Preparation and Evaluation of Engineering Geological Maps in 3-dimensional Geographic Information Systems Environment

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SUMMARY

Geological engineers have mostly been involved in geotechnical problems since the beginning of 19th century. Engineering geological maps and field data are needed to solve these problems. The amount of data for these maps is extremely large, so putting all the map elements on the map sheet causes difficulties while solving problems. The magic words, Geographic Information System (GIS) is a tool for modelling real world by use of computer technology. Mostly 2-dimensional GIS is used in many different application fields. Even this 2-dimensional GIS is used for many geoscientific studies, 3-dimensional modelling must be used if variation of subsurface is needed. 3-dimensional GIS is used for the preparation of engineering geological maps and evaluation of geotechnical problems for one of the municipality of Istanbul metropolitan area. It is seen that, for project like preparation of engineering geological map which use data such as multiple points from one boreholes and three-dimensional geotechnical data 3-dimensional GIS is needed. 2-dimensional GIS must be used with some graphics and bar charts which presents depth data with the real 3-dimensional GIS especially for geoscientists.

KEYWORDS: *2-Dimensional GIS, 3-Dimensional GIS, Engineering Geological Map*

INTRODUCTION

A system of integrated different data and preparation of different thematic maps have been used mostly by geologists since the beginning of 19th century. On the other hand, geology related environmental and engineering problems, which the human being faced, dates back to the more than 2300 years ago. The amount of data and the number of thematic maps which are used for the preparation of environmental and engineering geological maps and for the solution of geotechnical problems have increased rapidly from old to the new age. Putting all these graphic and non-graphic data in a proper place and creating a data model from the real world and consequently making a correct analyze needs a perfect organization. Geographic Information System, shortly called as GIS, fills the real need of this rapid growth of spatial data in this field.

Mostly GIS has been developed for different fields and used in 2-dimensional applications. This 2-dimensional aspect is not adequate for geological engineering studies sometimes called as geoscientific studies. Three-dimensions are needed for these studies and the data structure must be constructed according to this purpose. The most important difference that generally all geoscientific data like drilling boreholes data, seismic data looks like the real world if they are modeled and analyzed in 3-dimensional GIS.

The area, which 3-dimensional GIS has been applied for the evaluation of geotechnical data, was selected for the Kadikoy Municipality of Istanbul metropolitan area. The lithological boundaries, soil drilling-log data, road map was used in this study. At the end of this study, it is understood that 2-dimensional GIS can inform only a specific level or depth. However, 3-dimensional GIS is needed for these kinds of geotechnical studies for the determination of soil properties change and preparation of engineering geological maps.

ENGINEERING GEOLOGICAL MAPS

Engineering geology is defined as the discipline of geology applied to civil engineering, particularly to the design, construction and performance of engineering structures interacting with the ground in, for example, foundations, cuttings and other surface excavations, and tunnels (Dearman, 1991). Engineering geological map is a type of geological map, which provides a generalized presentation of all those components of a geological environment of significance in land-use, planning, and in design, construction and maintenance as applied to civil and mining engineering (UNESCO, 1976). These maps must include explanations, cross-sections for the complementary data. Sometimes additional map sheet is needed to inform all these symbols and graphical attributes. It is not easy to make accurate interpretation by using all these complicated explanations. Sometimes matrix type legend is used for the definition of map unit elements. It means that, the preparation of engineering geological maps are very complex, because different thematic elements must be indicated on the same map sheet. One of the other difficulties is the visualization of subsurface deposits in the map. Because map sheet is 2-dimension but the thickness of layers extend to the third direction, which is perpendicular to the map sheet.

3-DIMENSIONAL GIS FOR GEOSCIENTISTS

The term geographic information system (GIS) is now used generically for any computer-based capability for the manipulation of geographical data (Bernhardsen, 2002). Dangermond, known as one of the famous frontier of GIS, defined as “automated tools, for the efficient storage, analysis and the presentation of geographic data” (Dangermond, 1984). At its childhood age, GIS has consisted of only hardware and software, but nowadays remote sensing and GPS techniques are also complementary parts of it. As it is indicated before, generally GIS is restricted to data in 2-dimension, 3-dimensional GIS model must be used for geoscientists. Mainly most GIS have been developed in 2-dimensional applications, and they have lack 3-dimensional capabilities. Some GIS has been designed specifically for geological work, particularly for mining and oil exploration, it is needed to be fully 3-dimensional, so that each data object is characterized by its location in space with three spatial coordinates (x, y for horizontal and z for vertical position). For projects that involve data such as multiple points down boreholes, seismic sections, recumbent or complex faulted structures, or three-dimensional geotechnical and geophysical data, three-dimensions are needed (Bonham-Carter, 1994). This is the most famous fact that differentiate the geoscientific studies and researches with the others. Visualization is not a new concept in digital drawing but a new concept in GIS environment. Three-dimensional visualization of real world would give the GIS applicants a more realistic sight and more realistic conclusion.

Even the ordinary type 2-dimensional GIS can be used to represent the three dimensional view in the geological model. Opening and closing property of layers in the 2-dimensional GIS can be used to represent the complex data of engineering geological map more easily. Bar graphics, line charts, pie charts can be used to represent the z-dimension, which is corresponding to depth for geology. If there is no opportunity to obtain a real 3-dimensional GIS, 2-dimensional GIS can be used for indicating the depth variables. Therefore, it is proposed to categorize the GIS into two types according to its dimension. The ordinary 2-dimensional GIS which is used for representing 3-dimensional variables by using graphics and charts is defined as “pseudo 3-dimensional GIS”. On the other hand, if the available data is used and real 3-dimensional modelling is obtained it is defined as “real 3-dimensional GIS”. Both of this proposed GIS types are used in this study for the preparation of engineering geological maps and evaluation of the prepared maps.

STUDIED AREA

Istanbul is not known only the biggest city of Turkey but it is also among the top ten cities of the world. The studied area, which the pseudo and real 3-dimensional GIS applied is one of the municipalities of Istanbul. (as illustrated by figure 1). The name of this municipality, Kadikoy is one of the biggest municipality of Istanbul. The aerial coverage of Kadikoy is approximately 33 km^2. The population is around 1.000.000. It is in the Asian side and is connected to the European side by ferry.

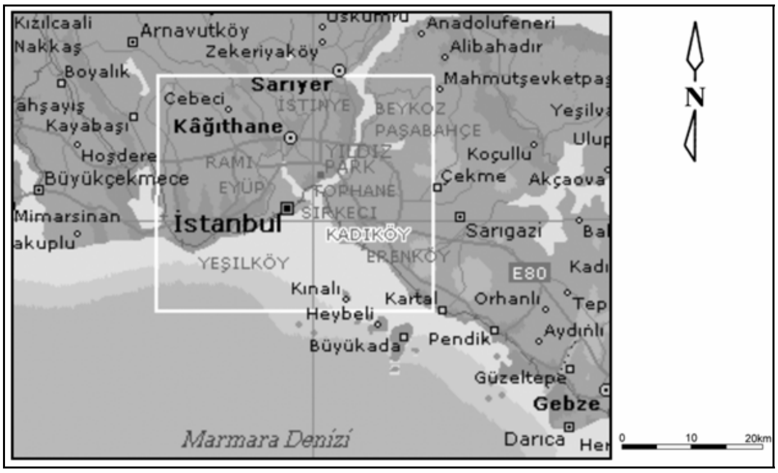

Figure 1: Location map of the Kadikoy municipality.

METHODOLOGY

As it is mentioned above 3-dimensional GIS was used as a powerful tool in the study. Because 3-dimensional GIS provides map that looks like real and in addition to that, the most important fact that it was used in this study is for modeling bore hole data.

3-dimensional GIS are created in each points which has X and Y coordinate values and at least one and generally more than one Z values. Generally these Z values are correspond to the bore holes data which gives physico-mechanical properties of the soil for geotechnical studies.

GIS was considered to have four main segments in this study as proposed by Gupta (1991) for geoscientific studies. (1) input, which deals with creating image-based GIS, from multi geo-data sets, (2) management, the purpose of which is efficient to storage and retrieval of data, (3) processing, data manipulation, feature enhancement and classification, etc. and (4) output, which provides thematic maps, images etc. for application.

At first, all the digitized maps and the interested data were collected from different organizations. These maps are geological map, road map and 1/1.000 scale city plans. In addition to these maps, soil drilling log data were obtained and database which indicates the physical properties of the soil were prepared. As it known primarily, “at the heart of any GIS is the database”. (Worboys and Duckham, 2004) Most time was used for the preparation of database in this study. Co-registration of maps, which is one of the general processes for GIS study, was processed. All maps were projected on the same projection and with the same scale. Consequently, the application and evaluation of 3-dimensional GIS by using these maps and data, which is the title of this study, were carried out. At first, ordinary 2-dimensional GIS with its third dimension possibilities, defined as pseudo 3-dimensional in this paper were used. Then, real 3-dimensional GIS was applied.

Pseudo 3-Dimensional GIS Applications

The geological map, which shows the different lithologies and road map were overlaid each other. The boundaries of the quarters are also seen on this map (as illustrated by figure 2). The data, which were collected from the drilling logs, were used in the 2-dimensional GIS and charts helped for the indication of the depth change on the engineering geological map.

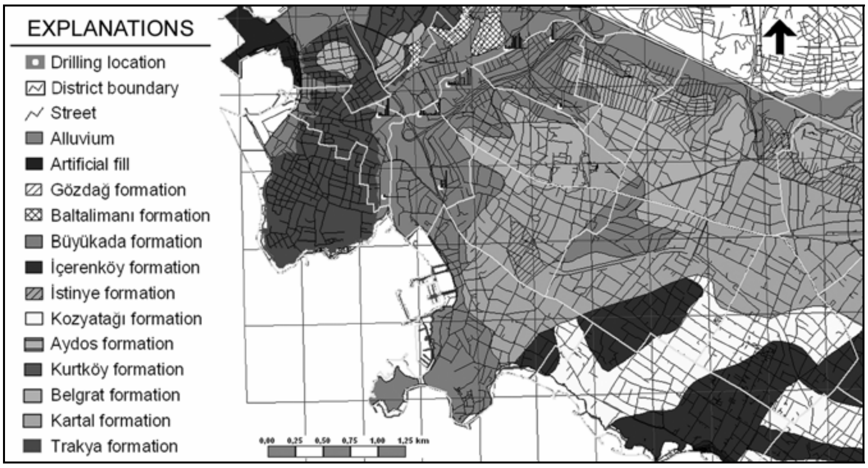

Figure 2. Lithological boundaries, roads and quarter boundaries of the Kadikoy can be seen easily.

Figure 3. All the information about the selected location (with a dot) on the map and data window can be seen at the same time.

Alluvial deposits cover the gray colored areas. These uncemented loose deposits, generally called as soil, has physical and index properties, which are used for construction of buildings. These disturbed and undisturbed samples are mostly obtained from the soil drilling. Therefore, these data must be located perpendicular to the map sheet. It is not easy to show this situation on a 2-dimensional map surface. Using charts, bars drawing capability of 2-dimensional GIS, it is very comfortable to give third dimension to an ordinary 2-dimensional GIS. Important physical and index properties of the soil can be evaluated by using these charts and bar graphs. Even accessing the database of the specific location and getting all the information for the construction is obtained only by one click (as illustrated by figure 3).

In the alluvial deposits of the studied area, the changing of standard penetration test (SPT) results with respect to depth is represented by bar graphs (as illustrated by figure 4).

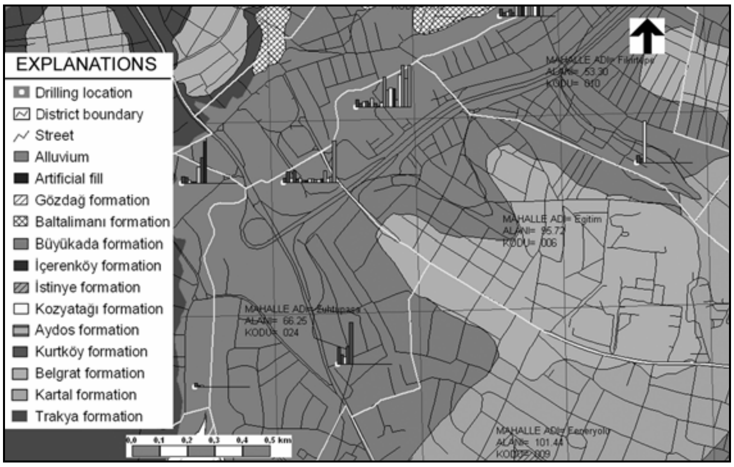

Figure 4. Presentation of the depth variables by using bar charts on the 2-dimensional GIS sheet.

In this figure 4, the increasing of SPT result with depth is indicated by the increasing of bar graph values. The SPT reaches the highest value at the lower depth in the middle of the alluvial deposits. On the other hand, it is obviously seen that SPT values reaches to high values at the zone close to the rock. Presentation of this data on an ordinary type engineering geological map is not available, but the presentation is very clear by using this type of pseudo 3-dimensional GIS. Low SPT values are seen from the graphical presentation in figure 4 indicates risky areas according to earthquake hazard. Generally these are located at the middle part of the studied area.

Real 3-Dimensional GIS Applications

Generally real 3-dimensional GIS applications are mostly used for geoscientific studies. The real 3-dimensional GIS can provide functionality for creating, managing, manipulating and analyzing 3-dimensional data. This type of GIS can accept any dataset contains X, Y and Z geometry and multiple data values. A dataset can be a 3-dimensional volume in the air, water or ground.

3-D grids are used to locate and reference the data points in 3-D volumes. Each grid intersection is called a grid node. A voxel, means volume elements in 3-D as opposed to pixel, is a 3-D sub-volume delineated by eight neighboring grid nodes. Voxels are the smallest elements in a 3-D volume. So, a 3-D volume is composed of numerous voxels (Anon., 1994).

The real 3-dimensional GIS were applied to the same studied region. The attribute, which was used as in the z-direction (depth), is based on soil grain size. The changing of grain size with the depth is obviously seen in the studied area (as illustrated by figure 5).

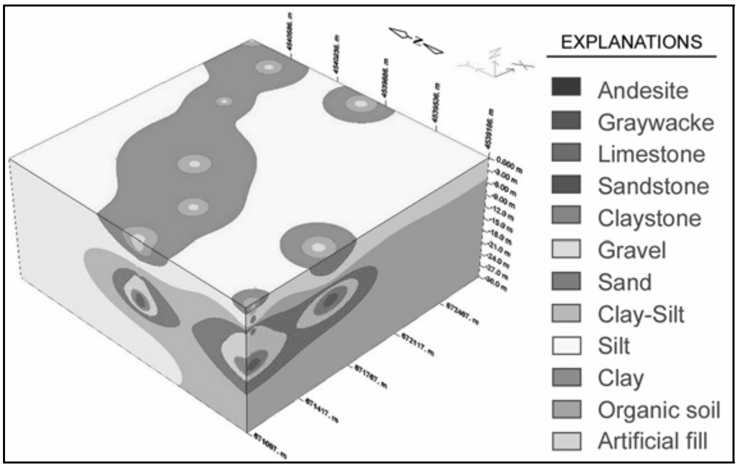

Figure 5. The variation of grain size with depth is seen on this real 3-dimensional volumetric diagram.

The elongation of clay deposits from south to north corresponds to the river channel. The location of sand and gravel concentrations are obviously visible on the volumetric diagram, which is not possible to observe from the top of the surface. Volume elements of the interpolated data can be obtained as opposed to pixel which means picture elements in 2-dimensional GIS. 3-dimensional GIS provides a suite of interpolation algorithms or methods to assist users for evaluating geoscientific data. By using interpolation algorithm, it is possible to obtain cutting chair shape of volumetric data and make interpretation about the interior of the volume (as illustrated by figure 6). The volumetric extend of the clay deposits is easily seen from the notch cut of the corner.

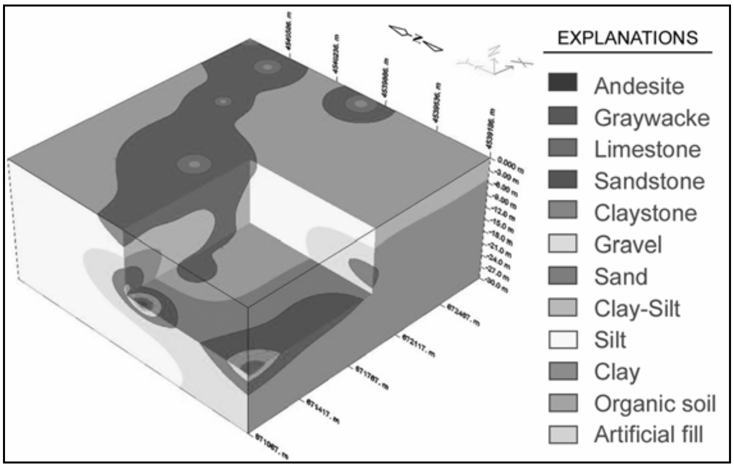

Figure 6. The interior of the interpolated data is seen from the notch cut of the volumetric data.

RESULTS AND RECOMMENDATIONS

It is seen that, for project like preparation of engineering geological map which use data such as multiple points from one boreholes and three-dimensional geotechnical data 3-dimensional GIS is needed.

At the end of this study it is understood that, “pseudo 3-dimensional GIS” and “real 3-dimensional GIS” are needed for the preparation of engineering geological maps. The complicated structure of these maps can be solved by using these kind of GIS. GIS fills the real need of this rapid growth of spatial data in this field.

“Pseudo 3-dimensional GIS” is the new term proposed by the authors and defined as ordinary 2-dimensional GIS with some complementary graphs and charts which are used as the presentation of the third dimension. “Real 3-dimensional GIS” has the capability of more realistic visualization. Three-dimensional visualization of the real world would give the GIS applicants a more realistic sight and more realistic conclusion. The location of subsurface structures are obviously visible on the volumetric diagram in the real 3-dimensional GIS.

As a recommendation, 3-dimensional GIS, whether it is pseudo or real 3-dimensional GIS must be used for the preparation of engineering geological maps and every other geoscientific studies. It is also recommended that, do not confuse the digital elevation modelling process as a 3-dimensional GIS.

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