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Research Article

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Geological spatial based modelling for economic imperatives in preliminary site investigation

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Highlights

- The data processing for engineering geological mapping
- Image classification methods for producing digital geological maps
- Analysing the site suitability for geological point of view by creating maps
- Understanding preliminary site investigation

Abstract

The alignment and general layout of the transportation corridors in the natural landscape have a major influence on slope, geology, environmental effects, resource consumption, and structural engineering costs. Transportation infrastructure is also strongly related to a number of sustainability concerns of primary policy relevance. Planners and engineers can use urban geology's information on urban geologic environments as a scientific foundation for proper land use planning and transportation development. Such mapping can be categorized according to its scale, content, and purpose. This study uses Istanbul's engineering geological mapping process as a case study. The Geographic Information System (GIS) was used to build the input layers (slope, topography, and lithology), which were then integrated to create engineering geological maps. A suitability map is used to display the results. The study area was thus divided into two categories: favorable and unfavorable. A spatial representation of intricate geological systems is provided by these segmentations. This study aimed to demonstrate a more thorough investigation of the target region in order to assess the imperatives that need the selection of places for building. Site-specific research, including in-situ and laboratory tests, should expand on the findings of this study in order to determine the necessary parameters for the constructions of greater significance.

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1. Introduction

Engineers are seeking to have the capability to characterize the surface and subsurface conditions in an urban area when they are working on structural geotechnical, geological and groundwater modeling, natural hazard prediction and comprehension, and environmental problem remediation. Big data analytics and smart cities have been more popular in recent years, demonstrating their connection. Databases include data from various sources utilized to automate decision-making, execute performance management, and forecast future behavior with ever-increasing precision. Combining a large amount of data from many sources is the aim of the smart city concept. Effectively storing and analyzing data in a database has made database applications a crucial component of municipalities and survey analysis processes for raising the bar for urban planning decision-making. In order to establish safe urban design and development, numerous studies have carried out for geological evaluations. The classification of geological and geotechnical datasets are valuable due to a variety of unexpected conditions pertaining to the construction of geotechnical structures.

Databases allow for a growing number of applications, and because they make it simple and rapid to retrieve data, they are especially popular in a variety of scientific fields. The significance of data analysis for geotechnical work planning and construction is demonstrated by the large number of databases devoted to engineering geological data that are utilized globally. There are geotechnical databases for a variety of geographic extents, including counties, cities or municipal areas, particular project sites, and bigger geographic areas like subcontinents or even entire continents.

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Big data has the power to drastically alter urban populations on several levels. A key component of success in many service fields, including applications for smart cities, is the efficient analysis and use of big data. One of the primary unresolved concerns that must be looked into and resolved in order to obtain a more complete picture of sustainable smart cities is the consequential relationship and efficient management of geotechnical information. Consequently, the accurate and exact determination of these datasets will help decision-makers plan for the growth of both surface-level and subterranean intelligent city projects [1].

In order to illustrate how an approach that combines the development of a comprehensive engineering geological database with GIS techniques, a case study is described in this paper. This implementation aims to create a practical adaptation with stimulating explanatory information for the design and construction of geotechnical works. Additionally, it provides the civil protection agency with comprehensive geoengineering data to manage and safeguard its citizens from particular geohazards. A crucial component of this research is the use of GIS to create thematic maps of diverse mechanical and physical characteristics, which offer seeing intuitively the engineering geological characteristics of formations at different depths. Using a range of geological and geotechnical datasets obtained from borehole recordings, the GIS application offers strong potentiality for visualization, spatial analysis and modelling in addition to the fundamental features for data processing and mapping issues.

The selection of database applications follows the assessment and admeasurement of engineering geological properties. The use of multi-hazard maps in urban development is highlighted for the database employment, along with the eventuality of engineering geological maps.

Geological conditions must be taken into account and evaluated prior to any design or construction of UUS (Urban Underground Spaces). To guarantee the safety and dependability of infrastructure construction, a thorough understanding of the geological conditions is necessary due to their potential complexity and unpredictability. It is crucial to carry out a comprehensive analysis of geological conditions and complete the data in order to lessen the impact of uncertainty on the UUS [2].

Using GIS and MCDA techniques, Ustaoğlu et al. [3] developed a spatial model for evaluating land suitability in peri-urban agricultural growth. In the research area, elemantary attributes, land use, natural resources, accessibility, geology and soil conditions were found to be important determinants of site appropriateness for peri-urban agriculture.

2. Methodology

2.1. The data processing for engineering geological mapping

Environmental, engineering and geotechnical engineers find databases extremely useful for the planning, design and construction of railway projects and natural hazard mitigation. A collection of discrete datasets organized in tables using a hierarchical method is called a database. Each database's primary structure and the connections between its tables are expressed through a unique description. In the database, every entry has a unique identity. Therefore, information can be separated at any time based on the field in which it is registered.

The core of the research approach is the database, which imports, analyzes, and correlates all data in its surroundings. The primary steps that make up the database are shown in a flowchart (Figure 1) along with the connections between them. Base map preparation and thematic map generation for geological suitability analysis are included in this work. Accuracy and resolution, as well as the nature of the topic to be studied, should be taken into consideration while choosing data sources. Slope and elevation databases are contained within the topography category. "Lithology of bearing layer, Formation combination, and Surficial geology" are the ground conditions. The evaluation of geological hazards must take into account the distance to debris flow, distance to landslides, liquefaction potential, and distance to faults. Groundwater statistics include "Depth to groundwater table, Corrosive potential of groundwater, Groundwater rise" [4]. One crucial issue is aligning pathways in intricate geological settings while reducing geohazards. Using information from remote sensing and field research, Zhao et al. [2] analyze route ideas according to geological background, including landforms, lithology, geological tectonics, and the distribution of geohazards.

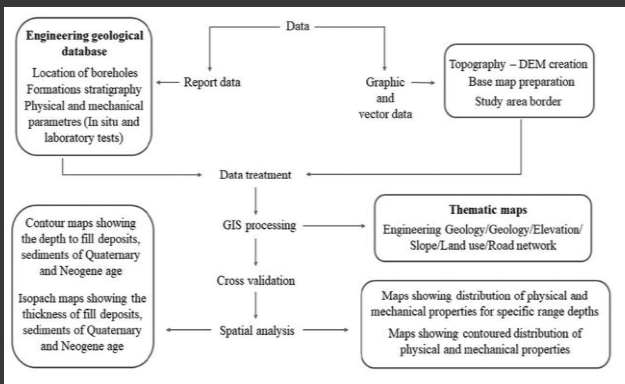

Figure 1. Flowchart of data processing

A basic map of surficial materials, interpretative maps, and data on resources and earth conditions were all created using the results of the geologic research. The following topics are included in geologic studies: (1) Fundamental geology, encompassing the subsurface stratigraphy of unconsolidated deposits as well as the relationship between soil and surficial geologic units (2) Groundwater geology, including the presence and characteristics of bedrock aquifers and glacial drift, and their relationship to waste disposal conditions (3) Mineral resources, including the presence and characteristics of clay deposits, peat deposits, sand and gravel, and borrow materials (4) Engineering geology, encompassing the hydrogeologic properties of earth elements in connection with building operations [5].

In order to address these issues, He et al. [6] presented a novel geological–geotechnical zoning framework that makes use of sparse data and is crucial for construction design, underground space development, and urban planning. There are five steps in the framework for combining geological and geotechnical data (Figure 2). In order to comprehend the underlying geological condition and evolution, the approach usually starts with geological desk study. This is followed by a macro examination of the surface strata in the metropolitan area. By identifying and classifying geological units according to dominating features and measurable standards, the previous analysis is utilized to enhance geological classification. Standardized boreholes are used to investigate the subsurface layers of each geological unit in order to gather thorough geological and geotechnical data. Determining the physical, strength, and deformation qualities is part of this. In order to produce an engineering geological zoning map, the last phase entails assessing the potential risks of soil and rock strata and combining the data.

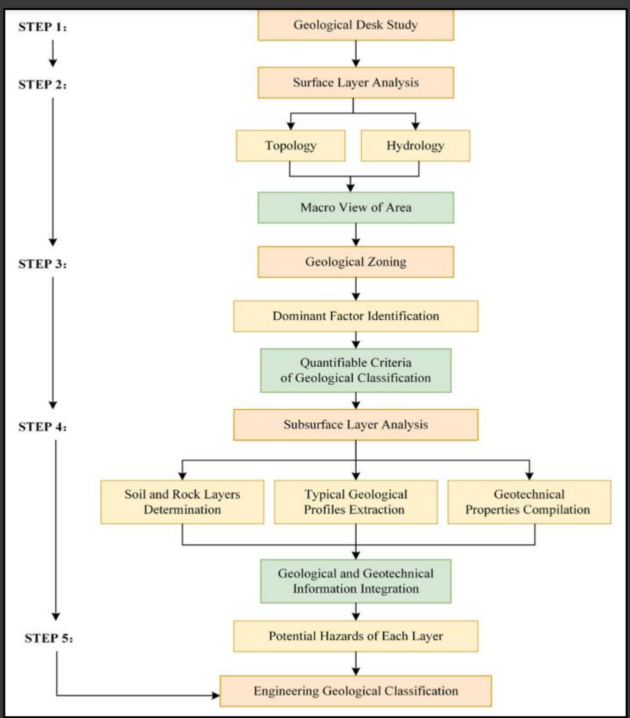

Figure 2. Flowchart of integrative geological–geotechnical classification framework

2.2. Engineering geological zoning

Three types of engineering geological zoning are distinguished: stability, appropriateness, and characteristic. In a researched area, characteristic zoning assesses engineering geological elements that restrict construction. Engineering geological and hydrogeological factors of a studied area are evaluated through suitability zoning. Stability zoning assesses the region under study for active fractures and adverse geological impacts. Suitability zoning includes engineering geology zoning and the evaluation of major infrastructure locations. A borehole engineering geological suitability index (BEGSI) was computed by Yang et al. [7] for the purpose of designating and assessing large-scale infrastructure locations. The BEGSI is a mathematical model based on the rock engineering system method and the geological data uncovered by the thorough exploration. This model is used to quantitatively carry out large-scale infrastructure site engineering geological suitability zoning and evaluation. Some methods for engineering geological zoning are given in Table 1.

Table 1. Engineering geological zoning methods.

Method	Application	Source
Variable-weight theory (VWT)	zoning method for Environmental engineering geological patterns (EEGPs)	[8]
Geographic information system (GIS)	Use of GIS technologies for zoning Urban areas by considering engineering-geological conditions	[9]
Remote sensing technology	Application of Remote Sensing Technology in Engineering Geological Surveying	[10]
Weighted model-based geological evaluation models and enhanced alignment with urban planning objectives	Resourceful geological–geotechnical zoning framework for urban planning: Wuhan’s experience	[6]
The settlement suitability of the municipal area by means of MCDA and geographic information systems (GISs)	Geotechnical land suitability assessment using spatial multi-criteria decision analysis	[11]

2.3. Image Classification Methods

The two types of classification techniques—pixel-based and object-based—can be separated based on the minimal classified feature [12].

Pixel-based classifications use radiometric properties to assign each pixel to a particular class. Salt-and-paper noise is frequently seen when using this method, particularly when classifications are based on high spatial resolution satellite images.

Satellite imagery segmentation is the initial stage of object-based classification. Segmentation is the process of breaking down a digital image into more manageable, uniform pieces (objects) with comparable properties. Adjacent pixels with comparable radiometric properties make up each item. The size and shape of objects can be changed to better represent the real world, or earthly objects. Each object is given statistical indicators based on the values of all the pixels it contains once it has been classified. Object classification using supervised, unsupervised, or hybrid approaches is the second phase.

Using ArcGIS software 10.8, "supervised" and "unsupervised" picture classification techniques were employed to create a thematic geological raster map.

Three areas have seen significant advancements in image categorization over the past few decades: (1) the use of complex classification algorithms (2) the use of a variety of remote sensing features (3) the incorporation of auxiliary data. Accuracy assessment is a crucial step in the picture categorization process. The most widely used method for measuring per-pixel classification accuracy is based on the error matrix, although fuzzy techniques are becoming more popular for evaluating fuzzy classification outcomes. Classification accuracy is significantly impacted by uncertainty and error proliferation across the image processing series. Improving the classification accuracy requires first identifying the unfunctional links and then lowering the uncertainty. Future picture categorization research will focus heavily on the analysis of uncertainty [13].

2.4. Building the Geological Thematic Map of the studied area

Istanbul Geological Map (1/100 000) jpeg format file were taken from the Directorate of Eartquake and Geotechnical Investigation [14] and the jpeg map file was coordinated via ArcGIS Georeferencing. Figure 3 shows the image file of Istanbul's geological map. In order to create a thematic map, the geological map must be digitized. For this purpose, the image file was converted in raster data format and classified according to its geological properties by using the 'Image Classification' feature in the ArcGIS program (Figures 4 and 5).

Point data file is produced for Beyoğlu region by Conversion tools as shown in Figure 6. *(From Raster to Point)* Reclassified geological point data file is shown in Figure 7.

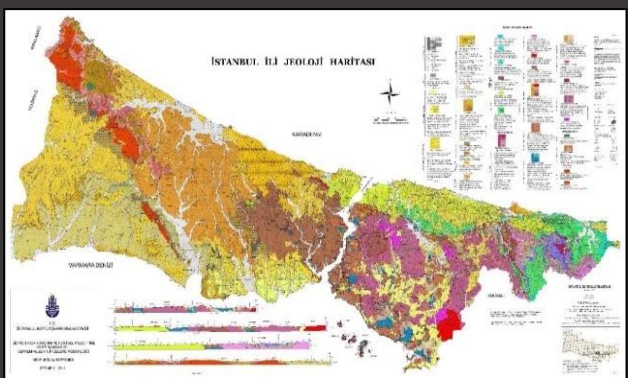

Figure 3. Geological Map of Istanbul Metropolitan Area

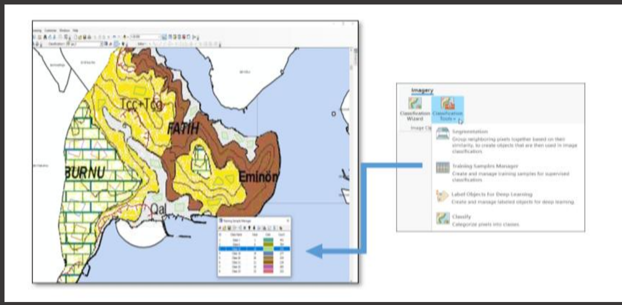

Figure 4. Supervised Classification (Training Sample Manager)

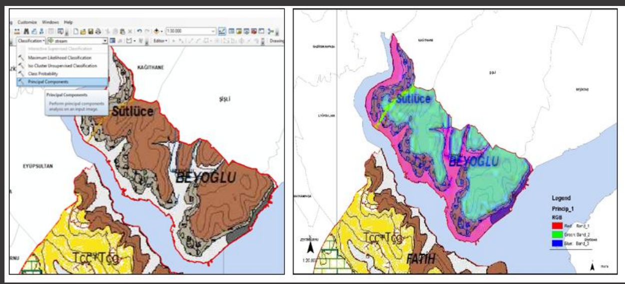

Figure 5. Principal Components

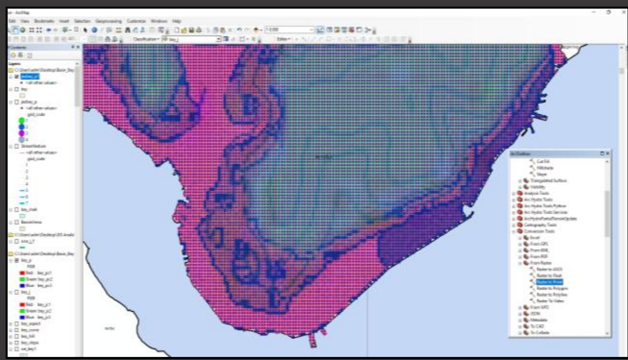
Figure 6. Point data

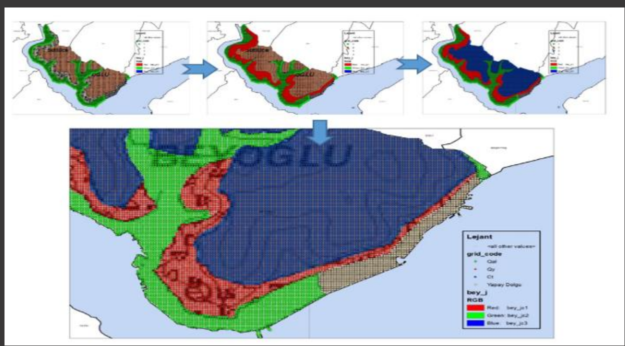

Figure 7. ReClassified Geological Point Data for Beyoğlu Region

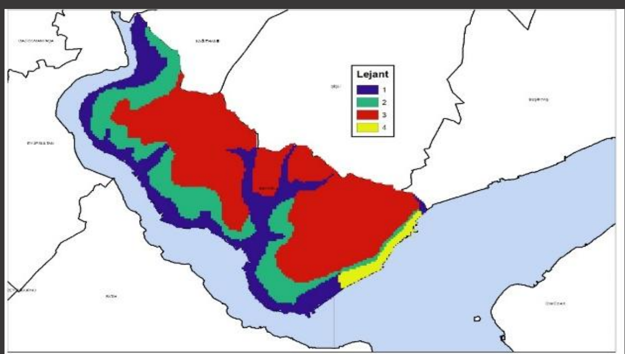

Figure 8. Geology raster data file for Beyoğlu region

Geology point data produced and classified for Beyoğlu district and then converted to raster data format with Conversion Tools. (Point to Raster) The final geology raster data document is shown in Figure 8.

2.5. Lithology Types and Decriptions

The study area have two main lithology tpyes. The first one is alluvium and artificial fill layers (Quaternary deposits) and the second one is Trakya formation Claystone. The stratigraphy of the tertiary deposits of Istanbul are given in Figure 9.

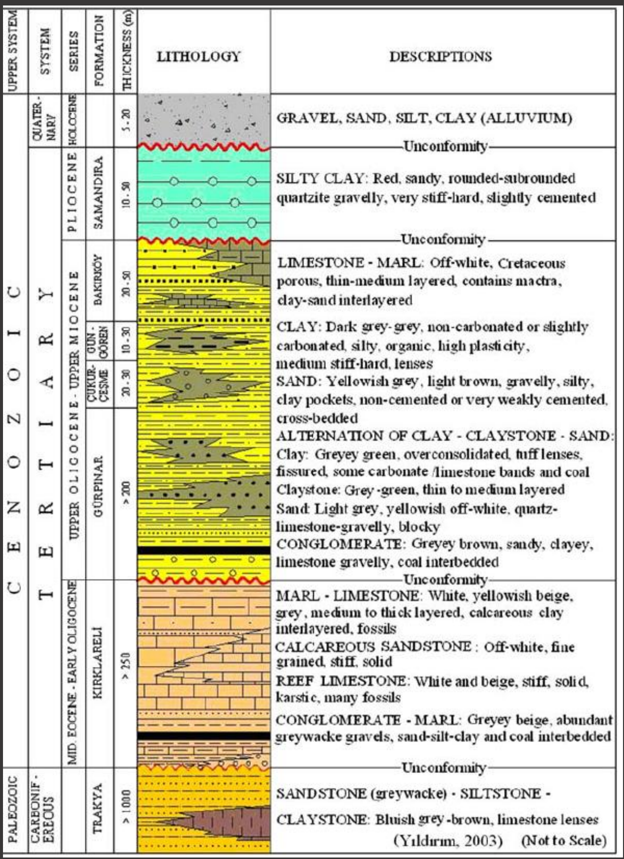

Figure 9. The stratigraphy of the tertiary deposits of Istanbul [15]

The study area was categorized into two different zones as: (1) unfavorable area; (2) favorable area (Figure 10). We calculated the area of the unfavorable and favorable areas. Favorable areas approximately 4883 square meters and unfavorable areas are calculated as 4185 square meters.

3. Discussion and Conclusion

Facilities that need substantial engineering and capital expenditure to finish are referred to as large-scale infrastructure. With steady and consistent functioning, it can be used to accomplish long-term objectives and tasks. Large-scale infrastructure sites encounter complex geological circumstances due to national strategy and limited land resources. For project setting, environmental evaluation, land acquisition, construction and operation, engineering geological zoning and analysis of large-scale infrastructure sites under complicated geological circumstances are essential.

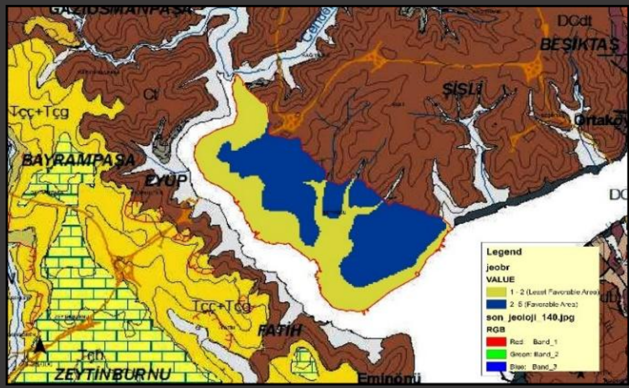

Figure 10. Favorable areas for study region

A digital geological map can be used to organize efficient field traverses for initial site exploration, which may improve geological interpretations. This makes it possible to identify areas of interest and potential structural patterns in the region. GIS The sustainability performance of transport infrastructure planning is improved by using the image pixel classification methodology to create methodologies for transportation planning where corridor design and location are based on geological sustainability criteria. Representative codes were assigned after a reclassification of the various lithologic categories that were transformed into a raster layer. For the best area extension, decision makers and engineers can utilize this final, user-friendly map.

Techniques for 3D geological modeling, 3D-GIS, and BIM have advanced quickly and are now widely used. There are five steps in evaluating 3D geological suitability: (1) gathering and integrating data; (2) building 3D geological models using implicit 3D geological modeling with geological data from multiple sources; (3) creating a 3D evaluation index system, taking into account local geological conditions based on the data that is available; (4) producing 3D thematic maps from the 3D geological models using 3D spatial analysis techniques; (5) producing 3D geological suitability maps, integrating all the 3D thematic maps using thorough evaluation techniques [16]. These methodologies include a range of approaches for spatial analysis, model building, data integration, and 3D data visualization.

The goal of microzonation is to lower a region's potential disaster threat through controlled land use. By studying geological, geophysical, and geotechnical characteristics against earthquake threat, microzonation is utilized to develop economically, socially, and politically suitable and useful zones in order to give planned and accurate land utilizing plans. One of the most widely used metrics in seismic hazard assessment and risk evaluation is microzonation, which is the zonation of ground motion characteristics while accounting for source and site variables. Seismic microzonation studies look at things like surface faulting, water floods, slope stability, liquefaction, ground amplification, and ground motion level.

Multidisciplinary studies known as microzonation studies serve as a foundation for planning initiatives aimed at assessing the risk of disasters in both developed and developing regions. They are also used to establish convenient and favorable goals, objectives, and preferential rating for urban rejuvenation and mitigation planning, as well as to make appropriate judgments regarding land use and zoning. Urban planning and land use management can benefit from microzonation, which is the process of identifying locations with varying seismic hazard potential [17]. Furthermore, Microzonation is necessary to integrate the three fundamental elements of structural, geotechnical, and seismology engineering. The third component of this analysis, known as the road vulnerability level, focuses on evaluating the region's roads' potential for damage.

The visualization and evaluation of massive, multi-source, multi-dimensional, heterogeneous, dynamic, and complex spatial data is attractively more crucial in 3D scene and geological modeling. Regarding data collection methods, morphological descriptions, and the intended uses of spatial objects, there are significant variations among different research domains. Researchers can identify and comprehend engineering geological information by using geographic information systems (GIS), which are specialized tools for gathering, storing, managing, analyzing, and expressing spatial data. Multiple sectors have taken advantage of its effective spatial analysis function and spatial data management capability, including digital land use analyses, digital geographic research, digital explorations, digital hydropower projects, digital disaster modeling, digital mine technologies, digital oil field technologies, and more [18].

Geological sustainability considerations were done in my previous search for the selection of railway alignment. Using ArcGIS software 10.8, image classification algorithms were tested as "supervised" and "unsupervised" classifications for the purpose of constructing thematic geological raster maps. Classification accuracies were insufficient for the segmentation of lithologic units due to the poor resolution of the input data file and the dissimilar areas with diverse constituents. This is why poligon lines are manually drawn from the boundary lines as part of the lithologic segmentation/geologic formation database building procedure. Following the creation and modification of the geo_poligon shape file, the lithologic formation data type and quality score were entered, and the poligon data file was subsequently transformed into raster format. The geological suitability mapping of a potential railroad line is displayed in Figure 11.

Figure 11. Geological suitability of an candidate railway line [19]

To sum up, Suitability analyses for settlement regions are the final maps created after evaluating all of the semi-product maps (local soil classes, etc.), final hazard maps (soil expansion, liquefaction, etc.), and raw data maps (geology, slope, subsurface water maps, etc.) created by the studies. In addition, these maps have engineering notes added to them. For road structures like viaducts, bridges, etc., a thorough site-specific research must be carried out at each location during the design phase in order to assess the local site conditions.

Every building site has different environmental, hydrological, and geological conditions. Understanding these variables through site assessment is crucial for figuring out the project's overall viability, structural soundness, and foundation design.

Engineers can optimize the design of structures to guarantee stability, longevity, and cost-effectiveness by gathering data on groundwater levels, soil characteristics, and other site-specific parameters. In a multidisciplinary approach, projects can be analyzed by integrating or incorporating many specialists or specialties.

By customizing the design to the unique site conditions, design optimization lowers the chance of structural failure and the need for expensive repairs. Geographic Information Systems (GIS) enable digital geologic mapping in the field in this way. These systems are still widely used due to their user-friendliness and ease of duplicating data for teamwork or field classes.

Digital geological maps are useful for showing a more thorough examination of the target area and can be used to describe the imperatives (motivating reasons) that make it vital to choose appropriate sites for building during the initial site inspection. For further developments for this study; different image-classification techniques can be tested according to the study's objective and Site-specific research should be added, including in-situ and laboratory tests for comparing on the findings and crosschecking the results of this study in order to determine the necessary parameters for the constructions of greater significance.

Declaration of Interest Statement

The author declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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