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The application of GIS in visualization of geotechnical data (SPT-Soil Properties): a case study in Eskisehir-Tepebaşı, Turkey

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ABSTRACT

Recently, three-dimensional visualization of soil characteristics has been widely used in geotechnical engineering applications. In this study, the 3-D visualization of Tepebaşı area soils, the province of Eskişehir, is prepared using SPT data, soil classes through Environmental Visualization System-Mining Visualization System (EVS-MVS) programs. Moreover, the local soil conditions were classified according to the Turkish Earthquake Code 2018 and digitized using Geographical Information Systems (GIS) and the data observed by the field and laboratory tests. The local soil conditions are observed utilizing the map classified according to the Turkish Earthquake Code 2018. By taking these 3D visuals and maps into consideration, it is determined that soil is alluvial. The ground water level is high, especially in the city center; the local soil type is ZD, ZE and ZF, according to the Turkish Earthquake Code (2018). Examination of the 3D visuals and maps reveal soil's the changing soil profile with a gradual gradation from fine grain soil (clayey and silty) at the surface; to coarse grain soil (sandy and gravelly). Therefore, the 3D visuals and maps established in the scope of this study may provide preliminary information to the researchers and pragmatists in the area.

1. INTRODUCTION

Turkey is situated on a tectonically active landscape, and it has frequently experienced major earthquakes until today. The North Anatolian Fault Zone, one of the most active fault systems in the world, causes severe damage in highly populated areas. Earthquake characteristics, soil conditions and structural characteristics are three main groups causing damages to the structures due to earthquakes (Cinicioglu et al., 2003). Therefore, soil engineering characteristics must be identified to reduce the damages of earthquakes and determine safe residential areas. This article concerns geotechnical properties determination and visualization of natural sediments formed as a result of geological processes. The aim of this study is to visualize the geotechnical properties (standard penetration test values, soil classification and local soil classes) of the Eskişehir-Tepebaşı region in 3D.

Soil properties are a must for micro zonation and to determine the safest residential areas. Before designing a safe structure, the geotechnical characteristics of the ground should include determining whether the residential area is safe against earthquake effects. Nowadays, a Geographic Information System (GIS) is preferred in geographic mapping due to the reasons such as data management, selection of geostatistical analysis and 3-dimensional (3-D) visualization of the subsurface with geoprocessing capability. Therefore, it is used to solve many geotechnical problems (Marache et al., 2009).

GIS is a computer-based system that collects, stores, analyses any data endued with coordinates (related to location). It is also a program that steps up the decision-making processes of physical, planning, directing works and provides practical and correct results. In addition to

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these, thanks to its specialty of adding attributes to geographical objects, it also visualizes user wants data (Avdan and Alkıs 2011). GIS technologies can solve the problems in disaster management and hazard mitigation (Yılmaz 2007).

Geoscientists mostly use GIS for determining natural hazard analyses, studies with general geology purposes, and geotechnical studies. Rackwitz (2000) has done work concerning the probabilistic approach to soils and foundation engineering. Chacon, et al. (2006) have created engineering geological maps by determining landslide susceptibility (Chacon et al. 2006). Kolat, et al. (2006) liquefaction potential of an area has ascertained using multiple criteria decision analysis. Orhan (2005), Orhan et. al.; (2007), Tosun and Orhan (2007) and Orhan and Tosun (2010) created seismic zonation maps using GIS. Balasubramani and Dodagoudar (2020) by creating a GIS-based 3D SPT model, provided a better overview of the subsurface geology, bedrock elevations, and geotechnical characteristics of the various soil types found in the study area. Moreover, GIS is also used for determining the damages on structures due to ground liquefaction during earthquakes (Mhaske and Choudhury 2010). The use of 3-D visualization for geotechnical studies is increasing day by day and it is preferred as the best choice for rigorous modeling studies (Hack et al. 2006).

3D modeling of engineering properties of the soil is getting more critical for the accuracy of engineering studies. Until this time, 3D visualization of the ground characteristics of the Eskişehir-Tepebaşı region has not been performed. For this reason, a pilot region (Eskişehir-Tepebaşı) was chosen.

In this study, data from 31 (thirty-meter deep) boreholes were analyzed to determine the ground properties of Eskişehir (Tepebaşı). A database has been created using the SPT values and ground class properties acquired from the boreholes. In the scope of the study, the engineering properties of the ground of Eskisehir-Tepebaşı region were examined with the database created. 3-dimensional visualization of SPT and soil classes data captured from boreholes in the region was performed in Environmental Visualization System-Mining Visualization System (EVS-MVS), a GIS software. In addition, the local soil class of the studied area was obtained using ArcGIS software by the Inverse Distance Weighting (IDW) according to TEC 2018. Thanks to these 3D visualizations and maps created, soil classes of the region and the variation of the SPT values depending on the depth were obtained.

2. METHOD

2.1. General Characteristics of the Investigated Area

Eskisehir Basin is located approximately 790 m above sea level in the northwest of Turkey, in the Central Anatolia Region, Turkey (Fig.1). The investigated area, the Tepebaşı region, is approximately 96 km². The studied region is located approximately 278.000 – 294.000 E and 4.404.000 – 4.410.000 N (UTM Zone 36, ED50).

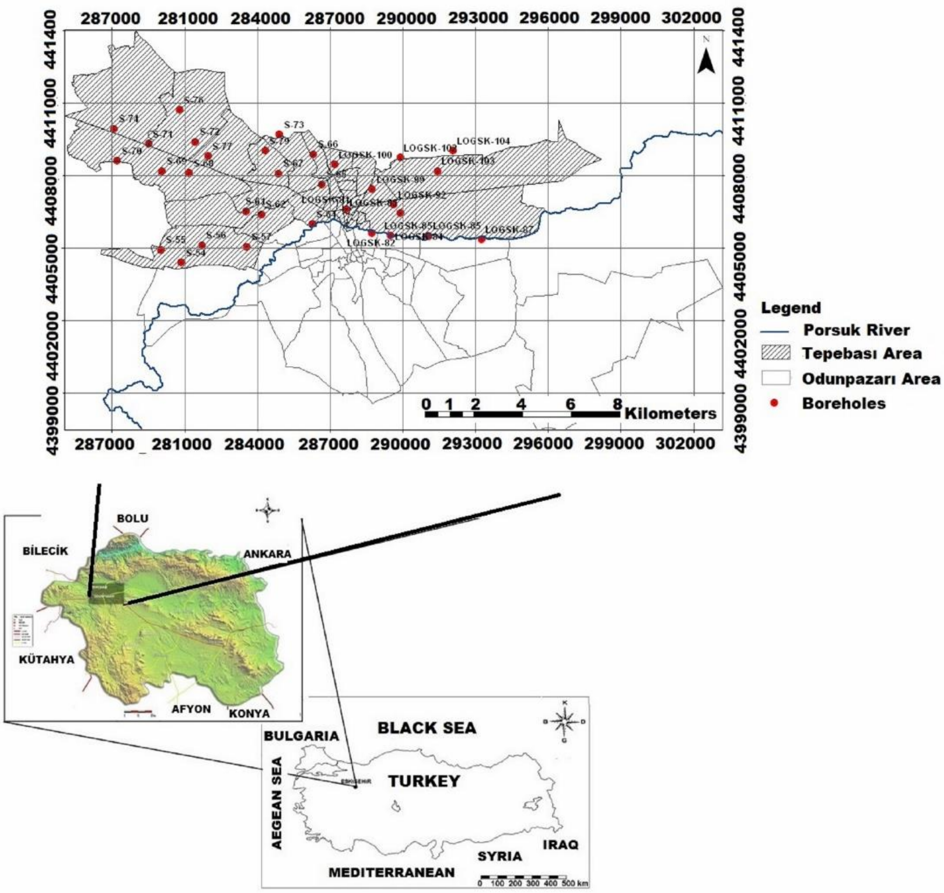

Figure 1. Location Map of Investigated Area

Eskisehir city center is located on the alluvial ground and threatened by earthquake disaster due to the Eskişehir Fault Zone. The Porsuk River is located in the district of Eskişehir in the southwest and passes through the center of the city and leaves the city from the east. Another river in the region is the Sarısu Stream. The Sarısu Stream, which extends east-west in the settlement area and flows eastward, was effective in transporting and storing the alluvial material downtown (Fig.2).

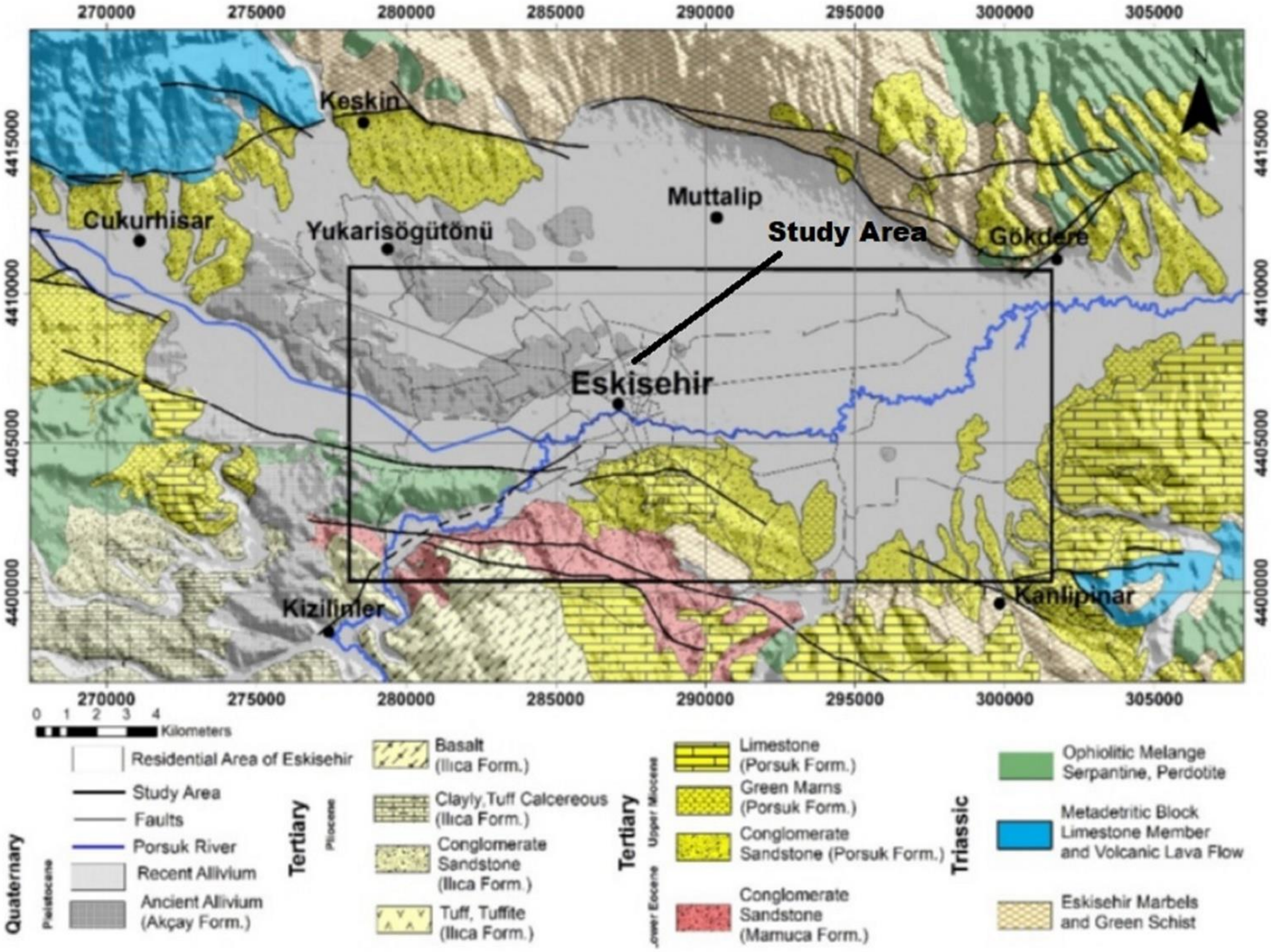

Figure 2. Geology of the Study Area (Güney et al., 2013)

2.2. Tectonic Properties of the Investigated Area

Eskişehir fault zone has a right-lateral strike-slip fault with the normal component. Eskişehir and its environment have experienced large and medium-sized earthquakes in the last 100 years, and the greatest earthquake in this period has been the earthquake of February 20, 1956 (M=6.4), causing various damages in and around the centers of Eskişehir, Bilecik, and Bozüyük (Altunel and Barka, 1998) (Fig.3).

According to the Turkey Earthquake Hazard Maps Interactive Web Application used in building design, the acceleration values of the Eskişehir ground range from about 0.24-0.3. But the damages of 1956 earthquake (M=6.4), the results obtained by seismic refraction studies by Seyitoglu et al. (2015) recent earthquakes occurred around the Çukurhisar-Sultandere segment (Fig.4) show that the main seismic hazard source of Eskişehir residential area is Çukurhisar-Sultandere segment. The researches on engineering characteristics of the soil at the residential areas of Eskisehir are_of vital importance and these areas should be investigated in terms of geotechnical aspects. This study investigates the soil characteristics of regions in Tepebaşı district, and engineering modeling and sectioning are performed using SPT values. Also, the soil classification used in this modeling is defined per the Unified Soil Classification System (USCS).

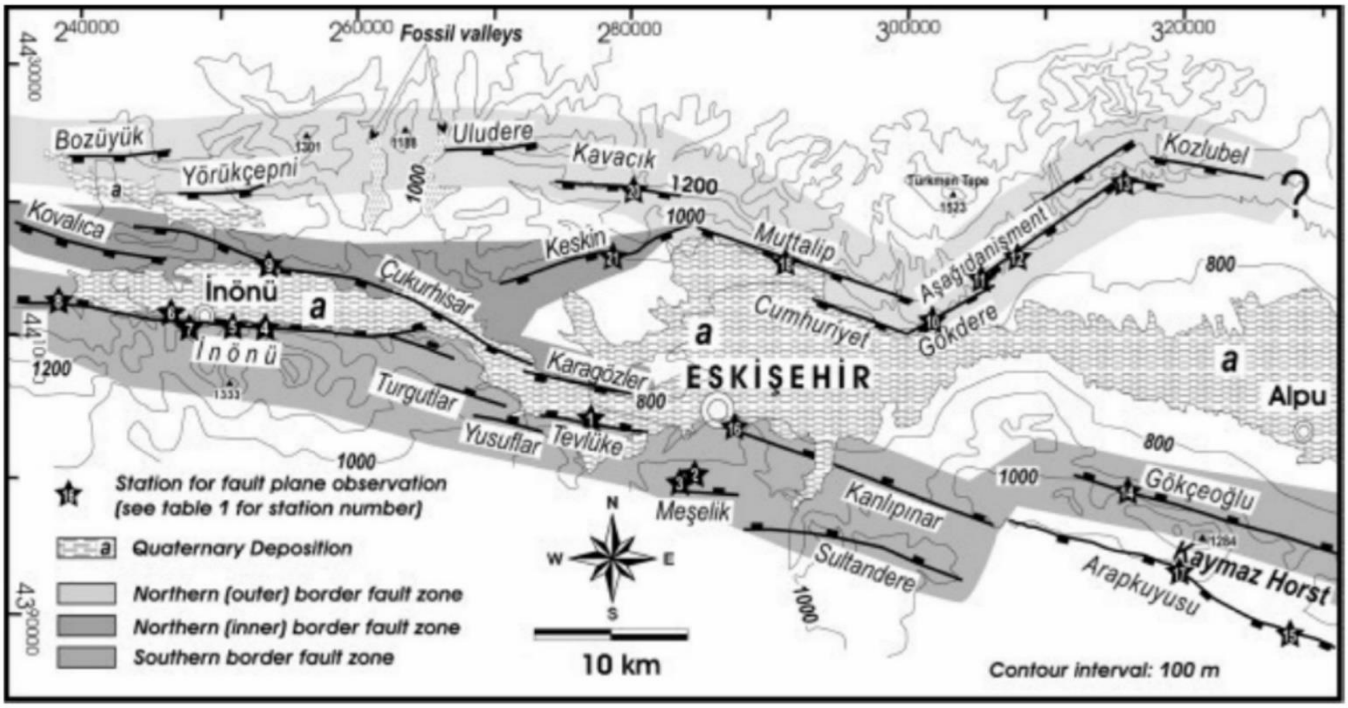

Figure 3. Eskişehir Fault segments (Ocakoglu, 2007).

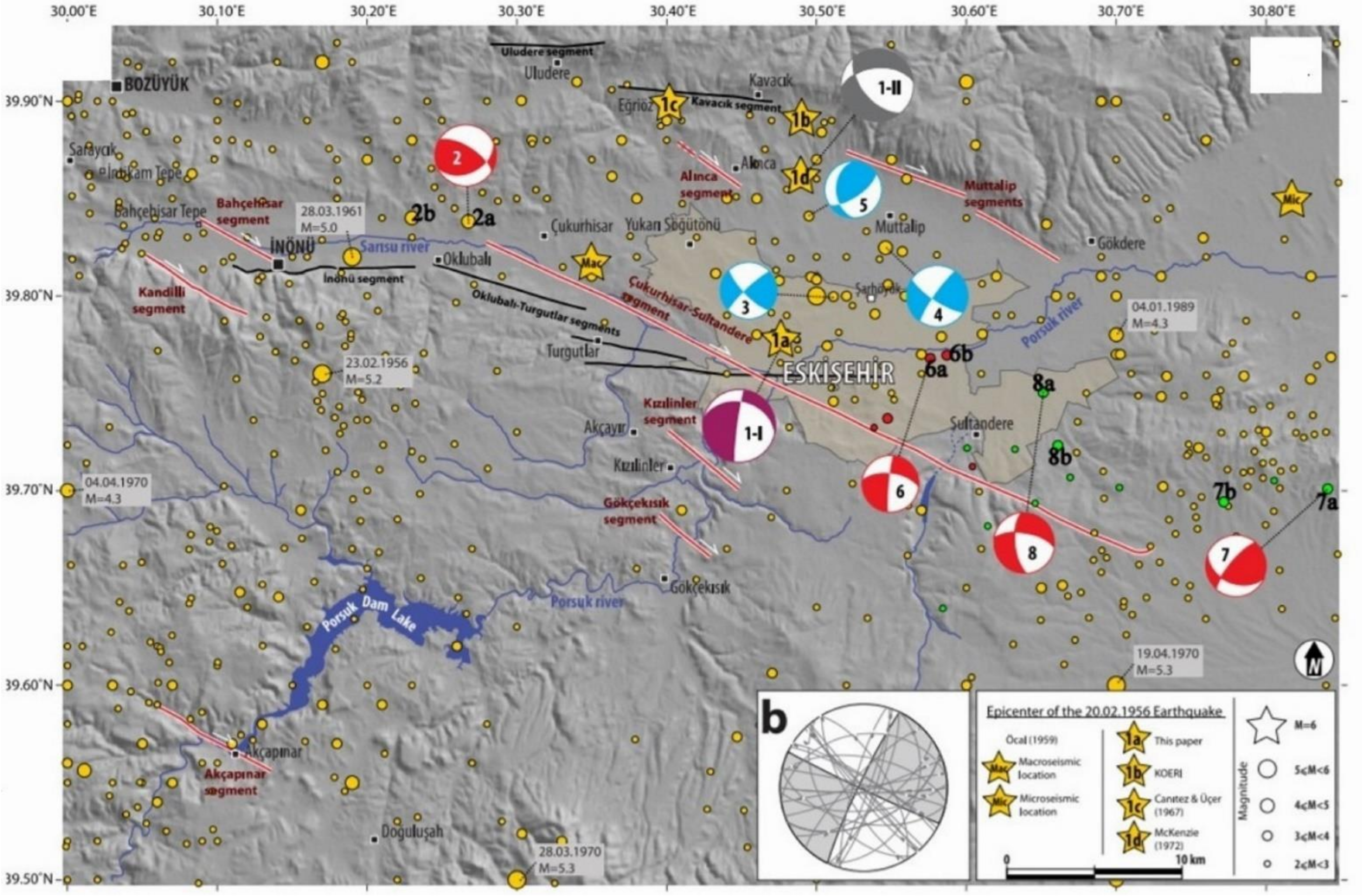

Figure 4. The seismicity of the study area and the epicenters of (3) 02.10.2003, (4) 03.10.2003, (5) 04.10.2003, Ocakoğlu et al. 2005, (6) 07.02.2010, (7) 17.02.2013, (8) 01.03.2013 and aftershock distributions of 2010 and 2013 events are shown with red and green dots, respectively (Seyitoğlu et al. 2015)

3. METHODOLOGY

3.1. Determination of geotechnical characteristics of the investigated area

Determining the engineering characteristics of the layers existing among the soil profiles is vital in geotechnical engineering. Standard Penetration Test (SPT), a dynamic shear experiment performed to evaluate ground strength and density to purpose remolded samples in the borehole. Standard Penetration Test, a dynamic penetration test, is one of the most widely used field experiments (Sivrikaya and Togrol 2007). The raw SPT values of layers are obtained during the experiment in the field. The raw SPT values determined in the field are transferred into corrected N (SPT blow count) values taken into consideration in calculations.

To interpret SPT results correctly, SPT construction and the instrumental details used in the experiment should be known. Therefore, they conducted an extensive survey in Sivrikaya and Togrol studies and gathered information from the drilling records about how SPT was made and the instrumental details used in the experiment. Their work made detailed linear regression analyses and proposed an empirical formula containing all the corrections for fine grain soils. This formula the equation "SPT $N60=0.75*CR*N_{ground}$" which is commonly preferred for fine grained soil in Turkey (Sivrikaya and Togrol 2007). Whereas N60 is corrected SPT blow counts, N_{ground} is raw SPT blow count in ground, CR is borehole rod length correction factor. In this study, visualizations were made by calculating corrected blows from the SPT blow counts obtained from the field.

The geotechnical properties of soil layers at the study area were obtained from the 33 boreholes drilled down to 30 m depths from the ground surface. The boreholes were drilled in Eskişehir within the framework of Micro zonation and hazard vulnerability studies for disaster mitigation project (MEER 2006) funded by the Project Implementation Unit of the Prime Ministry of the Republic of Turkey. The boreholes used in this study were obtained from the Meer (2006) project. In this study, the results obtained from the SPT field tests and laboratory tests such as sieve analysis, Atterberg limits, and consistency index tests were done in MEER (2006). About 660 Standard Penetration Tests and 587 identifying tests were carried out on the specimens taken from thirty-three boreholes with a depth of 30 meters. Results of laboratory and field studies are given in Table 1.

Table 1. A summary of laboratory and field studies

Study Type	Unit	Value
Boreholes	amount	33
Total Borehole Length	meters	990
SPT	amount	660
Definition Test	amount	587

3.2. 3D Visualization of The Study Area

Geotechnical investigation is works that aim to determine soil conditions in an area that is to be built. The study also includes the determination of the characteristics of occurring soils and rock. Field surveys should provide a basis for assessing how land should be used, e.g., the construction of buildings by determining the soil properties (Azaronak 2015). With the geotechnical model with studies, it is possible to visualize the three-dimensional geological-geotechnical characteristics of the subsoil.

Geotechnical information can come from different sources. In the early stages, geotechnical information can be obtained, for example, from geological maps and existing investigations. The 3-dimensional soil class is to visualize in 3D the ground class values of the study area using interpolation methods (for a depth of 30 m in this work). 3-dimensional soil class studies are the process of interpreting measurements at each point of investigation. Each borehole has X and Y coordinate, Z – is measured and represents the top-level of investigation point. Depending on soil structure, it can be different numbers of soil levels and Z values representing those levels at each point.

Generally, the modeling method to be used depends on the properties of the data. For this reason, there are different 3D visualization methods. In this study, soil class values obtained from drilling in the field were visualized for a depth of 30 meters.

A series of laboratory tests are carried out to determine soil classes. For this reason, ground class values are evaluated as categorical values. Because of the change in sedimentation conditions, the variation in depth and the river's flow rate, the soil classes may vary in both vertical and horizontal directions. Companies have developed various methods for modeling categorical and ordinal values, like the Geological Indicator Kriging Method (GIK), which is based on the probability of categorical values in all voxels in the model. In other words, the probability of the soil classes observed in the region is determined for each voxel. The final soil class of the voxel is the one that has the highest probability (Fig.5a). Geological Indicator Kriging Method is the most commonly used method for modeling the soil classifications by EVS – MVS programs (Akdeniz et al., 2011). The Geological Indicator Kriging (GIK) is an interpolation method. The interpolation effect of the GIK method shows that the distribution of the parameter is random. With GIK, a default grid is created (with a user-specified fineness) and this grid can be (and is in this case) defined between two geologic surfaces (e.g., ground surface and the bottom of gravel) (Pereira et al. 2017). On the other hand, variables such as SPT-N values, porosity, hydraulic conductivity coefficients of units, pollutant concentration are modeled by continuous variable algorithms such as 3D kriging (Rockworks 2010) (Fig.5b). It is a method used to estimate points whose value is unknown from points whose value is known. The final maps created due to these and similar systems also support up-to-date data with their convergence to real values. In this study, GIK method was used to visualize soil classes and the 3D kriging method was used to visualize SPT-N values.

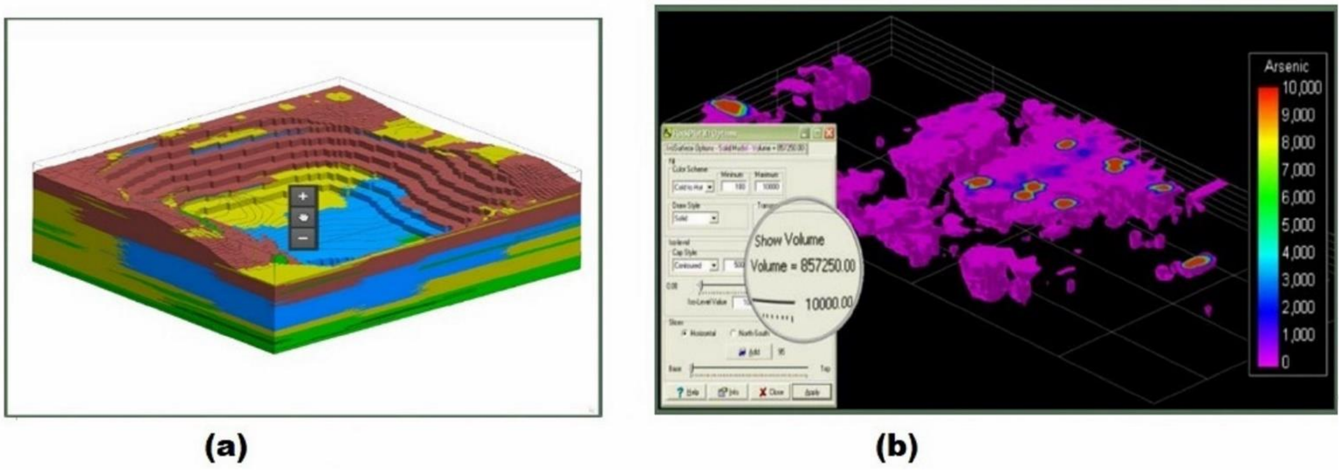

Figure 5. Modeling methods: a: Categorical Modeling, b: Continuous Variable Modeling (Rockworks,2010)

The creation of 3D visualization representing geological soil layers using the results of soil and rock investigations (geotechnical investigations) is of interest in providing geotechnical data and/or information.

4. Results and Discussion

SPT values provide information about the firmness and consistency of the ground. There are many variables that spread these values over a wide range of changes. The low reproducibility of this change or experiment causes difficulties in interpreting SPT results and using historical data safely. For this reason, 3D models that show the variation of SPT values with depth for fieldwork provide users with convenience (Figure 6).

The 3-D model of the area is prepared by EVS – MVS programs by making use of the corrected Standard Penetration Test results (Fig.6 and Fig. 7). In Fig.7, the vertical axis (z) represents the elevation of the drillings, and the horizontal axis represents the x and y coordinates. On the 3-D model, sections are taken in North-South and East-West directions for observing the variations with depth more clearly (Figs.8 and 9). In the Study Area obtained from the results of the SPT experiment was performed.3-D modeling of the adjusted N (blow numbers) values.

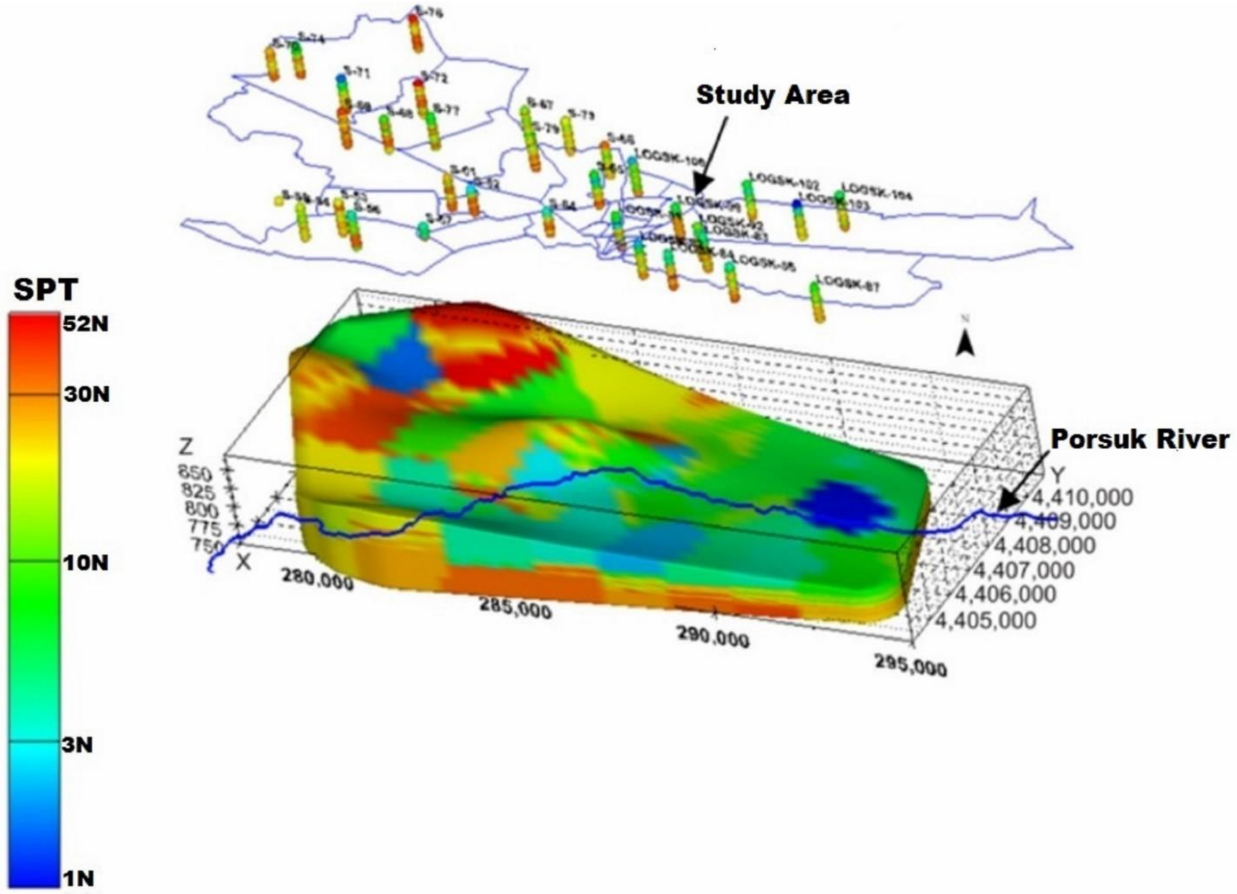

Figure 6. Standard Penetration Test (SPT) Model of Investigated Area

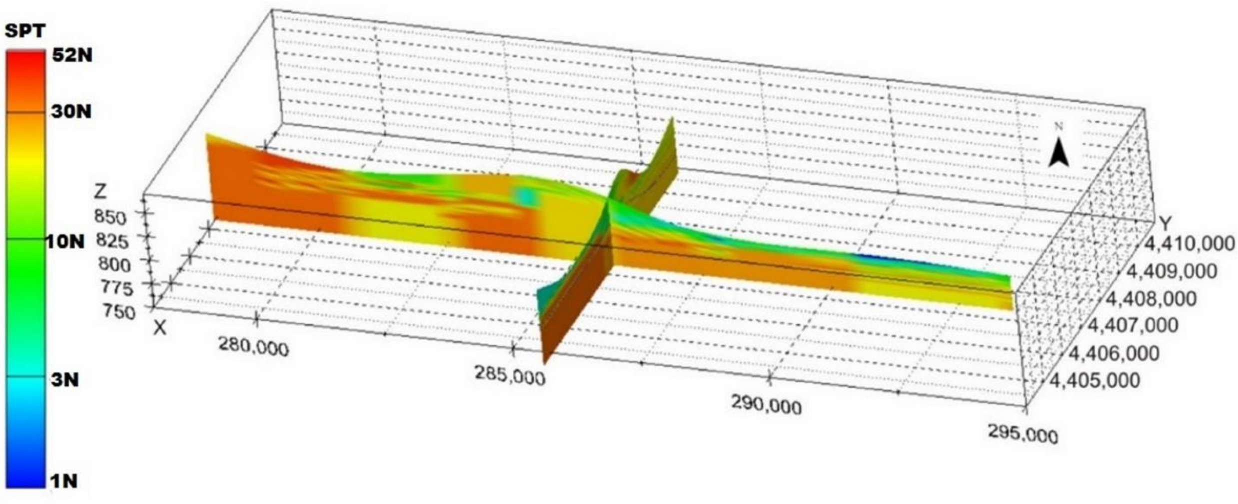

Figure 7. Standard Penetration Test (SPT) Sections of Investigated Area

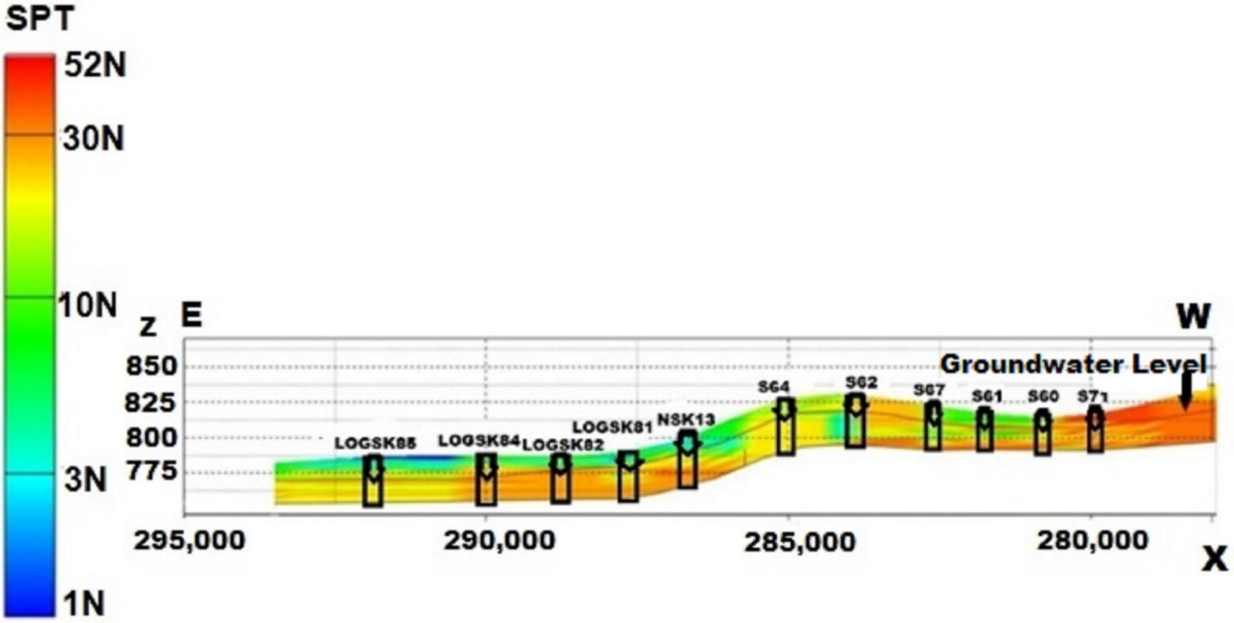

Figure 8. Cross Section of E-W Direction

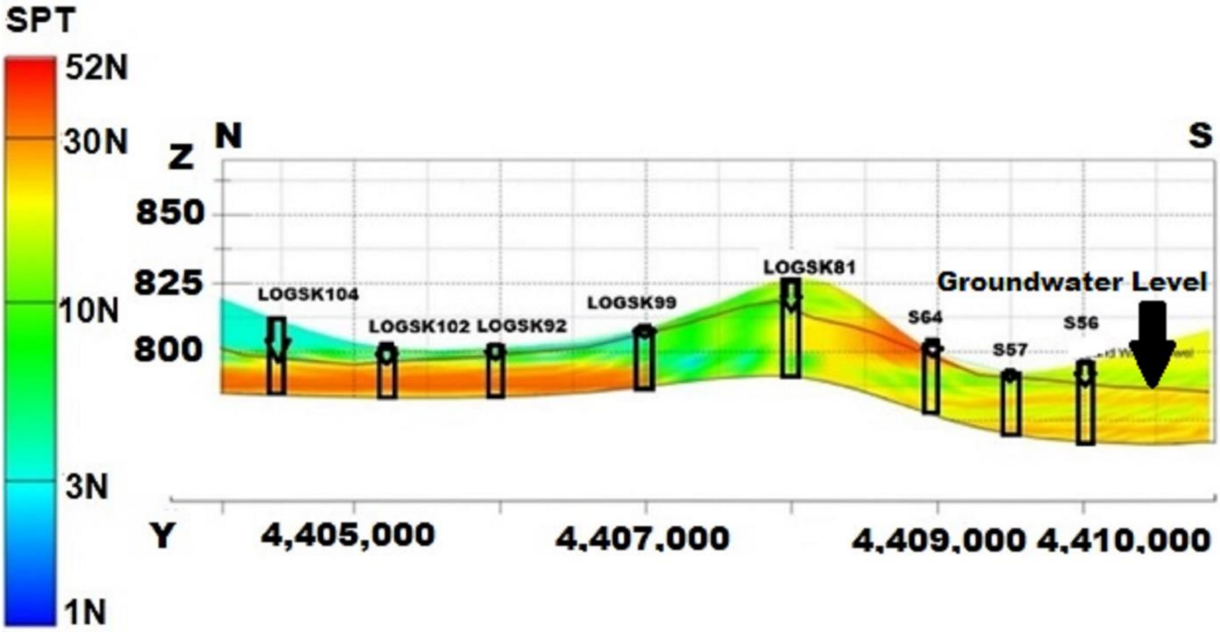

Figure 9. Cross Section of N-S Direction

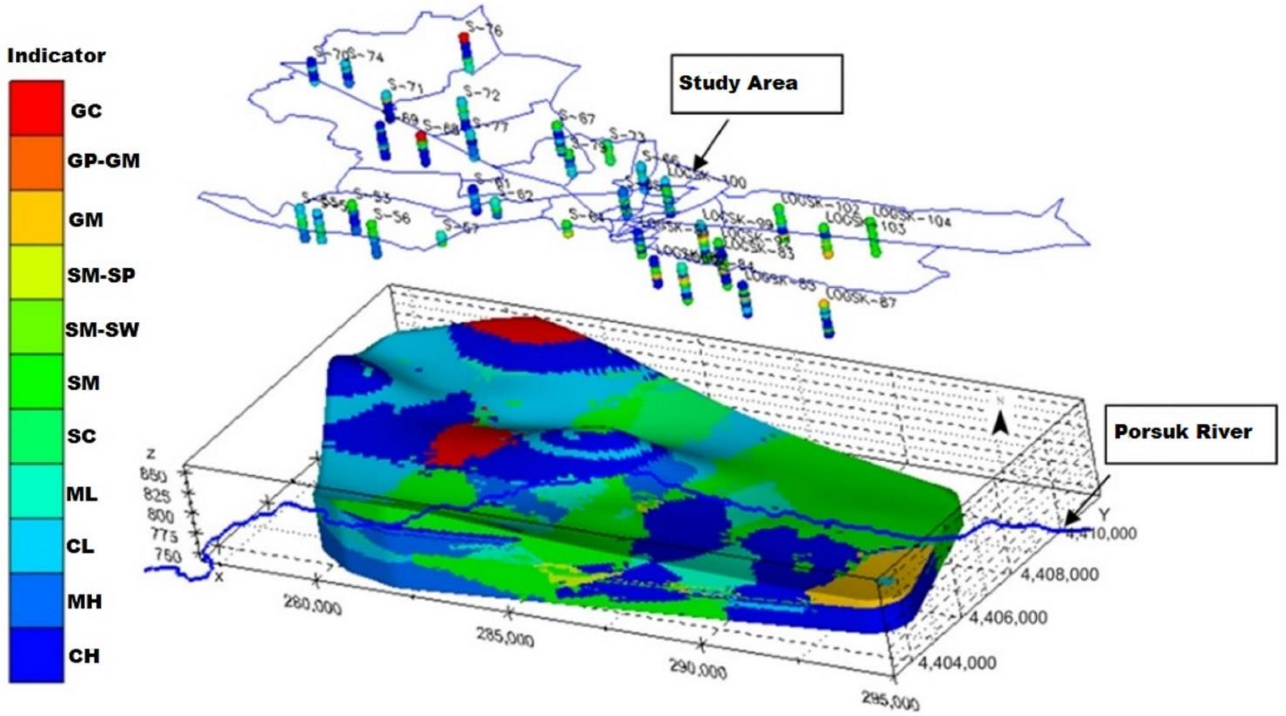

Figure 10. Soil Classes Model of Investigated Area

There are hundreds of different methods for gathering data. In this study, data were obtained from drilling. These are soil class and SPT values for all layers representing a depth of 30 meters. Once the data is collected, the data processing process begins. Data processing takes place when values obtained during the investigation process are converted to geotechnical parameters used for soil layer modeling and calculations. In this stage, geological interpretation (layout, range, thickness, and geological properties of layers) and later interpolation and data transformation are performed (Fig. 8, Fig. 9, Fig. 10, Fig. 11).

When this 3-D model is evaluated according to the variation with depth in more detail, it is observed that very significant results are obtained. When the sections of the 3-D Standard Penetration Test model among the North-South and East-West directions are evaluated in detail, it is observed that corrected N values are significantly low up to the depth of 5 meters and values tend to increase after this depth and reach the value of 52 as maximum (Figs.8,9). The soil with high values of corrected SPT results can be defined as "stiff – very stiff".

Modeling of soil type is the process of interpreting measurements at each point of investigation. Each borehole has x and–y coordinate, z – is measured and represents the top level of the investigation point. When all the data are gathered in the database, it is possible to create separate files for different soil layers. For example, the data taken from the boreholes are used for the 3-D soil classification modeling of the area by EVS – MVS programs (Fig.10). For these models, a simple interpolation application was made in the current version. The soil classification used in this modeling is defined per the Unified Soil Classification System (USCS) (Table 2).

For assessing the variation with depth in more detail on the 3-D model, sections in North-South and East-West directions are also considered (Fig.11). When these sections are analyzed in detail, it is observed that the upper levels of the soil are composed of fine-grained soils while the lower levels are composed of coarse-grained soils and that the size increases with depth (Figs.12,13).

When the North-South and East-West sections are analyzed in detail on the model, the soil profile of the study area is observed to be composed of clay, silt, sand, and gravel. In this profile, clayey soils are in a plastic state. The sandy levels are defined to be composed of clayey and sandy particles and vary in high scales in terms of grain sizes (Figs.12,13). The groundwater depth changes between 5-25 meters throughout the study area. The shallow groundwater level can be seen especially around the coast of Porsuk River.

Table 2. Soil Classifications (USCS)

Soil Classes	Definition	Soil Classes	Definition
CH	High Plasticity Clay	SM-SW	Well Graded Silty Sand
MH	High Plasticity Silt	SM-SP	Poor Graded Silty Sand
CL	Low Plasticity Clay	GM	Silty Gravel
ML	Low Plasticity Silt	GP-GM	Poor Graded Silty Gravel
SC	Clayey Sand	GC	Clayey Gravel
SM	Silty Sand		

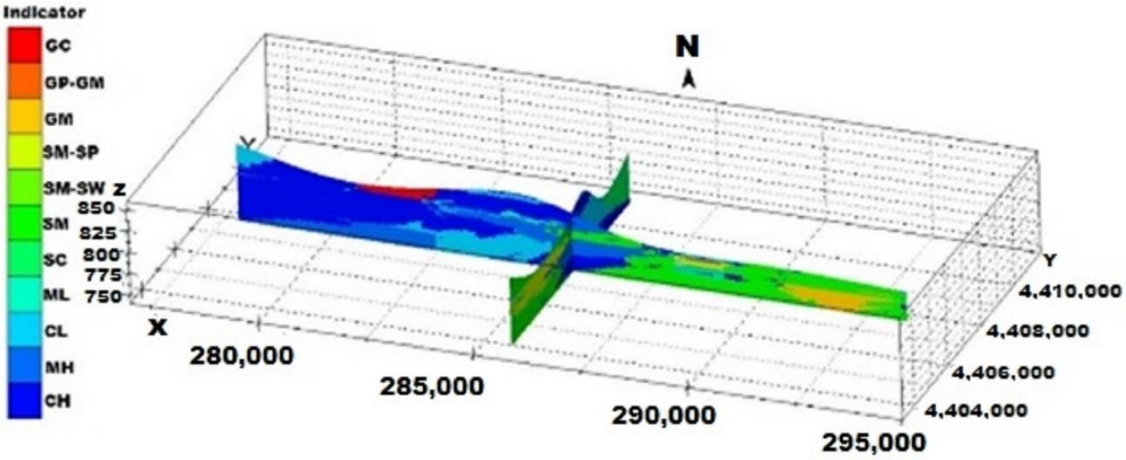

Figure 11. Soil Classes Sections of Investigated Area

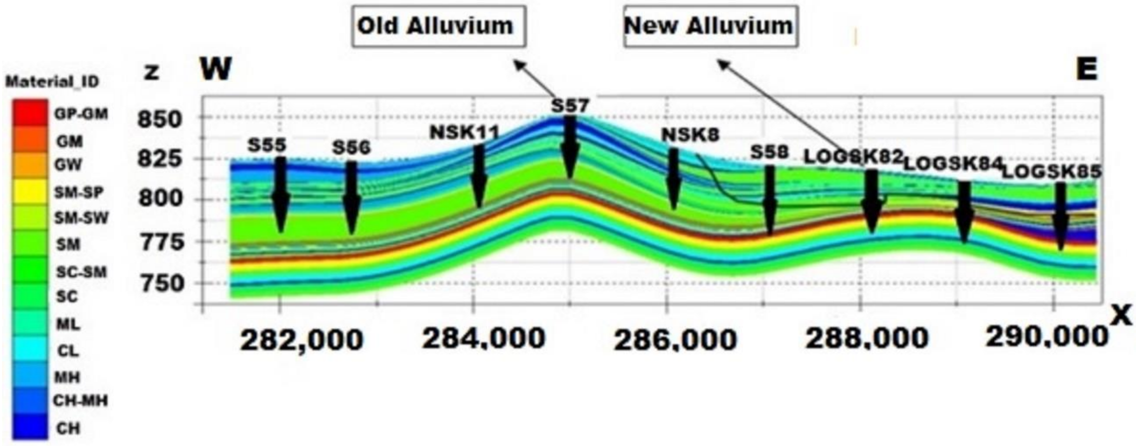

Figure 12. East-West Direction Cross Section of Soil Classes

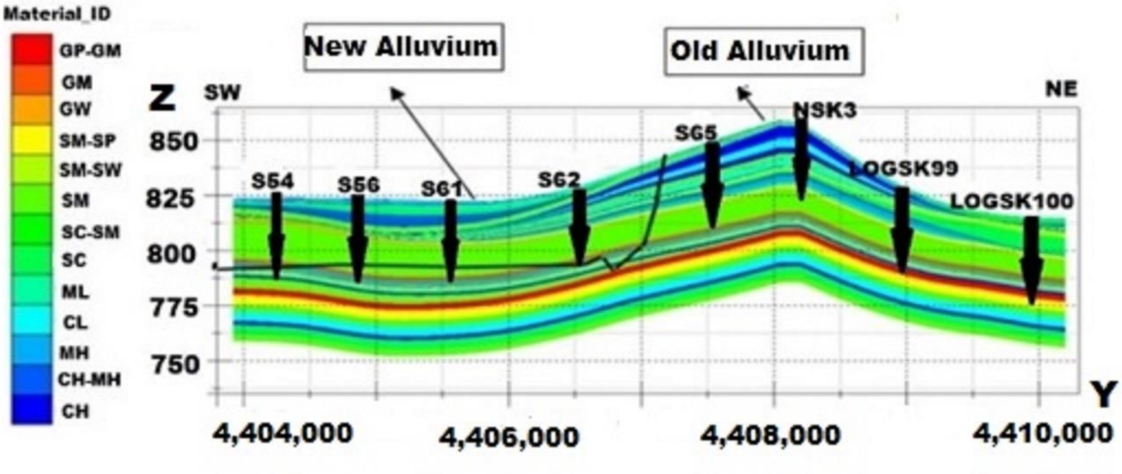

Figure 13. South West-North East Direction Cross Section of Soil Classes

The Turkish Earthquake Code (TEC), published in 2018, considers six soil classes for engineering calculations in designs against earthquakes and proposes the design of earthquake-resistant buildings according to the local soil classification. For this reason, identifying and mapping the local soil class is important for the design of earthquake-resistant structures.

According to the Turkish Building Earthquake Regulation (2018) published recently, the soil parameters will be determined for the 30 m-thickness of the soil profile starting from the bottom elevation of the foundation or pile cap to the top. In the soil profiles containing distinctly different soil and rock layers, the layers in the upper 30 meters shall be divided into an adequate number of sublayers and sequenced in a manner that i=1 at the top and i=N at the bottom. The average shear wave speed (VS) (meters/second), calculated for in the upper 30 meter-portion the average standard penetration blows are computed as 60 30 (N) (blow count) and the average non-drainage shear strength (u) (kPa) is calculated as 30 (c). There are 6 soil classes ZA, ZB, ZC, ZD, ZE, and ZF (TEC 2018) (Table 3).

In our previous study, mapping of local ground classes for a specific part of Eskisehir city center was made (Civelekler et. al. 2021). In this study, the local soil classes of the Tepebaşı area have been evaluated according to the 2018 Turkish Earthquake Regulation used recently. According to the characteristics of soil class classified as per the 2018 Turkish Earthquake Regulation, the boreholes have mostly the soil characteristics of ZD, ZE, and ZF. These soil classifications obtained according to the Turkish Earthquake Code 2018 are digitized utilizing the ArcGIS 10 program and by using the Inverse Distance Weighting approach (Fig.14).

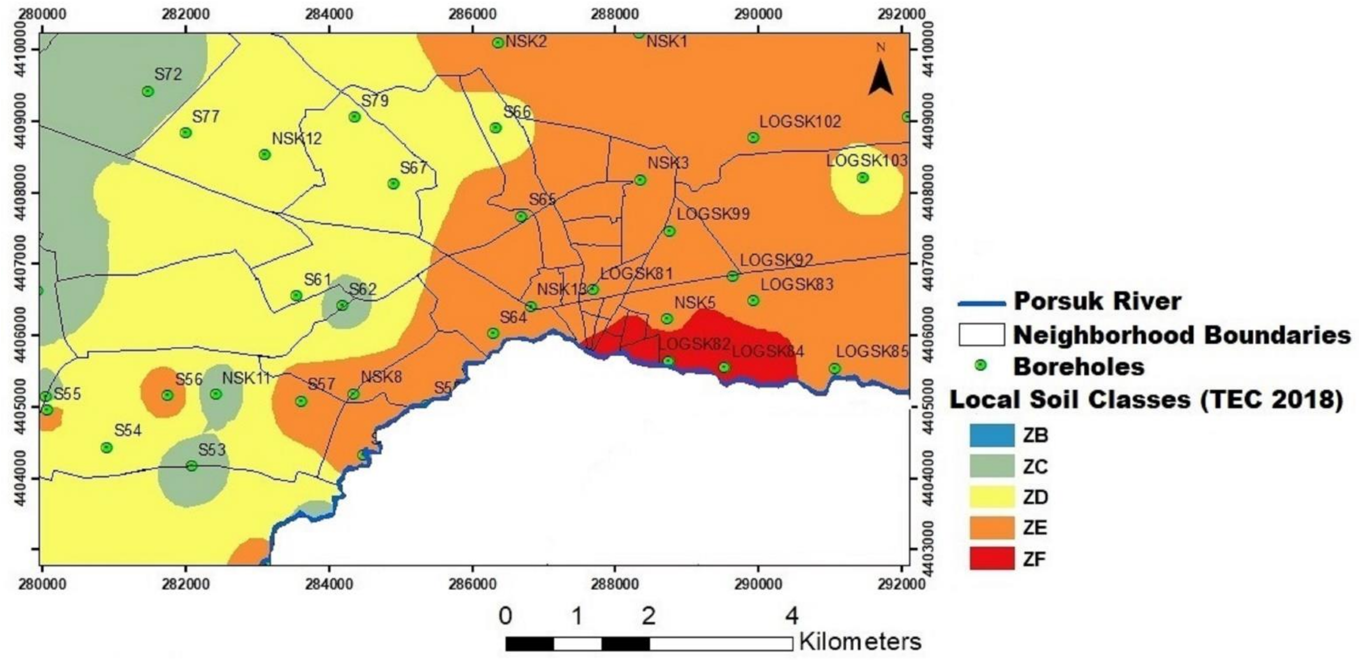

Figure 14 Local Soil Classes of Investigated Area According to Turkish Earthquake Code 2018

Table 3. Local Soil Classes According to Turkey Earthquake Regulation 2018 (TEC 2018)

Local Soil Classes	Soil Group	Upper 30 meters on average		
		$V_{s(30)}$ m/sn	$(N_{60})_{30}$ (blow/30 cm)	(Cu) 30 (kPa)
ZA	Sound, hard rocks	>1500	–	–
ZB	Slightly weathered, medium sound rocks	760-1500	–	–
ZC	Very dense sand, gravel and hard clay layers or dissociated, very cracked weak rocks	360-760	>50	>250
ZD	Medium dense – dense sand, gravel or very solid clay layers	180-360	15-50	70-250
ZE	Loose sand, gravel or soft - solid clay layers or profiles with a soft clay layer (cu <25kPa) thicker than 3 meters, providing PI> 20 and w> 40% conditions	<180	<15	<70
ZF	Soils requiring site-specific research and evaluation: 1. Soils at risk of collapsing and potential migration under earthquake (liquidable floors, highly sensitive clays, poor cemented soils etc.) 2. The total thickness is more than 3 meters’ peat and / or high organic clays, 3. Clays with high plasticity (PI> 50) having a t.otal thickness of more than 8 meters, 4.Very thick (> 35 m) soft or medium solid clays.			

5. CONCLUSION

85% of Eskişehir metropolis is covered with loose soil that is called Quaternary Alluvium. This formation is mainly composed of sandy, gravelly and silty soil and the groundwater level is shallow. In this study, laboratory tests for the Tepebaşı region are carried out using data from thirty-three boreholes with depths 30 meters. SPT values and soil classification, observed from local soil investigation reports, are considered and 3-D visualization of SPT values and soil classifications are prepared using GIS based EVS – MVS programs and some sections are obtained by using the data of boreholes. The variation of SPT values and soil classifications with depth is obtained thanks to these 3-D visualization studies. When the soil properties are investigated with depth, it is seen that the fine-grained soils composing the upper levels are in high plasticity and with the increase in depth the plasticity indices decrease, silt amount increases and soil formations tend to gradually become stiff. When the Standard Penetration Test results are evaluated in detail, it is observed that the Standard Penetration Test values are relatively low up to 5 meters of depth and the values increase as depth increases after 5 meters. Because the groundwater depth of Eskişehir is about 5 to 6 meters is also taken into account, it can be stated that the Standard Penetration Test values are affected by the groundwater level.

Taking into account the 3D visual and maps obtained as a result of this study, it is determined that basic soil is alluvial, the groundwater level is high and the especially in the city center local soil type is ZD, ZE and ZF according to the Turkish Earthquake Code (2018). The basic soil characteristic being alluvial and high groundwater level might result in liquefaction of the ground, loss of bearing capacity, and settlement during an earthquake which all seriously affect affects the safety of a structure. Appropriate engineering projects should be prepared for structures to be constructed on such soils by taking these 3D visuals and maps into account. The models established in the scope of this study may provide preliminary information to the researchers and pragmatists at the area.

Also, this study is aimed at the visualization of the soil characteristics specific to the site, which is stipulated by Part 16 of the latest TEC 2018. In addition, 3D visualization of the soil characteristics in the new area is important for Geoscience Studies.

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Author contributions

Ebru Civelekler: Conceptualization, Methodology, Software, Data curation, Geological Indicator Kriging Analyses, 3-Dimensional Visualization, Investigation, Writing-Reviewing and Editing. **Emrah Pekkan:** Visualization, Investigation, Writing Reviewing and Editing

Conflicts of interest

The authors declare no conflicts of interest.

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