-990	600-990

4.7. Standard Penetration Test, SPT

One of the fastest and least expensive tests to determine the relative density of granular soils, especially sandy soils is Standard Penetration Test, SPT. According to the presence of coarse-grained soils in districts 4 and 22, standard penetration test blow counts N_{SPT} was top of 50 and in many cases it was top of 100. N_{SPT} maps of districts 4 and 22 at depth 2 m are shown in Figure 13 as an example.

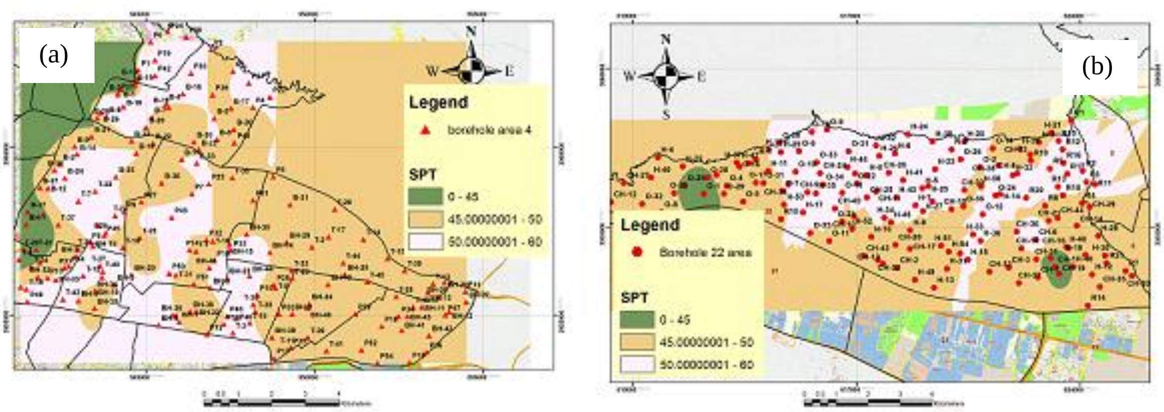

Figure 13. N_{SPT} zoning map of a) district 4 and b) district 22 at depth 2m

4.8. Permeability

Permeability maps of districts 4 and 22 at depth 2 m are shown in Figure 14. Based on existing maps permeability range of district 4 is 10^{-4}-10^{-2} cm/s and its range in district 22 is 10^{-5}-10^{-3} cm/s.

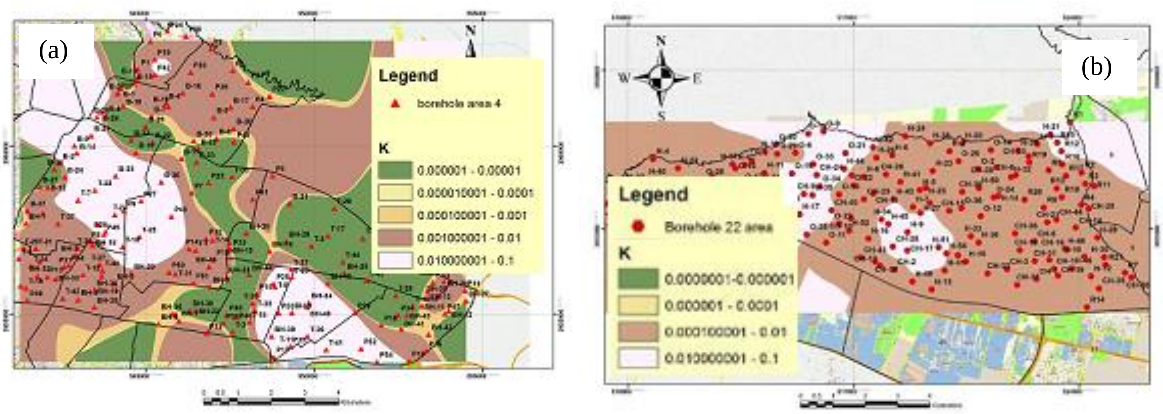

Figure 14. Permeability zoning map of a) district 4 and b) district 22 at depth 2m

Many studies about geotechnical zoning of great Tehran have been done so far. But, the scope of their study included the entire Tehran. Therefore, the number and the volume of their tests were limited, especially in districts 4 and 22 that were scope of this study.
Due to development of Tehran in district 4 and 22, especially in district 22 that high-rise buildings are constructed, the depths of boreholes were high. As well as, in this study, in addition to results of laboratory tests, the results of in situ tests were used.

5. Conclusion

Use of geotechnical data bank and geographic information system (GIS), analysis of geological engineering and geotechnical properties of deposits, statistical analysis on the data and fine-zoning maps of the major cities can provide a correct studding path to optimize cast and time of primary studies.
Due to the wide extent and the accidental nature of a site, acquisition of the perfect knowledge about subsurface condition is impossible and the data will be uncertainty. Hence, the most important method to data analysis in geotechnical engineering is statistical modeling and analysis. By using these methods it is possible to achieve an estimate of the unknown parameters of site with a certain confidence level. For more accurate assessment it is necessary to study the data of different depths of the site and analyze the changes of the geotechnical parameters. In this way geotechnical zoning maps can be used as useful tools.
Geotechnical maps of districts 4 and 22 of great Tehran in the Geographical Information System (GIS) make it possible to estimate the geotechnical parameters at different depths with UTM coordinates of any point.
Subsurface soils of districts 4 and 22 have low Liquid Limit (LL) and Plastic Limit (PL) and they are in non-plastic to low-plastic category and non-swelling materials. With regards to the coarse-grained soil of these districts there is no possibility of liquefaction in the earthquake.
Internal friction angle (φ) of soils in districts 4 and 22 are 30-37° that shows these material are coarse. As well as, the results of longitudinal and shear wave velocity indicate that soils of these districts have medium to high relative density.

Acknowledgment

In this way, the Authors express their gratitude to the companies that helped in the collection of geotechnical and geophysical data.

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