

T.R.
GEBZE TECHNICAL UNIVERSITY
GRADUATE SCHOOL

V_{s30} PROXY MODEL FOR KOCAELİ REGION



MESUT SERT

A THESIS OF MASTER OF SCIENCE
CIVIL ENGINEERING DEPARTMENT
EARTHQUAKE AND STRUCTURAL ENGINEERING
PROGRAM

ADVISOR: ASSOC. PROF. ABDULLAH CAN ZÜLFİKAR

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LİSANSÜSTÜ EĞİTİM ENSTİTÜSÜ

KOCAELİ İLİ İÇİN TAHMİNİ V_{S30} MODEL
OLUŞTURULMASI

MESUT SERT

YÜKSEK LİSANS TEZİ
İNŞAAT MÜHENDİSLİĞİ ANABİLİM DALI
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*To my
wife and son*

ABSTRACT

One of the most significant causes of damage and destruction following earthquakes is the local soil conditions. Neglecting local soil investigations, inadequate seismic design of structures, improper use of materials during construction, failure to establish a healthy relationship between the structure and the ground, or deficiencies in workmanship can all exacerbate the damage and destruction. Prioritizing local soil properties is especially crucial during the construction of new buildings. The degree of potential damage is directly related to the dynamic properties of the soil; therefore, accurately identifying soil characteristics during construction is essential to minimize earthquake damage. Geological findings, geophysical methods, and geotechnical data obtained from laboratory and field tests should be collectively evaluated when classifying soil.

In my thesis study, a correlation was established between 90 V_{s30} values obtained using geophysical methods in the Kocaeli province and SPT-N values obtained from nearby measurements. This correlation was then applied to estimate V_{s30} values for 1212 SPT-N Standard Penetration Test data points. The V_{s30} value represents the average shear wave velocity of a soil profile up to 30 meters deep and is a crucial parameter in soil classification. SPT-N values, on the other hand, are another important parameter used to measure soil resistance.

Additionally, in the study, three methods (Terrain Category, Slope Method, and Geological Category) were emphasized to develop an estimated model using Geographic Information Systems (GIS). These methods were used to evaluate the geographical distribution of soil properties and other significant factors in determining soil classes.

Accurately evaluating local soil conditions and carefully examining soil properties is of great importance in minimizing earthquake-induced damages. This study aims to contribute to soil classification and earthquake engineering applications. By correctly identifying soil properties and implementing appropriate engineering practices, the earthquake resilience of structures can be enhanced, thereby minimizing loss of life and property.

Keywords: V_{s30} , SPT-N, Terrain Category, Slope Method, Geological Category.

ÖZET

Depremler sonrasında meydana gelen hasar ve yıkımların en önemli nedenlerinden biri yerel zemin koşullarıdır. Yerel zemin etütlerinin ihmal edilmesi, yapıların yetersiz deprem tasarımı, inşaat sırasında malzemelerin hatalı kullanımı, yapı ile zemin arasında sağlıklı bir ilişkinin kurulamaması veya işçilikteki eksiklikler hasar ve yıkımı artırabilir. Yeni binaların inşası sırasında yerel zemin özelliklerinin önceliklendirilmesi özellikle önemlidir. Potansiyel hasarın derecesi doğrudan zeminin dinamik özellikleri ile ilişkilidir; bu nedenle, inşaat sırasında zemin özelliklerinin doğru bir şekilde belirlenmesi, deprem hasarını en aza indirmek için gereklidir. Zemin sınıflandırmasında jeolojik bulgular, jeofizik yöntemler ve laboratuvar ile saha testlerinden elde edilen jeoteknik veriler birlikte değerlendirilmelidir.

Tez çalışmamda, Kocaeli ilinde jeofizik yöntemler kullanılarak elde edilen 90 V_{s30} değeri ile yakın ölçümlerden elde edilen SPT-N değerleri arasında bir korelasyon kurulmuştur. Bu korelasyon daha sonra 1212 SPT-N Standart Penetrasyon Testi veri noktası için V_{s30} değerlerini tahmin etmek amacıyla uygulanmıştır. V_{s30} değeri, bir zemin profilinin 30 metre derinliğe kadar olan ortalama kesme dalgası hızını ifade eder ve zemin sınıflandırmasında önemli bir parametredir. SPT-N değerleri ise zemin direncini ölçmek için kullanılan bir diğer önemli parametredir.

Çalışmada ayrıca, Coğrafi Bilgi Sistemleri (CBS) kullanılarak bir tahmin modeli geliştirmek için üç yöntem vurgulanmıştır: Arazi Kategorisi, Eğimi Yöntemi ve Jeolojik Kategori. Bu yöntemler, zemin özelliklerinin coğrafi dağılımını ve zemin sınıflarının belirlenmesinde kullanılabilecek diğer önemli faktörleri değerlendirmek için kullanılmıştır.

Yerel zemin koşullarının doğru bir şekilde değerlendirilmesi ve zemin özelliklerinin dikkatlice incelenmesi, deprem sonrası hasarları en aza indirmek adına büyük önem taşır. Bu çalışma, zemin sınıflandırması ve deprem mühendisliği uygulamalarına katkı sağlamayı amaçlamaktadır. Zemin özelliklerinin doğru bir şekilde belirlenmesi ve uygun mühendislik uygulamaları ile yapıların deprem dayanıklılığı artırılabilir, böylece can ve mal kayıpları minimize edilebilir.

Anahtar Kelimeler: V_{s30} , SPT-N, Arazi Kategorisi, Yamaç Yöntemi ve Jeolojik Kategori.

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LIST OF SYMBOLS AND ABBREVIATIONS

V_{s30}	: Average shear wave velocity
SPT-N	: Standart Penetration Test Number
NAF	: North Anatolian Fault
GIS	: Geographic Information Systems
SPT	: Standart Penetration Test
NAFZ	: North Anatolian Fault Zone
SCPTU	: Seismic Cone Penetration Test
V_s	: Shear wave velocity
MASW	: Multichannel Analysis of Surface Waves
ReMi	: Refraction Microtremor
GMPE	: Ground Motion Prediction Equation
CENA	: Central and Eastern North America
PDB	: Profil Database
DEM	: Digital Elevation Maps
SCPT	: Seismic Cone Penetration Test
V_{sz}	: with z representing the averaging depth
NGA	: National Geospatial-Intelligence Agency
SRTM	: Shuttle Radar Topography Mission
SASW	: Spectral Analysis of Surface Waves
UBC	: Uniform Building Code
NEHRP	: National Earthquake Hazards Reduction Program
EC8	: Eurocode 8
TÜBİTAK	: The Scientific and Technological Research Council of Turkey
TADAS	: Turkey Strong Motion Database and Analysis System
AFAD	: Disaster and Emergency Management Authority
SSE	: Sum of Squared Errors
RMSE	: Root Mean Square Error
m/sn	: meter/second

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1. INTRODUCTION

After earthquakes, one of the primary causes of damage and destruction is local ground conditions. Neglecting ground investigations, inadequate seismic design of structures, improper use of materials during construction, or poor workmanship exacerbate damage and destruction. Particularly during the construction of new buildings, local ground characteristics should be prioritized. Since the extent of potential damage is directly related to the dynamic properties of the ground, it is essential to accurately define these properties during the construction of structures to minimize earthquake damage. Geological findings, geophysical methods, and geotechnical data obtained from laboratory and field experiments should be evaluated together when classifying the ground.

As part of this thesis study, a correlation was established between 90 V_{s30} values obtained using geophysical methods and SPT-N values obtained from close-distance measurements for Kocaeli province. This correlation was then applied to 1212 SPT-N (Standard Penetration Test) data to estimate V_{s30} values. Additionally, three methods (Terrain Category, Slope Method, and Geological Category) were attempted to create a proxy model using Geographic Information Systems (GIS).

1.1. The Purpose, Scope, and Goals of This Study

The aim of this study is to accurately predict the local ground class for a city like Kocaeli, which has high industrial and population density, located on the North Anatolian Fault (NAF) line, and to plan construction accordingly.

Geophysical data obtained during seismic fracture analysis and Standard Penetration Tests (SPT) conducted during drilling operations were considered in the study. The field test data, including both drilling and geophysical measurement locations, were transferred to a database based on their geographical coordinates. Using coordinate data, V_{s30} values obtained through different methods (seismic fracture data and SPT-N data) were utilized to create V_{s30} shear wave velocity and ground class maps for the study area. The generated maps were evaluated in relation to the region's geology.

Ultimately, the accurate characterization of Kocaeli's soils is pivotal in reducing potential earthquake damages and establishing a reliable settlement area.

1.2. Introduction of the Study Area

Kocaeli is located in the Çatalca-Kocaeli Section of the Marmara Region, between 29°22' and 30°21' east longitude, and 40°31' to 41°13' north latitude. It is bordered by Sakarya to the east and southeast, Bursa to the south, Yalova province to the west, the Gulf of İzmit, the Sea of Marmara, and İstanbul province to the west, and the Black Sea to the north. The 30° east longitude passing east of the city center of İzmit is considered the reference for Turkish time as shown **Figure 1.1**.



Figure 1.1: Location of Kocaeli Province within the borders of the Country
(Kocaeli Governorship, 2020).

Kocaeli is surrounded by the Black Sea to the north, Bursa to the south, İstanbul to the west and northwest, and Sakarya to the east as shown **Figure 1.2** The Kocaeli Plateau in the north has few hills, while mountains cover 18.8% of the province's land, with isolated hills in the northern part and the Samanlı Mountains in the southern part. The only significant lake within the borders of Kocaeli is Lake Sapanca, although the majority of it lies within the borders of Sakarya province. In general, the climate of the region is characterized by the intersection of the Black Sea and Mediterranean climates. Summers are hot and dry, while winters are rainy and relatively mild compared to many other regions of Turkey. The summer season experienced on the

Black Sea coast in the northern parts of the province is cooler compared to the summer experienced in the southern parts of the province.

The area of Kocaeli province is 3,397 km². As of the year 2023, the population of Kocaeli province is 2,102,907 people, with a population density of 619 people per km², making it the second-largest province in Turkey in terms of population density. Located at an important crossroads connecting Asia and Europe, it possesses a natural harbor, the İzmit Gulf, which is a busy maritime route. The northwest border of the province with Istanbul province passes east of the Kemikli stream, flowing between Gebze and Istanbul. In Kocaeli, the Samanlı Mountains stretch from the western bank of the Sakarya River to Bozburun north of Lake İzmit, dominating the depressions of İzmit, Sapanca, and Adapazarı. It is the seventh smallest province in Turkey in terms of area. Kocaeli province consists of 12 districts, including İzmit at the center, and surrounding districts such as Başiskele, Çayırova, Darıca, Derince, Dilovası, Gölcük, Gebze, Kandıra, Karamürsel, Kartepe, and Körfez.



Figure 1.2: Kocaeli Province map. (Geography of Kocaeli, 2024).

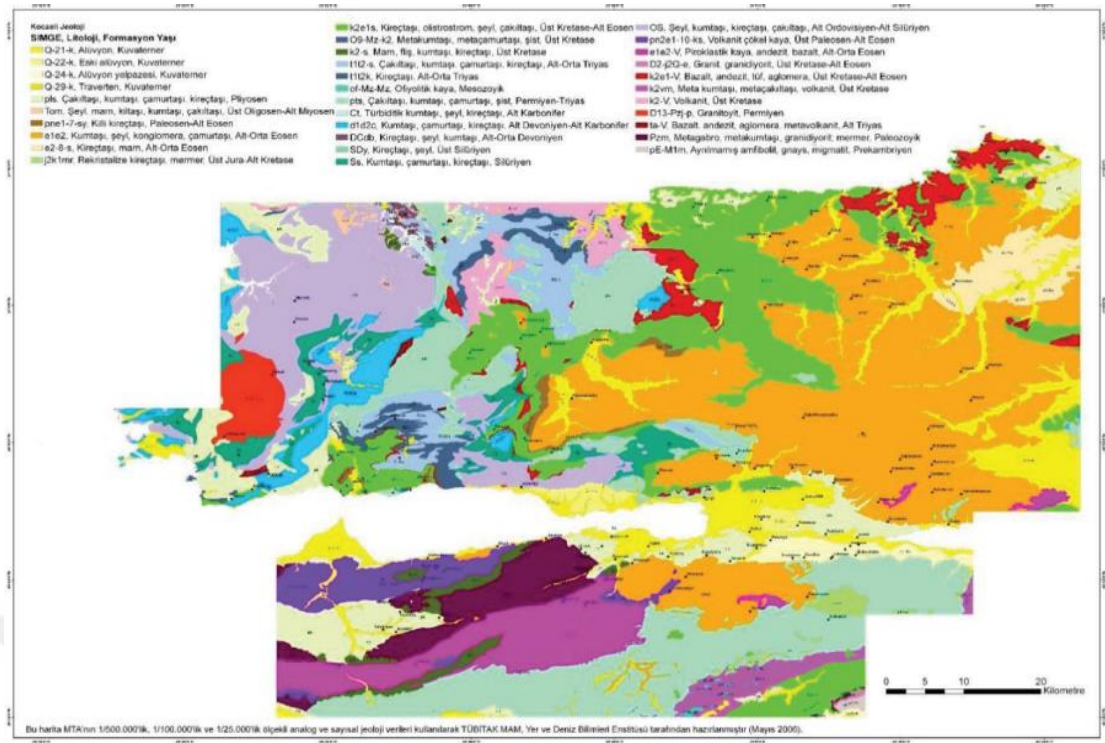
2. REGIONAL GEOLOGY

2.1. General Geology

The region is characterized by geological strata of Paleozoic, Mesozoic, and Cenozoic age rocks. The Paleozoic stratum consists of sandstone-limestone alternations, with a wide distribution north of Hereke, Derince, and İzmit. The Arkoz formation, Sopali formation, quartz arenites, Çenedağ formation, and Devonian sandstone-limestone layers known as the Çınarlıdere formation are found in these areas. Triassic remnants are widespread on the Paleozoic stratum, transitioning from coarse sediments to sandstone and siltstone layers in areas north of Hereke, Körfez, Derince, İzmit, and their northern elevations. This Triassic unit, composed of coarse sediments, is called the İzmit Formation. Thick carbonate deposits are observed in the upper layers of the Triassic, mainly around Hereke and Gebze. The upper Cretaceous sedimentation, starting with coarse sediments on the Triassic stratum, is observed in the north and northeast of İzmit. Along the coastal strip and coastal plain in the region, poorly consolidated Pliocene sediments and Quaternary alluvial deposits are present (**Kocaeli Governorship, 2020**).

The Kocaeli Peninsula, characterized by the Kocaeli Graben and the Armutlu Peninsula to the south, bounded by the North Anatolian Fault, is represented by two horsts. The geological evolution of the Kocaeli Peninsula reflects sedimentary sequences from the Paleozoic to the Quaternary. Various metamorphic and non-metamorphic sedimentary, plutonic, and volcanic rocks have contributed to the geological structure of the Armutlu Peninsula over different geological time intervals, from the Precambrian to the present (**Kocaeli Governorship, 2020**).

Furthermore, the İzmit Gulf Graben, with a width of 6-10 km between two horsts, is limited by fault scarps on both sides. Areas above the gulf waters consist of alluvial fans, coastal plains, deltas, and beach deposits in front of fault scarps as shown **Figure 2.1**.



Triassic and Upper Cretaceous aged karstic limestone is present, the western Dil Creek to the eastern region between Upper Hereke and Serçetepe, and extending north to the Köseköy-Tepeköy area, is a typical section where karstification processes are observed. In this area, where karstification progresses deeper, numerous and varied karstic depressions, dry valleys, sinkholes, disappearing streams, springs, and caves can be found, formed by various lapies, dolines, and uvalas (**Kocaeli Governorship, 2020**).

2.2.1.2 Geomorphological Features of the Southern Region of Kocaeli Province

The southern part of Kocaeli province is formed by the central section of the Samanlı Mountains, which extend east-west and form a high massif. This section, constituting the watershed area between the Izmit Gulf and Lake İzmit, partially including the Sakarya River, consists of plateaus at various elevations. Particularly noteworthy are the significant elevations such as Mount Kartepe (1601 m), Mount Karlık (892 m), Mount Dikmen (702 m), and Mount Naldöken, located in the northern part of the province, showing differences in morphology compared to the Kocaeli Peninsula to the north. The topographic slope is steeper compared to the north of Kocaeli. The foundation of this section consists of Paleozoic-aged formations, mainly comprising metamorphic schists, crystalline limestones, and marbles. Mesozoic-aged formations are partially present in the southern part, with Tertiary-aged formations being common, often discordant.

Additionally, volcanic formations cover extensive areas in this section. The volcanic units, mainly composed of andesites and dacites, extend northeast and eastward, reaching Gölcük and Maşukiye, forming the high mountains and plateaus constituting the watershed area between the Izmit Gulf and Lake İzmit.

These areas composed of volcanic units are particularly prone to mass movements such as rockfalls and landslides, necessitating attention in terms of civil engineering services and settlement.

The area between the Hersek Delta and the west of Gölcük in the southern part generally exhibits a high cliff coastline type. In between, there are occasional low coastlines belonging to small deltas, such as those found on the shores of Karamürsel, Ereğli, and Yalıdeğirmendere. Conversely, the coastlines to the east and west of this

area, including vast areas, display a low beach character. Indeed, towards the east, between Gölcük and the end of the Izmit Gulf, the coastline has formed an alluvial strip due to the accumulation of sediments brought by numerous rivers flowing into the area. Towards the west, the coastlines of the Hersek and Laledere deltas, forming extensive alluvial protrusions into the sea, constitute low coastlines (**Kocaeli Governorship, 2020**).

2.2.1.3 The Tectonic Structure of Kocaeli Province

The North Anatolian Fault (NAF) constitutes one of the most active seismic faults in the world. With a total length of around 1000 km, the total slip along the fault varies between 25 km and 80 km. While the fault exhibits narrow linear features and reverse component characteristics, with widths ranging from a few hundred meters to the east, it widens as it progresses westward, reaching up to 5 km, and displays normal component characteristics.

Beginning from the triple junction point with the East Anatolian Fault in Karlıova in the east, the fault forms an outward convex curve in its middle section, extending to the western end of the Mudurnu Valley segment. West of the Mudurnu Valley segment, it bifurcates into two main branches, with the northern branch following the north of Lake Sapanca and the Armutlu Peninsula, extending through the Marmara Sea to the Saros Gulf and continuing towards the Corinth Gulf in the Aegean Sea. The fault is notably visible along the south of Lake Sapanca to the İzmit Gulf. The general strike of the fault varies between approximately east-northeast (N80E-N80W) and east-southeast (EW). The length of the fault segment between Sapanca and Gölcük is 60 km. The fault cuts through all rock formations in the region, controlling Quaternary units. Near Gölcük, the fault exhibits a left-lateral displacement, forming a small pull-apart basin. This pull-apart basin developed between the Sapanca-Gölcük and Gölcük-Karamürsel segments. The earthquake on August 17, 1999, caused the coastline corresponding to the pull-apart basin to slide into the bay between Gölcük and Değirmendere. The fault extends westward into the sea between Gölcük and Karamürsel, parallel to the coastline. In the southern segment of the fault, landslides are commonly observed around Yalova as shown **Figure 2.2**.

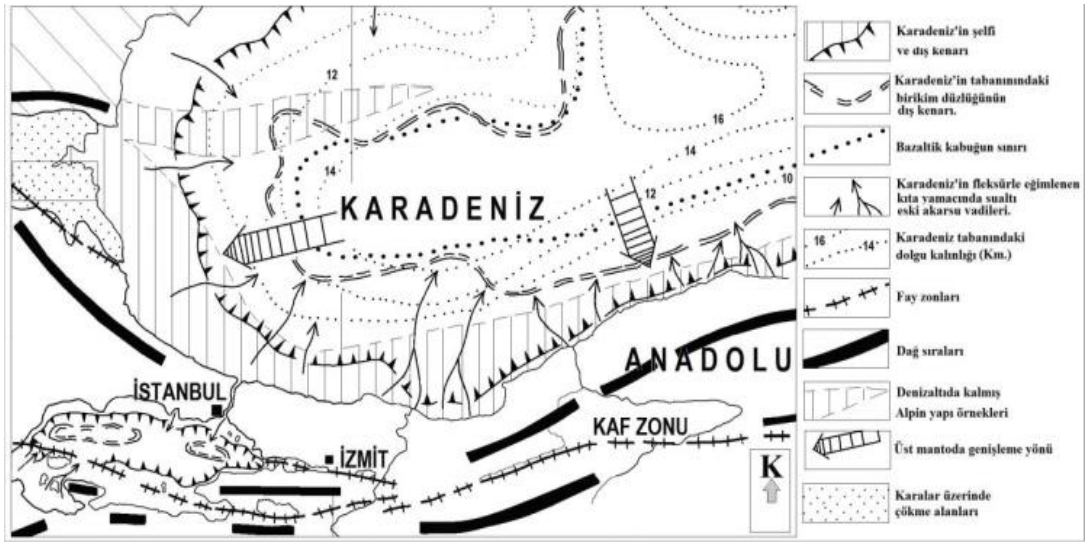


Figure 2.2: Map showing the geomorphological units of the Black Sea basin from (Kocaeli Governorship, 2020).

The extension of the North Anatolian Fault Line in Kocaeli runs from the middle of Kocaeli territory in a northwest-southeast direction. The points where the fault line passes through are mostly located close to alluvial or alluvial soil, which are the most vulnerable grounds against earthquakes. The areas where the population is concentrated, as well as large industrial, chemical, and petroleum facilities, are situated on the most vulnerable areas, which are the alluvial soils, concerning seismic activity.

2.2.1.4. The Hydrological and Hydrogeological Condition of Kocaeli Province

Throughout Kocaeli province, rivers generally flow in a north-south direction due to the influence of the topography and the east-west orientation of the İzmit Gulf, ultimately draining into the İzmit Gulf. The tributaries of these rivers, under appropriate conditions, flow in an east-west direction and merge with the north-south flowing perennial rivers. In addition to the long perennial rivers in the area, there are also numerous seasonal streams. Other hydrological features in the vicinity include the İzmit Gulf and Lake Hersek as shown **Figure 2.3**.

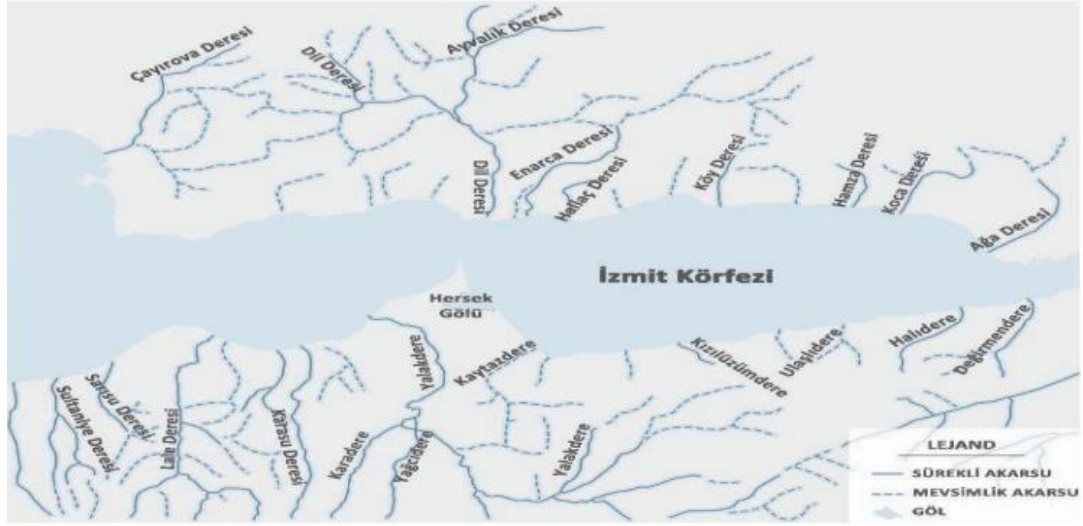


Figure 2.3: Hydrogeological Structure of Izmit Bay and Its Surrounding (Kocaeli Metropolitan Municipality ISU Activity Report, 2020).

3. LITERATURE REVIEW SUMMARY

(Hasancebi & Ulusay, 2007), conducted a comprehensive study comparing shear wave velocity (V_s) values determined through Seismic Cone Penetration Test (SCPT) with those empirically derived from Standard Penetration Test (SPT- N_{30}) values. This investigation was carried out in an area with 37 boreholes, utilizing downhole and borehole techniques to measure V_s within a depth range of 10 to 20 meters. The study revealed that the empirically derived shear wave velocity values are reliable and provide meaningful results. This correlation underscores the validity of using empirical methods in estimating shear wave velocity for seismic site characterization.

(Akin, Kramer, & Topal, 2011), conducted a study in the seismically active region of Erbaa, located along the eastern segment of the North Anatolian Fault Zone (NAFZ), to investigate empirical correlations between shear wave velocity (V_s) and Standard Penetration Test (SPT-N) blow counts for different soils. This study was part of a seismic microzonation effort aimed at obtaining shear wave velocity values of the geological units in the area for site response analyses. The geological units in the study area mainly consist of alluvial and Pliocene deposits. These layers were evaluated based on drilling, in-situ testing (e.g., SPT, SPT-based uphole, and SCPTU), and laboratory testing.

The study focused on defining shear wave velocity profiles by considering the empirical correlations between shear wave velocity (V_s) and SPT-N values. SPT-based uphole tests were performed during drilling operations to measure shear wave velocity. The SPT-based V_s values were computed using various empirical formulas and compared with the measured SPT-based uphole V_s values. It was found that empirical correlations required modifications to provide the best site-specific correlation. The depth factor was also considered in developing new empirical equations. Consequently, a site-specific formula was proposed to obtain V_s profiles for all layers in the study area.

(Kanbur, Silahtar, & Özsoy), their study titled "Investigation of Shallow Structures Using Shallow Seismic Reflection, MASW, and ReMi Methods: A Case Study of Plio-Quaternary Sediments in the Northern Part of Isparta Urban Area," researched the

shear wave velocity values of sediments located in the Süleyman Demirel Campus. Within this scope, they determined the S-wave velocities using shallow seismic reflection, MASW (Multichannel Analysis of Surface Waves), and ReMi (Refraction Microtremor) methods. The conclusion of the study indicates that the results obtained from seismic reflection, MASW, and ReMi techniques support each other in revealing the seismic velocity characteristics of Plio-Quaternary sediments down to a depth of 50 meters.

In **(Boore D. M., 2004)**, the V_{s30} parameter, which represents the average velocity to a depth of 30 meters and is crucial for site classification and seismic shaking prediction, is examined. When shallow velocity models do not extend to the required depth, methods for extrapolating velocities become necessary. Using data from 135 boreholes in California, where velocity models reach at least 30 meters depth, four different extrapolation methods were investigated.

Methods based on correlations between shallow velocity and V_{s30} are more effective in reducing bias compared to the simplest method, which assumes the lowest velocity extends to 30 meters. Regardless of the method used, the site misclassification rate is generally low, dropping to insignificant levels when velocity models extend to at least 25 meters depth.

Although methods employing correlations generally offer more precise estimates of V_{s30} , the simplest approach tends to yield lower V_{s30} values, resulting in a more conservative estimate of ground motion, which typically increases as V_{s30} decreases.

In **(Boore, Thompson, & Cadet, 2011)**, by analyzing velocity profiles from various sites across Japan, California, Turkey, and Europe, we observe a strong correlation between the time-averaged shear-wave velocity to 30 meters (V_{s30}) and the average velocities to depths less than 30 meters (V_{sz} , with z representing the averaging depth). Particularly, data from sites in Japan, corresponding to the KiK-net network, exhibit a systematically higher V_{s30} compared to profiles from other regions, primarily due to the placement of KiK-net stations on rock or rock-like sites, while stations in other regions are typically situated in urban areas underlain by sediments.

Utilizing the velocity profiles from the KiK-net network, we establish equations that relate V_{s30} to V_{sz} for depths ranging from 5 to 29 meters at 1-meter intervals. These equations, along with those for California velocity profiles provided by (Boore D. M., 2004), enable the estimation of V_{s30} from V_{sz} for sites where velocity profiles do not reach 30 meters. The variability in $\log V_{s30}$ decreases with depth, with even a 1 standard deviation variation resulting in less than a 20% uncertainty in ground motions predicted by recent ground-motion prediction equations GMPE's (Ground Motion Prediction Equation) at short periods, even for an averaging depth as shallow as 5 meters.

(Kottke, Hashash, Stewart, & Mosa, 2011) found that while the sensitivity of ground motions to V_{s30} uncertainty is more pronounced at longer periods, it remains modest, with variations of less than a factor of 1.2 for averaging depths exceeding approximately 20 meters. Moreover, they found that V_{s30} correlates with V_{sz} for depths as deep as 400 meters for sites within the KiK-net network, which provides rationale for employing V_{s30} as a site-response parameter for predicting ground motions at periods where wavelengths significantly exceed 30 meters.

The time-averaged shear wave velocity within the upper 30 meters of a site (V_{s30}) serves as a crucial parameter in ground motion prediction equations (GMPEs) for assessing seismic site response. However, it is common to encounter sites lacking direct V_{s30} measurements; for instance, in the NGA-East site database, only 45 out of 1149 sites possess measured V_{s30} values. Consequently, V_{s30} estimates are often derived using readily available proxies such as ground slope, geomorphic terrain categories, and surface geology.

To investigate the efficacy of slope and geomorphology-based proxy methods, the researchers compiled a comprehensive database comprising 1930 measured and inferred V_{s30} values in Central and Eastern North America (CENA). The findings reveal biases in existing proxy methods, particularly for sites with V_{s30} values exceeding 400 m/s. Following a thorough examination of geological conditions in the CENA region, they proposed nineteen geologic classes based on various factors including setting (e.g., glaciated or non-glaciated), age, and depositional environment.

These classes can serve as the foundation for geology-based proxy estimates of V_{s30} , as well as for constructing simplified stratigraphic columns.

(**Dikmen, 2009**), this study investigates the relationship between shear wave velocity and standard penetration test blow counts (SPT-N). Specifically, it examines the correlation between SPT-N and shear wave velocity (V_s) across various soil types, including all soils, sand, silt, and clay-type soils. New empirical formulas are proposed to establish the correlation between SPT-N and V_s , based on data collected in a specific area of the Eskişehir settlement in the western central Anatolia region of Turkey. These formulas are developed using geotechnical soundings and both active and passive seismic experiments.

The study compares and evaluates the newly proposed formulas with previously suggested ones that demonstrate correlations between uncorrected SPT-N and V_s using the same dataset. The findings indicate that better estimations of V_s are achieved when using uncorrected blow counts, with the blow count being a crucial parameter and soil type having minimal influence on the results. In cohesive soils, plasticity contents, and in non-cohesive soils excluding gravels, graded contents have little effect on V_s estimation. These results largely align with conclusions drawn from previous studies.

While the practical relationships established between SPT-N and V_s offer valuable insights for geotechnical engineering, caution is advised in their application, and they should be validated against measured V_s data.

(**Parker, et al., 2017**) investigated the development of proxy-based methods for estimating shear wave velocity (V_{s30}) in Central and Eastern North America (CENA). The study focused on the need for proxy methods due to the fact that only 6% of the seismic recording stations contributing data to the NGA-East project have measurement-based V_{s30} values. To address this, the researchers developed a hybrid geology-slope approach for V_{s30} estimation using large-scale geological maps, the extent of the Wisconsin glacial cover, sedimentary basin structure, and 30 arc-second topographic slope.

The study compiled a database of measured V_{s30} values in the CENA region to evaluate the performance of proxy methods. When considering the extent of the Wisconsin

glacial cover, it was found that non-glaciated regions exhibited lower natural logarithmic variability in V_{s30} ($\sigma \ln V \approx 0.36$) compared to glaciated regions ($\sigma \ln V \approx 0.66$), making proxy-based V_{s30} estimates more reliable in non-glaciated areas.

Based on these findings, the study provided estimates of the natural logarithmic mean and standard deviation of V_{s30} for NGA-East recording stations. The results underscore the importance of using V_{s30} as a reliable site response parameter and suggest that more accurate estimates can be made in non-glaciated regions. The study also recommends improvements in proxy-based V_{s30} estimates in the NGA-East database, demonstrating that geological conditions inferred from larger-scale maps are more reliable.

(Stewart, et al., 2014), examined the time-averaged shear-wave velocity within the upper 30 meters of a site (V_{s30}), a key parameter in ground-motion prediction. When direct measurements of velocities are unavailable, V_{s30} is often estimated using proxy-based relationships developed for global or local applications. In this study, they focused on developing a local relationship for Greece.

Their approach began with the compilation of a profile database (PDB) sourced from published materials and engineering reports. The PDB comprised 314 sites, with 238 having profile depths of at least 30 meters, and 59 located within 100 meters of accelerographs. They observed that existing relationships for extrapolating time-averaged velocities to V_{s30} tend to overpredict V_{s30} , prompting them to present new equations for these extrapolations.

Additionally, they gathered proxy data for PDB sites, including terrain type, surface geology, and surface gradients at resolutions of 30 and 3 arcseconds derived from radar-derived digital elevation models (DEMs). Upon comparison with ground survey data, they found ground elevations from 3 arcsecond DEMs to be more accurate than alternatives at 30, 9, and 1 arcsecond resolutions.

Expert input guided the development of geologic categories based on factors such as age, gradation, and depositional environment, which were then assigned to PDB sites. Notably, they identified biases in an existing 30 arcsecond gradient-based global model relative to local V_{s30} data for gradients exceeding approximately 0.05 m/m.

Further discrepancies relative to a California model were found for specific geomorphic categories, necessitating the provision of new (local) values.

Statistically significant effects of the 3 arcsecond gradient on V_{s30} were observed for Quaternary and Tertiary materials, while no gradient effect was found for Mesozoic materials. Within Quaternary sediments, consistent V_{s30} -gradient trends were noted for certain subcategories, while others exhibited faster velocities.

Based on their findings, Stewart et al. recommended the combined use of modified terrain- and geology-based methods for proxy-based VS30 estimation in the study region.

(Stewart, Bray, Dickenson, & Bray, 2003) focused on the time-averaged shear-wave velocity within the upper 30 meters of a site (V_{s30}), which is critical for ground-motion prediction. Due to the lack of direct velocity measurements, they aimed to develop a local relationship for Greece using proxy-based methods. They compiled a profile database (PDB) from published materials and engineering reports, including 314 sites, with 238 having profile depths of at least 30 meters. They noted that existing methods often overpredict V_{s30} , leading to the development of new equations. Proxy data, including terrain type, surface geology, and surface gradients, were gathered from radar-derived digital elevation models (DEMs). Expert input guided the development of geological categories, revealing biases in global models for gradients exceeding 0.05 m/m. They found that terrain- and geology-based methods provided more accurate proxy-based V_{s30} estimates, particularly for Quaternary and Tertiary materials.

(Scasserra, Irikura, Yamazaki, & Midorikawa, VS30 mapping in South America for seismic hazard assessment, 2009) conducted an extensive analysis of V_{s30} values across South America, focusing on the correlation between V_{s30} and various geomorphic and geological parameters. They compiled a comprehensive database of velocity profiles and observed significant regional variations. Their study proposed new proxy-based V_{s30} estimation models tailored to South America's unique geological and topographical characteristics. These models aimed to enhance seismic hazard assessments by incorporating local conditions, thereby improving the accuracy of seismic risk predictions in the region.

(Sun, Lin, Xu, & Zhang, 2018) evaluated the applicability of using topographic slope as a proxy for V_{s30} estimation in China. They compared slope-based V_{s30} predictions with measured values across different regions and found that while topographic slope can serve as a useful proxy, regional adjustments are necessary for precise seismic site characterization. The study highlighted the need for localized calibration of proxy-based methods to account for regional geological variations, thereby enhancing the accuracy of seismic hazard assessments in China.

(Wald & Allen, 2007) developed a method to estimate VS30 using topographic slope derived from digital elevation models (DEMs). This global approach aimed to provide consistent and reliable estimates of seismic site conditions and ground motion amplification, especially in regions lacking direct V_{s30} measurements. The method utilized high-resolution DEMs to derive slope-based proxies, offering a valuable tool for seismic hazard assessments worldwide. Their findings emphasized the effectiveness of this proxy-based method in improving the understanding and prediction of seismic ground motions.

(Wills & Clahan, 2006) developed a detailed geological map for California to categorize site conditions based on shear-wave velocity. By correlating geological units with measured velocity profiles, they refined VS30 estimates, aiding in more precise ground-motion calculations. The map was designed to improve seismic hazard assessments by providing a standardized classification of site conditions. Their work highlighted the variability of shear-wave velocities within geological units and the importance of detailed geological mapping for accurate seismic risk predictions.

(Yong, Hough, Iwahashi, & Braverman, 2012) developed a technique for estimating V_{s30} using an automated terrain classification method proposed by Iwahashi and Pike. This method was applied to California, resulting in a detailed map of site conditions. The study demonstrated that automated terrain classification could effectively estimate V_{s30} , enhancing the understanding of seismic risk in the region. Their approach involved integrating various geospatial datasets and terrain attributes to produce accurate site classifications, which are crucial for seismic hazard assessments.

(Zargli, Papadopoulos, & Ganas, 2013) investigated the correlation between topography and geology in Greece using digital elevation model (DEM) data. They

found that while slope is a somewhat biased proxy for solid rock sites, it is effective for alluvial deposits. Their study supports the use of terrain and geological proxies for earthquake risk assessment in high seismicity areas like Greece. The findings suggest that integrating slope-based proxies with geological data can enhance the accuracy of V_{s30} estimates, providing valuable insights for seismic hazard mitigation.

(Allen & Wald, 2009) evaluated the use of high-resolution topographic data as a proxy for seismic site conditions (V_{s30}). They proposed using digital elevation models (DEMs) from the Shuttle Radar Topography Mission (SRTM) to estimate V_{s30} by correlating topographic slope with V_{s30} measurements. By comparing high-resolution DEMs (3 and 9 arc-seconds) with lower-resolution SRTM data (30 arc-seconds), they found that while higher-resolution data recover finer-scale topographic variations, it offers minimal improvement in V_{s30} estimates over lower-resolution data. This method is beneficial for regions lacking detailed geotechnical data.

(Iwahashi & Pike, 2007) developed a method for terrain classification using DEMs to estimate seismic site conditions. They categorized terrains based on slope, local convexity, and texture, providing a comprehensive framework for terrain classification that can be used to predict V_{s30} values. This approach facilitates improved seismic hazard assessments by leveraging digital terrain data.

(Lee & Dobry, 2004) investigated the applicability of using topographic slope as a proxy for V_{s30} in Taiwan. They used DEM data to correlate slope with V_{s30} measurements, finding that slope-based estimates provide a reasonable proxy for seismic site conditions. Their study supports the use of topographic slope in regions lacking detailed geotechnical data.

(Matsuoka, Wakamatsu, Fujimoto, & Midorikawa, 2006) created a shear-wave velocity map for Japan using the Japan Engineering Geomorphologic Classification Map (JEGM). They calculated average shear-wave velocity V_{s30} for approximately 2,000 sites and correlated these with geomorphologic units. Multivariate regression analysis enabled the creation of a nationwide V_{s30} map, providing valuable data for seismic hazard assessments.

4. THEORETICAL FOUNDATION

4.1. General Principles of the Seismic Refraction Method

The seismic refraction method is a widely utilized geophysical technique aimed at identifying and characterizing subsurface geological structures. This method capitalizes on the principles of wave propagation and refraction, particularly as outlined by Snell's Law, to gather detailed information about the subsurface.

In seismic refraction surveys, seismic waves are generated using various energy sources such as hammer strikes, explosive charges, or mechanical vibrators. These waves propagate from the surface into the subsurface and interact with different geological layers. When these waves encounter boundaries between layers with different seismic velocities, they bend or refract. The degree of this refraction depends on the contrast in seismic velocities between the layers, and it is governed by Snell's Law, which relates the angles of incidence and refraction to the velocities of the waves in the respective media.

As shown in **Figure 4.1** the seismic refraction method involves the detection of refracted waves by geophones, which convert ground vibrations into electrical signals recorded by seismographs. The data collected includes the travel times of the seismic waves from the source to the detectors. By analyzing these travel times and the corresponding distances, geophysicists can determine the depths and seismic velocities of the subsurface layers. This data is often represented in time-distance graphs, which help in interpreting the subsurface geological structures.

The seismic refraction method has a wide range of applications. It is extensively used in engineering geology to assess the suitability of sites for construction and to identify potential geotechnical hazards. Environmental studies utilize this method for groundwater investigations and to map subsurface contamination. In the field of natural resource exploration, particularly in oil and gas exploration, seismic refraction is employed to delineate subsurface formations and identify stratigraphic contacts. Its ability to provide detailed subsurface images makes it invaluable for various scientific and industrial applications.

For instance, (Telford, Geldart, & Sheriff, 1990) emphasized the significance of this method in engineering and environmental geophysics, highlighting its contributions to a better understanding of subsurface structures.

In summary, the seismic reflection method is a robust and effective technique for subsurface exploration. By leveraging the principles of wave propagation and refraction, it provides comprehensive insights into the geological characteristics of the subsurface, supporting a wide array of engineering and scientific endeavors. Diagram illustrating the seismic reflection method. Seismic waves generated at the shot point travel through the subsurface, reflecting off different geological layers and being detected by geophones. The recorded data helps in constructing a detailed image of subsurface structures, showcasing the principles of wave propagation and reflection.

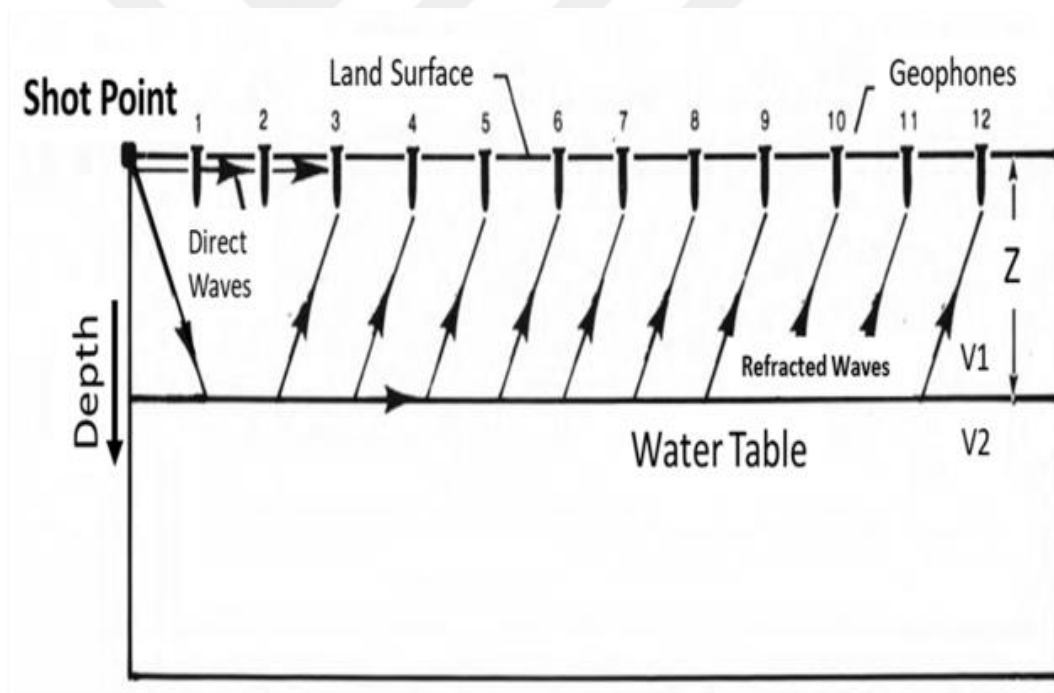


Figure 4.1: Diagram illustrating the seismic reflection method. Seismic waves generated at the shot point travel through the subsurface, reflecting off different geological layers and being detected by geophones. The recorded data helps in constructing a detailed image of subsurface structures, showcasing the principles of wave propagation and reflection.

4.2. Types and Propagation Characteristics of Seismic Waves

Seismic waves are divided into two main groups: body waves and surface waves. Body waves consist of P-waves and S-waves, while surface waves are further divided into Rayleigh waves and Love waves see **Figure 4.2**.

Body waves travel through the interior of the Earth, playing a crucial role in determining the properties of subsurface structures. P-waves (primary waves) are the fastest seismic waves and are transmitted through compression. They can propagate through solids, liquids, and gases. S-waves (secondary waves), on the other hand, travel more slowly and are shear waves that can only move through solid materials.

Surface waves travel along the Earth's surface and are known for their destructive effects. Rayleigh waves involve elliptical particle motion and have both vertical and horizontal movement components. Love waves, in contrast, involve horizontal shear motion and travel along the surface.

In this context, **Figure 4.2** visualizes the propagation directions and characteristics of different types of seismic waves. This figure explains how body and surface waves propagate and interact with various subsurface layers. In **Figure 4.2**, P-waves (a), S-waves (b), Rayleigh waves (c), and Love waves (d) are detailed.

In conclusion, seismic waves are powerful tools for examining and characterizing subsurface structures. Both body waves and surface waves provide significant information in geophysical studies and earthquake engineering. Understanding these waves is crucial for determining subsurface dynamics and structural properties.

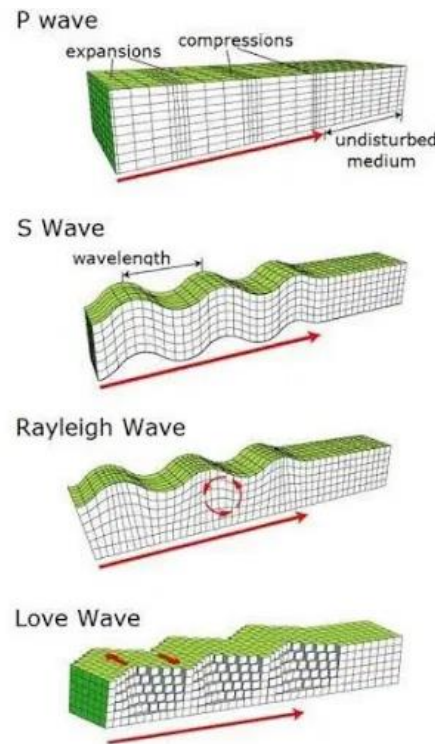


Figure 4.2: Different types of seismic waves. The diagram illustrates the propagation characteristics of (a) P-wave (Primary wave) showing expansions and compressions, (b) S-wave (Secondary wave) showing wavelength and transverse motion, (c) Rayleigh wave exhibiting elliptical particle motion, and (d) Love wave demonstrating horizontal shear motion along the surface.

4.3. Understanding the Critical Role of Shear Wave Velocity (V_s) in Geotechnical and Earthquake Engineering

Shear wave velocity (V_s) is a critical parameter in determining the dynamic properties of soil layers. It is directly related to the shear modulus (G_{max}) of soils and rocks, which is calculated using the equation $G_{max} = \rho * V_s^2$, where ρ is the density of the material. This relationship highlights the importance of V_s in understanding the stress-strain behavior of geomaterials (Wair, DeJong, & Shantz, 2012).

In geotechnical and earthquake engineering, V_s is crucial for assessing soil stiffness and for the design of earthquake-resistant structures. The measurement of V_s can be conducted through various field and laboratory methods. Invasive techniques such as downhole and crosshole tests involve drilling boreholes, which might not always be feasible due to logistical and economic constraints. Non-invasive methods like Spectral Analysis of Surface Waves (SASW) and Multichannel Analysis of Surface

Waves (MASW) are also commonly used to estimate V_s (**Halasan, Magnaye , Grutas, & Solidum, 2022**).

For example, in a study conducted in Metro Manila, researchers developed an empirical correlation between standard penetration test (SPT) resistance and V_s . This study provided a practical and cost-effective alternative for determining V_s values, essential for regional geotechnical assessments (**Halasan, Magnaye , Grutas, & Solidum, 2022**). Additionally, V_{s30} , the time-averaged shear wave velocity to a depth of 30 meters, is a widely adopted index in the earthquake engineering community to account for seismic site conditions. V_{s30} is typically derived from geophysical measurements and is used to evaluate ground motion amplification during earthquakes (**U.S. Geological Survey, 2019**).

Shear wave velocity is also instrumental in liquefaction analysis, soil classification, and regional microzonation studies. Accurate determination of V_s is vital for predicting soil behavior during seismic events and ensuring the safety of structures (**Tunusluoglu, 2023**).

4.4. The Concept of V_{s30}

The average shear wave velocity to a depth of 30 meters, known as V_{s30} , is a crucial parameter in geotechnical and earthquake engineering. It provides a measure of the subsurface conditions by averaging the shear wave velocities of the upper 30 meters of soil and rock layers. This parameter is essential for assessing the dynamic behavior of soils and plays a significant role in the design and assessment of earthquake-resistant structures.

V_{s30} is derived from in situ seismic measurements and is used to characterize the stiffness of the near-surface soil layers. According to the U.S. Geological Survey, V_{s30} is an essential factor in seismic site classification and is widely used in seismic hazard assessments and building codes (**U.S. Geological Survey, 2019**). The parameter is particularly useful in regions where the engineering bedrock ($V_s > 760$ m/s) is relatively shallow or in dense soil conditions with simple horizontal stratigraphy.

V_{s30} is integrated into several key building codes and standards, highlighting its importance in ensuring the seismic safety of structures. These include:

Uniform Building Code (UBC): The UBC utilizes V_{s30} values to classify soil types and to determine the appropriate seismic design criteria for buildings. This helps engineers design structures that can withstand seismic forces based on the specific soil conditions at a site.

National Earthquake Hazards Reduction Program (NEHRP): NEHRP guidelines incorporate V_{s30} to develop seismic hazard maps and to specify ground motion parameters for earthquake-resistant design. This ensures that buildings are constructed with an understanding of the local seismic conditions ((BSSC), 2003).

Eurocode 8 (EC8): This European standard uses V_{s30} to categorize site conditions and to define seismic action for structural design. EC8 provides detailed procedures for incorporating V_{s30} into the seismic analysis of structures, thereby enhancing their earthquake resilience (Eurocode 8, 2004).

Turkish Earthquake Building Regulation: The Turkish seismic code also adopts V_{s30} as a critical parameter for soil classification and seismic design. This regulation ensures that buildings in Turkey are designed to withstand earthquakes, considering the specific soil conditions of the region.

The measurement of V_{s30} involves various field techniques, including invasive methods like downhole and crosshole tests, as well as non-invasive methods such as Spectral Analysis of Surface Waves (SASW) and Multichannel Analysis of Surface Waves (MASW). These methods analyze the propagation of shear waves through the soil layers to determine their velocity profiles.

A study by (Tunusluoglu, 2023) highlighted the importance of accurate V_{s30} measurements in the Canakkale residential area of Turkey. The study used empirical correlations between shear wave velocity and penetration resistance to develop reliable V_{s30} profiles for seismic hazard assessment (Tunusluoglu, 2023).

Similarly, (Wair, DeJong, & Shantz, 2012) emphasized the significance of V_{s30} in estimating the dynamic properties of soils. They noted that V_{s30} is crucial for understanding soil behavior under seismic loading and for designing earthquake-resistant structures (Wair, DeJong, & Shantz, 2012)

In summary, V_{s30} is a vital parameter in geotechnical and earthquake engineering, providing essential information about the dynamic behavior of soils. Its integration into various building codes and standards underscores its importance in ensuring the

seismic safety of structures. Accurate measurement and application of V_{s30} are critical for effective seismic hazard assessment and for the design of earthquake-resistant buildings.

4.4. Soil Classifications

4.4.1. Soil Classification Based on V_{s30} Values

V_{s30} , the average shear wave velocity to a depth of 30 meters, is a critical parameter used to assess the dynamic behavior and seismic performance of soils. This parameter is widely utilized in geotechnical and earthquake engineering to enhance the safety of structures. V_{s30} values are fundamental in various national and international building standards and serve as a key criterion in soil classification.

4.4.2. Soil Classification

Soils are categorized into various classes based on their V_{s30} values. These classifications help evaluate the seismic responses of soils and the performance of structures during earthquakes. The classification of soils based on V_{s30} values is shown in **Table 4.1**.

Table 4.1: ((BSSC), 2003) Soil Classes Based on V_{s30} Values.

No	Classification	V_{s30}	Soil Type
1	A	>1.500 m/s	Hard Rock
2	B	760-1.500 m/s	Rock
3	C	360-760 m/s	Very dense soil and soft rock
4	D	180-360 m/s	Rigid Soil
5	E	<180	Soils with special specifications

National Earthquake Hazards Reduction Program (NEHRP): NEHRP guidelines incorporate V_{s30} to develop seismic hazard maps and specify ground motion parameters for earthquake-resistant design. This ensures that buildings are constructed

with consideration of local seismic conditions. The soil classification based on V_{s30} according to NEHRP is shown in **Table 4.2 ((BSSC), 2003)**.

Table 4.2: NEHRP Soil Classification Based on V_{s30} .

Site Class	Description	Average Properties in top 30m		
		Shear-wave velocity, V_{s30} (m/s)	SPT N (Blows/300mm)	Undrained shear strength, S_u (kPa)
A	Hard Rock	> 1500	Not applicable	Not applicable
B	Rock	760 - 1500	Not applicable	Not applicable
C	Very dense soil and soft rock	360 - 760	> 50	> 100
D	Stiff soil	180 – 360	15 – 50	50 – 100
E	Soft soil	< 180	< 15	< 50
		Plus any profile with more than 3m of soil having the following characteristics: Plasticity index, $PI > 20\%$ Moisture content, $w \geq 40\%$ Undrained shear strength, $S_u < 25\text{kPa}$		
F*	-	Any profile containing soils with one ore more of the following characteristics: Soil vulnerable to potential collapse under seismic loading, e.g. liquefiable soils, quick and highly sensitive clays, collapsible weakly cemented soils. Peats and/or highly organic clays ($H > 8\text{m}$ of peat and/or highly organic clay) Very high plasticity clays ($H > 8\text{m}$ with $PI > 75\%$) Very thick soft/medium stiff clays ($H > 36\text{m}$)		

Eurocode 8 (EC8): This European standard uses V_{s30} to categorize site conditions and define seismic action for structural design. EC8 provides detailed procedures for incorporating V_{s30} into seismic analyses to enhance the earthquake resilience of structures. The soil classification based on V_{s30} according to Eurocode 8 is shown in **Table 4.3 (Eurocode 8, 2004)**.

Table 4. 3: Eurocode 8 Soil Classification Based on V_{s30} .

Eurocode 8 (Europe) [3]			NCSE-02 (Spain) [4]			ASCE 7-16 (USA) [5]		
Soil Type	Description	V_{s30} (m/s)	Soil Type	Description	V_{s30} (m/s)	Soil Type	Description	V_{s30} (m/s)
A	Rock or other rock-like geological formation, including at most 5 m of weaker material at the surface.	$V_s > 800$	I	Compact rock, very dense cemented or granular soil	$V_s > 750$	A	Hard rock	$V_s > 1500$
						B	Rock	$750 < V_s \leq 1500$
B	Deposits of very dense sand, gravel, or very stiff clay, at least several tens of meters in thickness, characterized by a gradual increase of mechanical properties with depth.	$360 < V_s \leq 800$	II	Very fractured rock, dense or cohesive hard granular soils.	$400 < V_s \leq 750$	C	Very dense soil and soft rock	$360 < V_s \leq 750$
C	Deep deposits of dense or medium dense sand, gravel, or stiff clay with thickness from several tens to many hundreds of meters.	$180 < V_s \leq 360$	III	Granular soil of medium compactness or cohesive soil of firm consistency to very firm.	$200 < V_s \leq 400$	D	Stiff soil profile	$180 < V_s \leq 360$
D	Deposits of loose-to-medium cohesionless soil or of predominantly soft-to-firm cohesive soil.	$V_s < 180$	IV	Loose granular soil or soft cohesive soil.	$V_s < 200$	E	Soft soil profile	$V_s < 180$
E	A soil profile consisting of a surface alluvium layer with v_s values of type C or D and thickness varying between about 5 m and 20 m, underlain by stiffer material with $v_s > 800$ m/s.	-	-	-	-	F	Other. See ASCE 7-16 Table 20.3-1	-

4.5. Standard Penetration Test (SPT) Overview

The Standard Penetration Test (SPT) is a widely used geotechnical investigation method for assessing the subsurface soil properties. Developed in the early 20th century, the SPT provides valuable information on soil resistance and density, which are critical for foundation design, site characterization, and understanding soil behavior under load.

4.5.1. Methodology

The SPT involves driving a hollow, cylindrical sampler into the soil at the bottom of a borehole using a standardized hammer of specific weight (usually 63.5 kg) dropped from a height of 76 cm. The number of hammer blows required to drive the sampler 30 cm into the soil, after an initial penetration of 15 cm, is recorded as the N-value or SPT blow count. This N-value serves as an indicator of the soil's density and strength.

The test procedure is standardized to ensure consistency and reliability across different testing locations. According to **(Bowles, 1996)**, the SPT is one of the most commonly performed in situ tests due to its simplicity, cost-effectiveness, and ability to provide immediate results about the soil conditions.

4.5.2. Applications and Interpretation

The SPT N-value is used to estimate various soil properties such as relative density, shear strength, and bearing capacity. For example, **(Schmertmann, 1978)** developed

empirical correlations between SPT N-values and soil parameters such as internal friction angle and relative density for sandy soils. Similarly, **(Seed, Tokimatsu, Harder, & Chung, 1985)** used SPT data to evaluate soil liquefaction potential during earthquakes, establishing correlations between N-values and the cyclic stress ratio that induces liquefaction.

The SPT is particularly valuable for its ability to provide continuous profiles of soil resistance with depth, which is essential for identifying changes in soil stratigraphy and detecting weak layers. **(Liao & Whitman, 1986)** emphasized the importance of SPT data in the seismic design of foundations, noting its role in determining soil amplification factors and site response characteristics.

4.5.3. Advantages and Limitations

The main advantages of the SPT include its widespread acceptance, ease of execution, and relatively low cost. It provides a quick assessment of soil conditions, which is particularly useful in preliminary site investigations. Additionally, the extensive database of SPT correlations allows engineers to make informed decisions based on empirical relationships.

However, the SPT also has limitations. The test results can be influenced by various factors such as borehole diameter, rod length, and hammer energy efficiency. Additionally, the SPT is less effective in very soft or very hard soils, where the blow count may not accurately reflect the soil properties. According to **(Terzaghi, Peck, & Mesri, 1996)**, the variability in SPT results necessitates careful consideration of test conditions and potential corrections to improve accuracy.

5. MATERIALS AND METHODS

5.1. Analysis of Soil Engineering Properties in Kocaeli Province

This study was conducted to understand the engineering properties of soil in Kocaeli province and to design appropriate foundations for construction projects. Within the scope of the thesis, 90 V_s (seismic velocity) measurements and 1212 SPT-N (Standard Penetration Test - N) measurements were taken. Specific procedures were followed to conduct these measurements.

5.2. V_s Measurements

V_s measurements were performed to determine the elastic properties of the soil. These measurements, conducted using seismic instruments, are designed to determine the velocity of surface waves. Instruments generate waves on the ground using impulse or vibratory sources, and these waves are recorded through receivers. The obtained data is then processed to calculate important parameters such as the elastic modulus of the soil. The V_s data used in this study were provided by TÜBITAK, Kocaeli Metropolitan Municipality, and TADAS AFAD, ensuring high reliability and accuracy in the analysis.

5.3. SPT-N Measurements

SPT-N measurements, on the other hand, were conducted to determine the resistance of the soil. In this test, a sample of soil is drilled with a borehole, and a hammer is repeatedly driven into it to a certain depth. The SPT-N value represents the resistance of the soil during this hammering process. A higher SPT-N value typically indicates a denser and more resistant soil. SPT-N values can be used to assess the engineering properties of the soil, design foundations, or understand soil behavior. The SPT-N data used in this study were provided by the Kocaeli Metropolitan Municipality.

This study provided an analysis of the data obtained from V_s and SPT-N measurements conducted in Kocaeli province. These data will contribute to understanding the soil properties in the region and planning future construction

projects. The findings are expected to be utilized in engineering applications and infrastructure projects in the region.



6. RESEARCH FINDINGS

6.1. Determination of V_s and V_{s30} Values Based on SPT-N Data

The first step involved examining the locations of the measured V_s values and SPT-N values on Google Earth. The coordinates of V_s are shown in **Figure 6.1**, the coordinates of SPT-N are shown in **Figure 6.2**, and both together are shown in **Figure 6.3** on Google Earth.

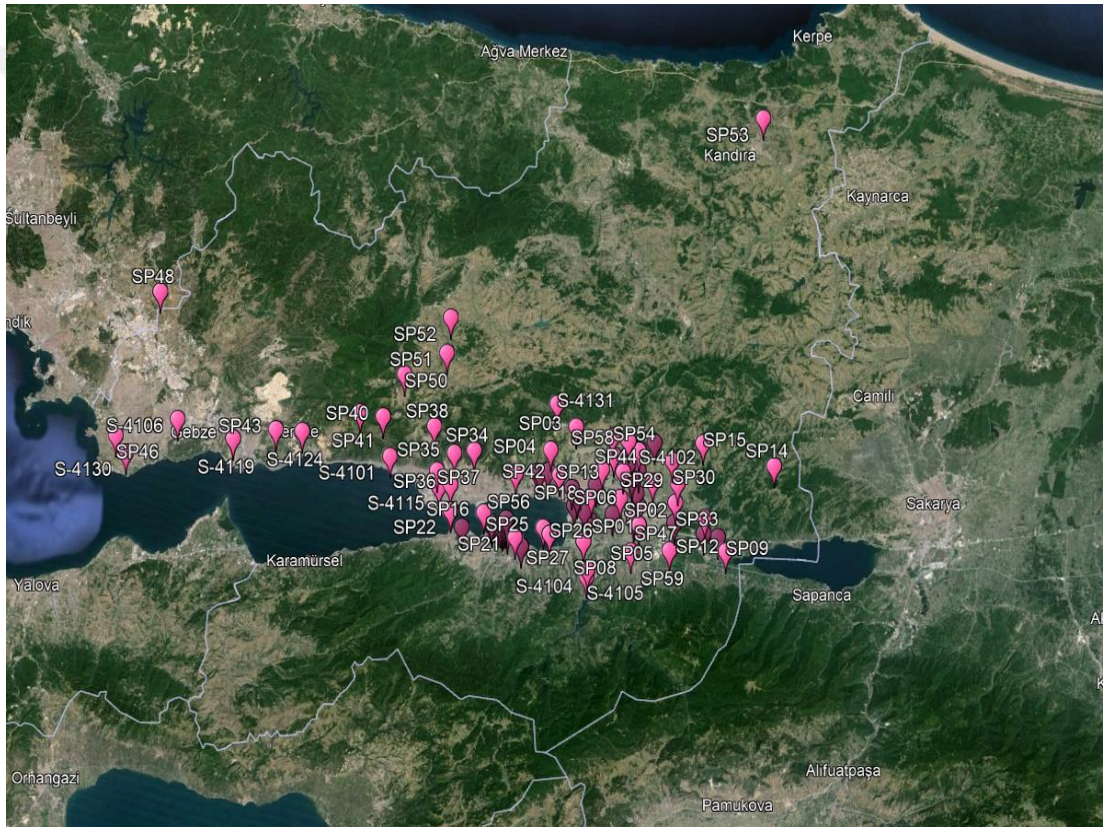


Figure 6.1: Locations of V_s Measurement Points in Kocaeli Province.

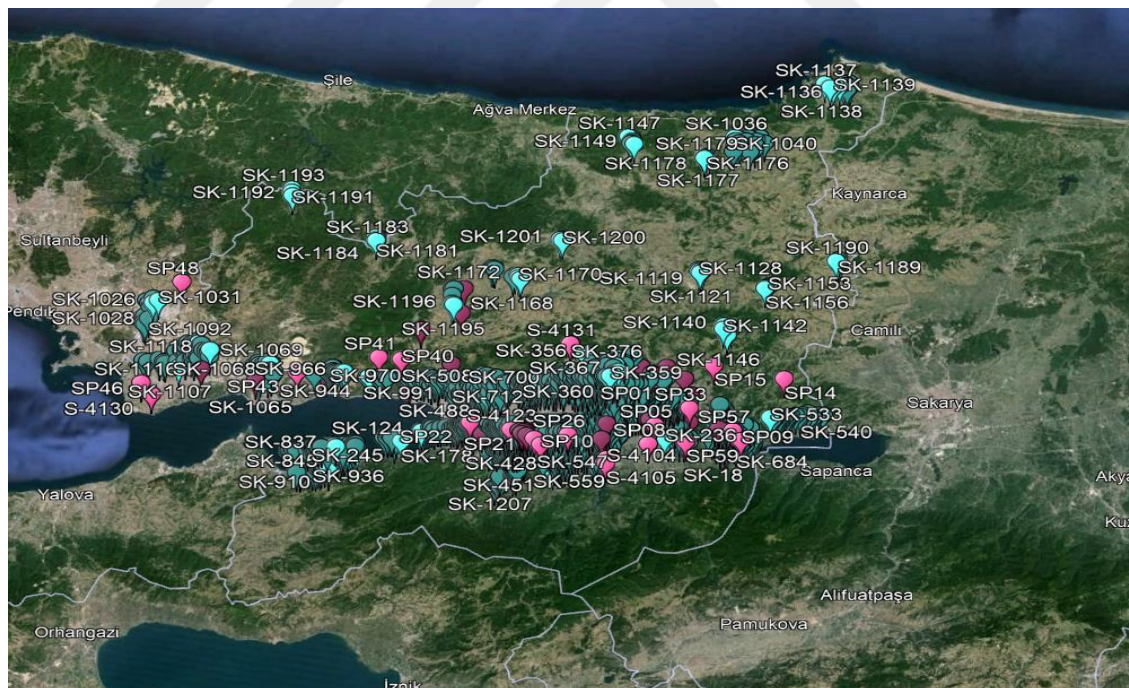
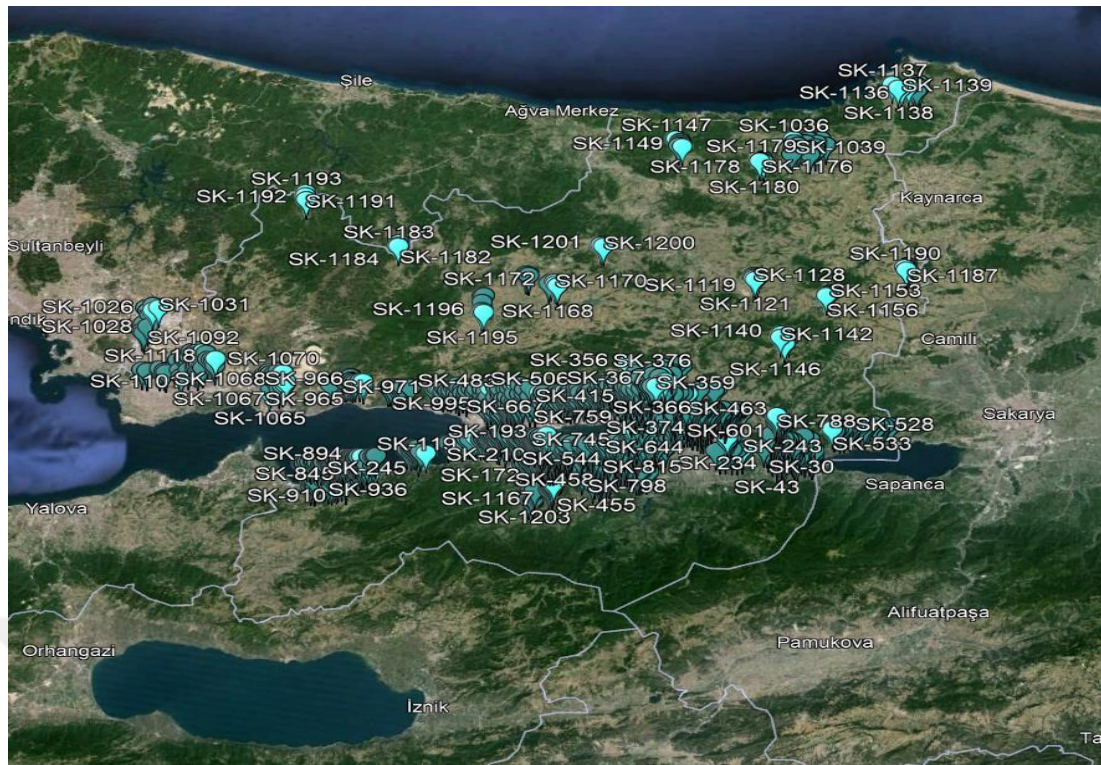


Figure 6.3: The coordinates of the measured V_s values and the coordinates of the drilling locations.

(Wills & Clahan, 2006) described the geologic and shear-wave velocity (V_{s30}) characteristics for each NGA (Next Generation Attenuation) site using a geologic map

and tested these V_{s30} estimates by determining the V_{s30} of any measured profile within 300 meters of an NGA site. Inspired by the method established by **(Wills & Clahan, 2006)**, in this study, the V_s values measured for the Kocaeli region were determined by referencing SPT (Standard Penetration Test) boreholes located within 300 meters of each measurement point.

Using Python software the process of finding the measured V_s stations and SPT-N boreholes within a 300-meter proximity was carried out. Our aim is to derive a region-specific equation. The written code is provided below, and the results are shown in **Table 6.1**.

6.1.1. Calculation

```
import pandas as pd
from geopy.distance import geodesic
import numpy as np

df = pd.read_excel('b.xlsx')
results = []

for index, row in df.iterrows():
    enlem1 = row[1]
    boylam1 = row[2]

    if not np.isnan(enlem1) and not np.isnan(boylam1):
        for inner_index, inner_row in df.iterrows():
            enlem2 = inner_row[4]
            boylam2 = inner_row[5]

            if not np.isnan(enlem2) and not np.isnan(boylam2):
                koordinat1 = (enlem1, boylam1)
                koordinat2 = (enlem2, boylam2)

                mesafe = geodesic(koordinat1, koordinat2).meters

                if mesafe < 300:
                    results.append([index + 1, inner_index + 1, mesafe])

result_df = pd.DataFrame(results, columns=["Satır 1", "Satır 2", "Mesafe (metre)"])
result_df.to_excel('mesafe123.xlsx', index=False)
```

6.1.2. Results

Table 6.1: Measured Vs values within 300 meters of SPT borehole locations.

VS	SPT	Distance (m)
SP-01	SK-611	185.4816037
SP-04	SK-693	298.8583806
SP-06	SK-372	117.5751821
SP-07	SK-640	288.5713433
SP-16	SK-108	226.310563
SP-19	SK-625	265.3771946
SP-21	SK-350	95.68176707
SP-22	SK-50	113.5871556
SP-22	SK-51	276.6782004
SP-22	SK-78	147.3939143
SP-22	SK-79	256.3635018
SP-23	SK-100	288.8562224
SP-24	SK-200	62.48695962
SP-24	SK-201	247.8963395
SP-24	SK-204	62.41548358
SP-25	SK-441	208.5618123
SP-26	SK-419	218.4675417
SP-26	SK-444	207.9612499
SP-32	SK-781	215.6328791
SP-34	SK-508	45.90460407
SP-36	SK-999	167.8287718
SP-37	SK-1010	217.4480553
SP-47	SK-632	281.1361051
SP-49	SK-743	238.2657935
SP-54	SK-365	146.4403144
SP-56	SK-706	57.41142128
SP-57	SK-673	273.4294648
SP-59	SK-242	293.3226642
SP-60	SK-212	255.5095032
SP-60	SK-217	148.5136043
S-4122	SK-590	245.1079806
S-4122	SK-591	241.3037209
S-4122	SK-592	113.116478
S-4123	SK-200	210.476403
S-4123	SK-201	135.1284925
S-4123	SK-204	285.4808797
S-4123	SK-210	240.4978589
S-4126	SK-761	122.1225548
S-4128	SK-633	176.5403334
S-4129	SK-2	247.0866639
S-4129	SK-10	196.2658656
S-4129	SK-11	213.7052955

The attempt was made to establish a correlation between SPT-N boreholes in close proximity to the measured Vs values. The resulting outcome appeared to be reasonable in terms of the average value obtained through multiple conditions. Additionally, a linear equation was derived using the SPT-N numbers to estimate the Vs values. This

estimation was then compared to the Vs-SPT-N relationships obtained in previous studies. This comparison is presented in **Table 6.1**, with SSE and RMSE values.

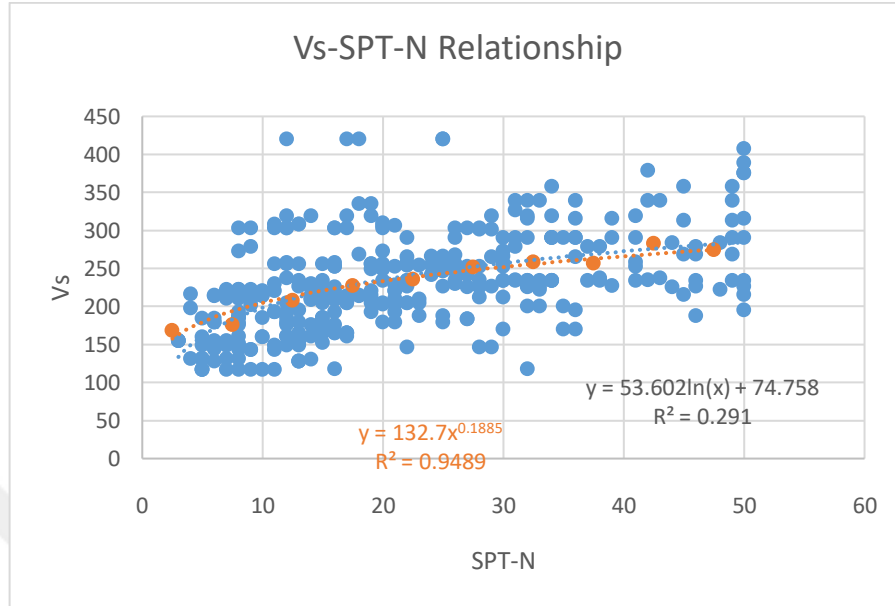


Figure 6.4: Vs (m/s) SPT-N relationship.

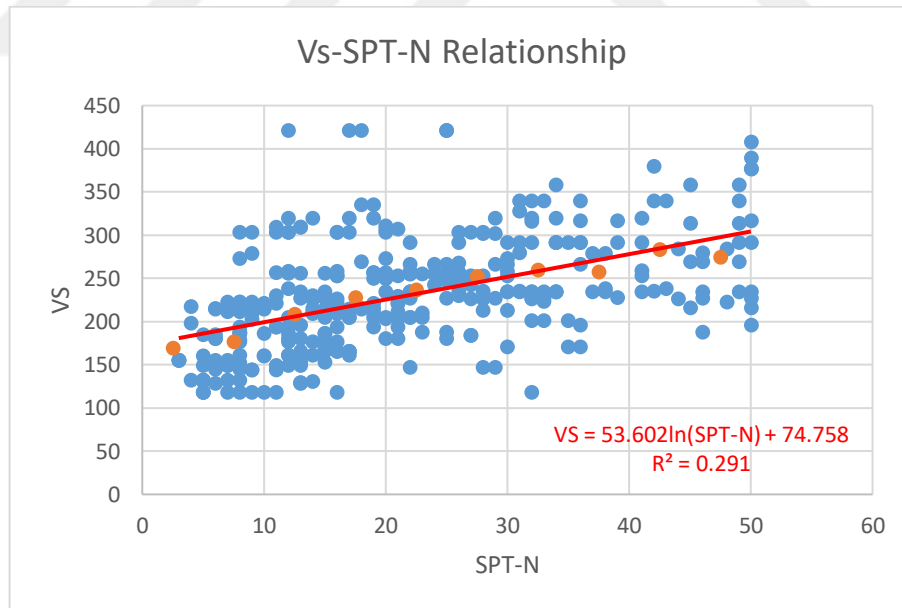


Figure 6.5: Vs (m/s) SPT-N relationship fit.

To determine the local soil class of the Kocaeli region, the Vs value was obtained from the SPT-N values using the equation specified in **Figure 6.4** and **Figure 6.5**.

6.1.3. SSE and RMSE Method

Sum of Squares Error (SSE) is a statistical measure commonly utilized in regression analysis. It quantifies the discrepancy between the observed values and the values predicted by a regression model. SSE serves as an indicator of the model's bias towards the observed data.

In regression analysis, the objective is to establish a relationship between independent variables (x values) and a dependent variable (y values). The model estimates the dependent variable based on the independent variables and calculates the difference between the predicted values (y') and the actual observations (y). These differences are squared and then summed to compute the SSE.

A smaller SSE indicates a better fit of the model to the observed data and implies more accurate predictions. Therefore, minimizing SSE is a common goal when evaluating the performance of regression models.

SSE is a fundamental metric used to assess the goodness of fit of a regression model. It is widely employed alongside other metrics such as R-squared and Root Mean Square Error (RMSE) for comprehensive model evaluation.

Table 6.2: SPT-N vs. Vs relationship from previous studies and the SPT-N vs. Vs relationship we found, including SSE and RMSE values.

Relationships	SSE	RMSE
OHBA_VS	1147069.088	3.051319
Imai 1975 $V_s = 76 N^{0.33}$	1288052.955	3.233402
fujiwara $V_s = 92.1 N^{0.337}$	1248783.551	3.183732
Ohsaki (1973) $V_s = 81.4 N^{0.39}$	1579569.553	3.580653
Imai et al (1975) $V_s = 89.9 N^{0.341}$	1209005.369	3.132615
Imai(1977) $V_s = 91 N^{0.337}$	1201958.387	3.123472
Ohta and Goto (1978) $V_s = 85.35 N^{0.348}$	1131418.486	3.030432
Seed and Idriss (1981) $V_s = 61.4 N^{0.5}$	2537980.593	4.538758
Imai and Tonouchi (1982) $V_s = 97 N^{0.314}$	1146211.661	3.050179
Jinan (1987) $V_s = 116.1(N+0.3185)^{0.202}$	6200165.452	7.094055
Athanasopoulos (1995) $V_s = 107.6 N^{0.36}$	3879396.563	5.611448
Sisman (1995) $V_s = 32.8 N^{0.51}$	3233248.428	5.122859
Iyisan (1996) $V_s = 51.5 N^{0.516}$	1643782.359	3.652709
Kanai (1966) $V_s = 19 N^{0.6}$	5604463.852	6.744658
Jafari et al (1997) $V_s = 22 N^{0.85}$	6998959.823	7.537193
Kiku et al (2001) $V_s = 68.3 N^{0.292}$	2641978.937	4.630816
Hasancebi and Ulusay (2006) $V_s = 90 N^{0.309}$	1032858.031	2.895431
acquired specifically for the field	994493.9585	2.841149

The measured V_s values were obtained by incrementally increasing the average velocity values from a depth of 1.5 meters to a depth of 30 meters at intervals of 1.5 meters. The Python code used for this process is presented in Figure 4. As an example, Figure 12 illustrates a measurement for station number 4105. This Python code was executed for each station.

Table 6.3: Here is an example of the station data for station number 4105.

VS							
Top depth	Mid depth	Bottom detph	Thicknes s	VS	Longitude	Latitude	Name
0	0.4	0.8	0.8	229	29.96935	40.67441	S-4105
0.8	1.35	1.9	1.1	221			
1.9	2.55	3.2	1.3	222			
3.2	4.05	4.9	1.7	243			
4.9	5.95	7	2.1	249			
7	8.2	9.4	2.4	256			
9.4	11.05	12.7	3.3	258			
12.7	14.7	16.7	4	265			
16.7	19.2	21.7	5	277			
21.7	26.85	32	10.3	448			

6.1.4. Calculation

```
import pandas as pd
from openpyxl import load_workbook
from openpyxl import Workbook

dosyaAdi = 'Tadas_VS.xlsx'

workbook = load_workbook(dosyaAdi, read_only=True, data_only=True)

result_workbook = Workbook()
result_writer = result_workbook.active

for sayfaAdi in workbook.sheetnames:
    sayfa = workbook[sayfaAdi]

    sayfa_df = pd.DataFrame(sayfa.values)

    sayfa_df = sayfa_df[2:]

    sayfa_df = sayfa_df.iloc[:, 7:10]

    print("\n")
    print(f'Sayfa Adı: {sayfaAdi}')

    col7 = sayfa_df[7].values
    col8 = sayfa_df[8].values
    col9 = sayfa_df[9].values

    idx = 0
    toplam = 0
    results = []

    for x in col7:
        if x > 1.5 and idx == 0:
            result = col8[idx] / col9[idx]
```

```

        print(idx, "büyüktür", x, "sonuç", result)
        toplam = toplam + result
        results.append(f'Vs,1.5 = {round(1.5 / toplam, 2)}
m/sn')
        break
    elif x > 1.5:
        result = (1.5 - col7[idx - 1]) / col9[idx]
        print(idx, "büyüktür", x, "sonuç", result)
        toplam = toplam + result
        results.append(f'Vs,1.5 = {round(1.5 / toplam, 2)}
m/sn')
        break
    elif x <= 1.5:
        result = col8[idx] / col9[idx]
        print(idx, "küçüktür", x, "sonuç", result)
        toplam = toplam + result
        idx = idx + 1
    print("Vs,1.5 = ", round(1.5/toplam,2),"m/sn \n")

    idx = 0
    toplam = 0

    for x in col7:
        if x > 3 and idx == 0:
            result = col8[idx] / col9[idx]
            print(idx, "büyüktür", x, "sonuç", result)
            toplam = toplam + result
            results.append(f'Vs,3 = {round(3 / toplam, 2)} m/sn')
            break
        elif x > 3:
            result = (3 - col7[idx - 1]) / col9[idx]
            print(idx, "büyüktür", x, "sonuç", result)
            toplam = toplam + result
            results.append(f'Vs,3 = {round(3 / toplam, 2)} m/sn')
            break
        elif x <= 3:
            result = col8[idx] / col9[idx]
            print(idx, "küçüktür", x, "sonuç", result)
            toplam = toplam + result
            idx = idx + 1
    print("Vs,3 = ", round(3/toplam,2),"m/sn \n")

    # (This structure is repeated for x > 4.5, 6, 7.5, etc.)

result_workbook.save('results224_tadas.xlsx')

```

Table 6.4: Measured average Vs velocities from 1.5 meters to 30 meters depth and the average Vs values of SPT-N.

Depth	1.5	3	4.5	6	7.5	9	10.5	12	13.5	15	16.5	18	19.5	21	22.5	24	25.5	27	28.5	30
S-4101	641.55	609.77	506.29	479.91	472.27	501.17	526.53	554.2	580.3	603.48	630.2	654.34	676.27	699.62	722.87	744.52	764.73	785.41	806.9	827.27
S-4102	839.06	841.67	786.56	745.65	771.42	796.6	830.63	863.35	890.96	918.68	942.68	963.66	977.13	987.26	996.21	1004.17	1005.57	1003.22	1001.14	999.27
S-4104	607.83	593.28	550.45	495.67	456.2	480.02	502.06	526.89	549.65	570.22	593.84	615.08	634.28	655.39	676.19	695.51	713.49	732.14	751.29	769.41
S-4105	225.2	223.45	228.7	233.1	236.52	239.56	241.96	243.86	245.72	247.52	249.01	251.01	252.84	254.42	259.06	266.07	272.58	278.65	284.3	289.59
S-4106	445.71	629.58	633.99	584.45	552.98	532.28	517.97	507.73	528.67	546.71	562.41	579.91	597.43	613.3	627.76	642.85	658.9	673.85	687.81	700.89
S-4115	127.01	230.42	225.04	222.44	207.19	196.97	190.72	197.92	203.9	208.96	214.9	221.9	228.2	233.89	239.06	244.83	250.17	255.11	259.7	263.97
S-4116	165.03	166.01	165.56	164.8	163.39	162.42	161.62	161.03	161.83	162.61	163.25	165.01	166.7	168.17	169.6	171.91	174	175.9	177.63	179.62
S-4119	300	594.13	652.06	685.47	707.89	734.14	736.21	730.85	712.92	699.21	688.37	678.06	668.74	660.94	654.34	648.66	655.56	664.73	673.15	680.91
S-4120	124.54	225.1	225.4	225.55	223.91	222.73	221.77	220.23	219.04	218.11	218.79	220.34	221.68	222.83	224.17	226.96	229.48	231.76	233.85	235.76
S-4121	120.87	241.74	278.23	278.42	278.54	276.74	275.15	273.97	273.18	272.85	272.59	272.37	272.19	274.47	277.25	279.73	281.95	283.95	286.09	289.81
S-4122	124.07	248.15	267.44	267.08	266.46	264.12	262.47	261.25	261.68	262.39	262.98	263.47	265.54	268.6	271.32	273.73	275.91	278.39	281.91	285.15
S-4123	156.9	273.77	275.49	275.88	272.11	269.65	265.94	260.36	256.18	252.93	255.78	258.39	260.63	262.59	266.55	273.29	278.57	283.43	287.92	292.36
S-4124	146.85	293.71	440.56	587.41	734.27	823.16	777.67	746.71	724.29	707.3	693.98	683.26	675.51	675.83	676.11	676.35	676.56	676.75	676.92	677.08
S-4126	166.85	205.31	205.34	199.85	188.25	174.56	167.94	173.14	177.41	182.05	189.12	195.43	201.12	205.86	209.92	213.6	216.97	220	222.44	224.69
S-4127	108.85	208.88	207.91	207.43	205.23	203.09	201.58	202.61	204.31	205.69	206.83	210.66	214.18	217.3	220.08	222.96	226.68	230.08	233.22	236.11
S-4128	130.11	228.88	228.59	228.39	227.29	226.56	226.53	227.55	228.36	229	230.52	231.95	233.18	234.24	235.92	237.99	239.84	241.52	243.03	244.6
S-4129	214.13	214.57	214.71	214.08	213.46	212.01	210.98	210.21	209.62	209.26	209.33	209.38	209.43	210.21	210.96	211.62	212.2	213.86	215.69	217.37
S-4130	274.31	548.62	663.55	665.15	666.11	664.01	660.77	658.36	656.5	650.25	644.16	639.17	635.01	631.56	629.28	627.29	625.56	624.02	622.65	622.45
S-4131	149.47	282.6	285.98	287.71	278.75	270.58	265.04	267.62	271.14	274.02	272.24	284.61	291.27	297.23	302.6	307.72	312.64	317.14	321.28	325.11
KS1	142.5	164.22	168.21	182.65	193.73	202.82	211.44	220.13	227.74	236.34	243.87	251.23	258.6	265.26	271.89	278.59	284.78	290.78	297.38	303.59
KS2	104.17	123.73	129.63	132.51	135.03	137.32	140.9	145.75	150.12	156.04	161.25	166.35	171.47	176.12	180.35	184.2	187.73	191.39	196.35	201.04
KS3	120.83	138.15	138.31	143.75	147.98	151.5	154.13	156.16	157.92	160.27	162.24	165.24	169.34	173.01	176.66	180.37	183.76	187.3	192.19	196.82
KS4	97.5	117.79	120.73	126.38	127.56	127.92	131.04	133.98	138.97	143.34	148.09	153.36	158.2	163.04	167.98	172.6	177.1	182.06	186.76	191.86
KS6	95.83	124.77	131.57	137.32	143.37	149.58	153.95	156.98	159.66	163.4	166.59	170.33	174.72	178.67	182.84	187.31	191.45	195.36	199.3	202.99
KS7	131.67	145.47	142.19	144.06	150.8	160.3	167.23	172.16	176.42	181.28	185.45	190.18	195.59	200.48	205.37	210.36	214.97	219.63	225.49	231.04
KS8	119.17	124.35	124.21	137.33	149.04	160.06	169.83	178.91	187.12	197.07	206.04	215.01	224.21	232.75	241.01	249.09	256.68	264	271.62	278.86
KS9	105	115.67	120.01	139.37	148.53	151.05	157.97	169.42	179.89	191.5	202.18	191.56	167.1	150.62	147.35	154.65	161.72	168.59	175.32	181.86
KS10	158.33	187.97	185.26	181.48	180.81	181.5	183.95	187.89	191.21	194.69	197.65	201.12	205.19	208.81	212.69	220.79	225.06	231.88	238.38	244.6
KS11	100.83	111.62	109.73	112.35	117.28	123.49	127.32	129.29	131.16	134.47	137.3	141.12	146.07	150.59	154.92	159.11	163.01	166.95	171.91	176.62
SP01	55.95	111.89	167.84	223.79	264.33	276.4	285.71	293.12	299.16	304.77	310.33	315.12	319.29	322.95	326.19	329.08	331.68	334.02	336.14	338.77
SP02	32.52	65.04	97.56	130.08	162.23	169.47	175.05	179.48	183.08	186.44	191.01	194.99	198.48	201.58	205.51	209.2	212.56	215.64	218.48	222.04
SP03	45.69	91.39	137.08	182.77	228.46	274.16	319.85	343.35	358.41	371.44	382.83	392.86	401.78	410.51	421.57	431.75	441.16	449.87	457.95	465.95
SP04	57.9	115.79	173.69	231.58	289.48	347.38	405.27	423.97	427.41	430.21	432.53	435.08	437.86	440.28	442.4	444.26	445.92	447.41	448.75	449.96
SP05	16.26	32.53	48.79	65.06	81.32	97.59	113.85	130.12	146.38	162.64	178.91	190.87	194.62	197.95	200.93	203.61	206.03	208.24	210.25	212.09
SP06	13	26	39.01	52.01	65.01	78.01	91.02	104.02	117.02	122.24	126.47	130.23	133.59	136.49	139.34	141.82	144.08	147.48	150.67	153.65
SP07	19.58	39.17	58.75	78.34	97.92	117.51	137.09	156.68	170.57	179.38	187.29	194.45	200.94	206.86	212.28	217.72	221.85	226.1	230.34	233.81
SP08	64.96	129.72	194.57	209.76	212.93	215.09	220.52	230.51	238.93	246.12	252.34	257.76	262.54	268	273.09	277.72	281.93	285.78	289.32	292.58
SP09	62.71	125.41	188.12	233.76	246.01	254.91	261.68	268.41	280.21	290.42	299.35	307.21	315.8	323.68	330.84	337.36	344.84	351.9	358.46	364.69
SP10	25.4	50.81	76.21	101.62	126.96	131.79	135.47	138.36	140.17	142.63	144.25	145.63	149.33	153.58	157.45	161.01	164.28	167.75	171.46	174.95
SP11	41.19	82.38	123.57	163.27	171.68	177.79	182.43	187.45	194.22	199.99	204.98	209.33	213.73	217.99	221.82	225.34	229.13	232.61	235.82	238.78
SP12	18.11	36.22	54.33	72.43	90.54	108.65	126.76	144.87	162.98	177.28	182.81	187.68	192.02	195.89	199.38	202.54	205.71	209.61	213.23	216.59
SP13	62.82	125.65	188.47	251.29	314.12	361.92	372.06	380.04	386.49	391.81	405.93	419.77	432.24	443.53	453.81	463.24	473.94	483.87	493.21	501.75
SP14	64.43	128.86	199	166.92	172.07	180.14	186.64	192.44	198.27	203.2	208.15	212.46	217.15	222.54	227.44	231.91	236	239.76	243.23	246.43
SP15	31.76	63.52	95.28	127.04	158.8	190.56	222.32	254.09	275.85	285.2	293.34	300.48	306.8	312.44	318.95	325.37	331.26	336.67	341.67	346.3
SP16	112.25	219.87	216.22	214.45	212.08	210.29	208.05	206.4	205.55	205.34	207.61	210.86	213.7	216.19	218.4	220.37	223.41	226.84	230	232.92
SP17	11.07	22.14	33.22	44.29	55.36	66.43	77.5	88.58	99.65	110.72	121.79	132.87	139.57	143.4	146.9	150.11	153.05	155.77	158.28	160.62
SP18	13.09	26.18	39.26	52.35	65.44	78.53	91.62	104.71	117.79	130.88	143.97	156.88	163.61	169.86	175.67	181.09	186.16	190.91	195.37	199.57
SP19	45.29	90.59	135.88	181.17	226.47	255.64	252.93	250.94	249.41	248.2	247.22	246.4	247.47	251.94	255.94	259.55	262.82	265.91	269.69	273.22
SP20	10.36	20.72	31.08	41.44	51.79	62.15	72.51	82.87	93.23	103.59	112.2	117.81	123.01	127.85	132.36	136.58	140.53	144.24	147.73	151.02
SP21	17.34	34.68	52.01	69.35	86.69	104.03	121.37	138.7	151.46	156.62	161.11	165.05	168.54	171.65	174.44	176.96	179.24	181.98	185.35	188.5
SP22	77.62	155.23	232.85	303.6	306.63	309.24	313.22	316.28	317.63	319.03	325.48	331.05	335.91	340.19	344	347.48	352.01	356.14	359.92	363.58
SP23	46.33	92.66	138.99	179.69	185.96	190.39	193.69	196.63	203.64	209.58	214.71	219.53	225.15	230.19	234.75	238.97	243.11	247.13	250.83	254.27
SP24	16.98	33.95	50.93	67.91	84.88	101.86	118.84	135.81	152.79	169.77	186.74	203.72	220.7	235.07	2					

The average V_s values were calculated for the boreholes reaching up to 30 meters depth and beyond for the SPT-N numbers. These boreholes are referred to as SK boreholes in the **Table 6.5** above.

In the **(Boore, Thompson, & Cadet, 2011)** study, a more comprehensive approach was adopted to estimate V_{s30} velocities for locations with depths less than 30 meters. The study utilized velocity profiles from sites in Japan, California, Turkey, and Europe. Notably, for the KiK-net network sites in Japan, V_{s30} was systematically higher for a given V_{sz} value compared to other regions. Initially, the relationships between V_{sz} and V_{s30} for depths less than 30 meters were examined, and equations were developed for depths ranging from 5 to 29 meters in 1-meter increments using KiK-net velocity profiles. Given that the data exhibited a log-normal distribution, a second-order polynomial was used to model the relationship between $\log V_{s30}$ and $\log V_{sz}$. Standard deviation values and equations were calculated within this framework. Consequently, V_{s30} prediction equations were formulated for depths from 5 to 29 meters, and these equations can be used to estimate V_{s30} for velocity profiles that do not extend to 30 meters. Additionally, since the velocity profiles for K-NET stations generally do not exceed 20 meters, it was noted that the KiK-net equations could be used for K-NET sites with depths up to 10 meters, while the California equations might be more appropriate for K-NET sites with depths of 20 meters.

In the **(Boore D. M., 2004)** study, various methods were employed to estimate V_{s30} velocities for locations with depths less than 30 meters. Among these methods, the correlation-based extrapolation method was particularly prominent. This method examined the relationships between V_{s30} and the velocities at certain depths (V_{sz}), and predictions were made using data from existing velocity profiles.

In the **(Boore, Thompson, & Cadet, 2011)** model, the values of 5, 10, 14, and 20 meters were used for V_{s30} and V_{sz} . In this study, we created a model for V_{sz} that ranges from 1.5 meters to 30 meters, incrementing by 1.5 meters. Graphs for some of these values, including 6, 12, 18, and 24 meters, are shown in **Figure 6.6**, **Figure 6.7**, **Figure 6.8** and **Figure 6.9** respectively.

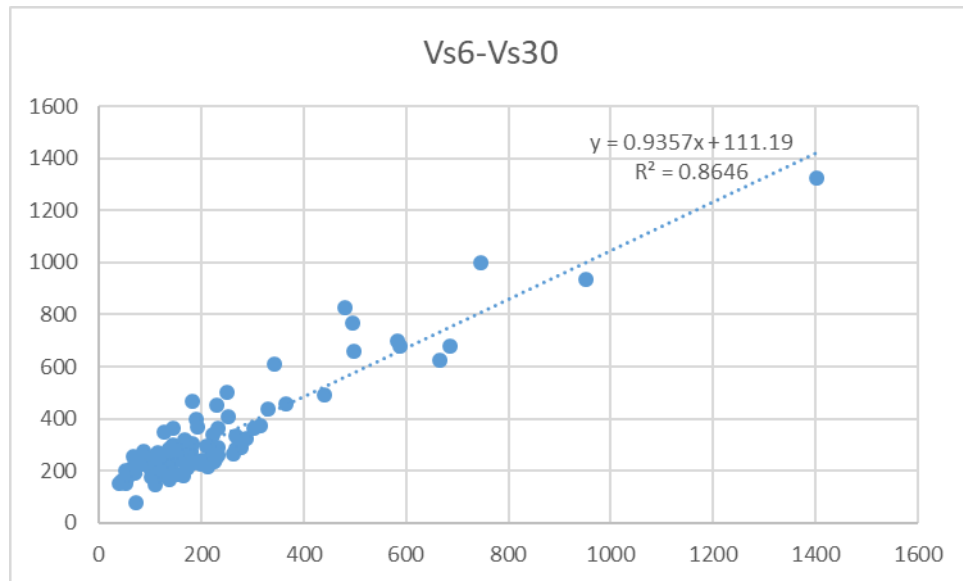


Figure 6.6: V_{s6} - V_{s30} (m/s) relationship.

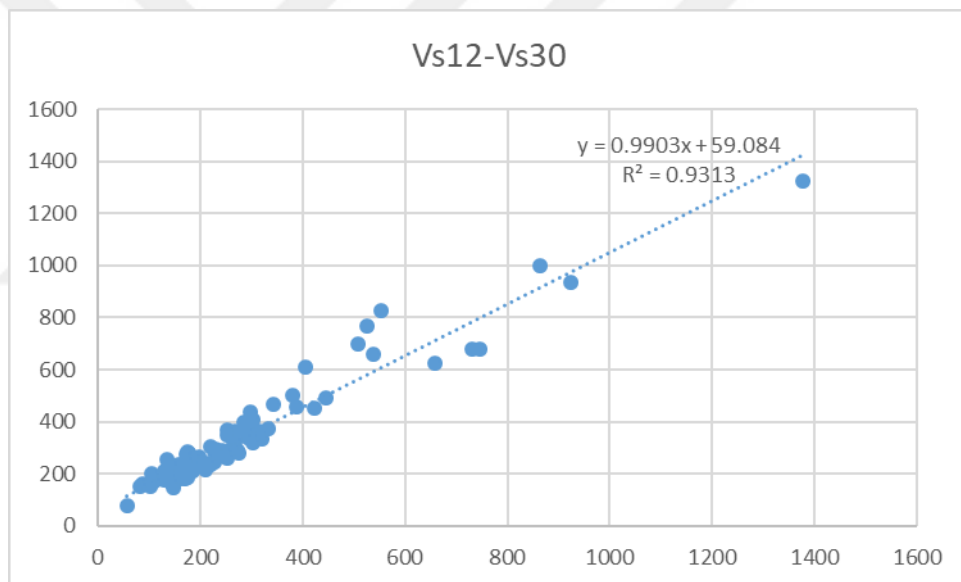


Figure 6.7: V_{s12} - V_{s30} (m/s) relationship.

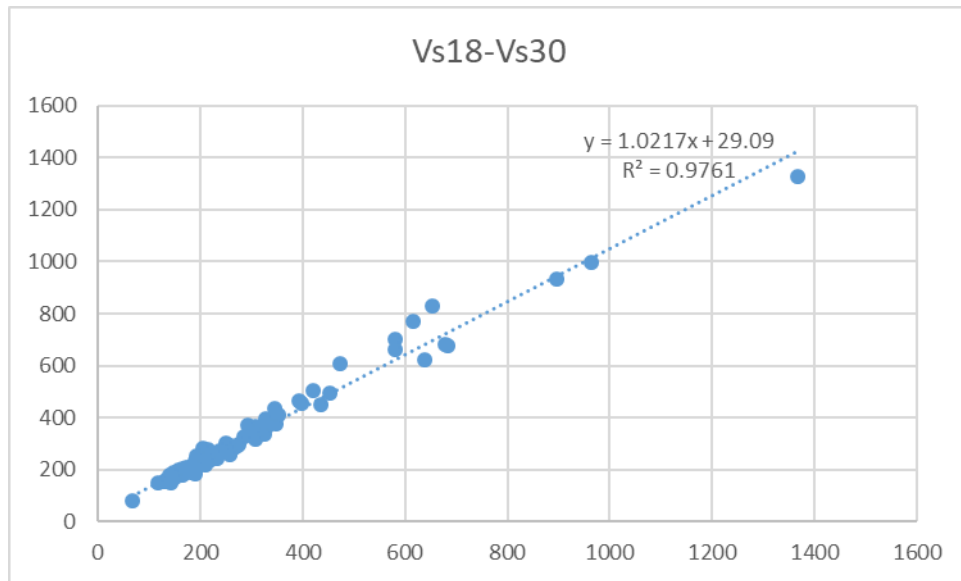


Figure 6.8: V_{s18} - V_{s30} (m/s) relationship.

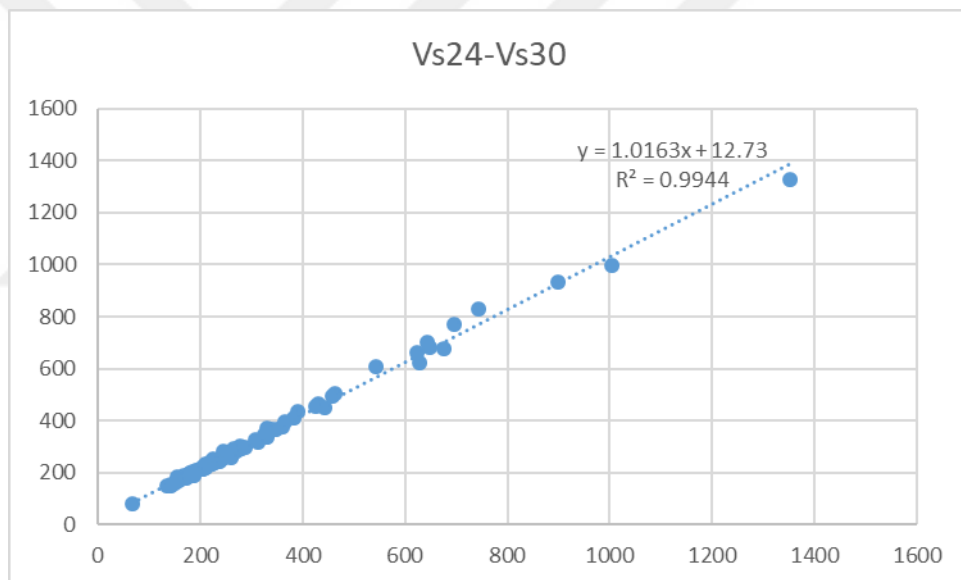


Figure 6.9: V_{s24} - V_{s30} (m/s) relationship.

Table 6.5: The coefficients and R^2 values of all obtained linear equations.

	a	b	R2
1.5	0.9391	205.53	0.6673
3	0.8803	162.49	0.7637
4.5	0.919	131.58	0.8392
6	0.9357	111.19	0.8646
7.5	0.9493	95.412	0.8786
9	0.9534	83.747	0.894
10.5	0.973	70.465	0.9145
12	0.9903	59.084	0.9313
13.5	1.0047	49.196	0.9463
15	1.0138	41.691	0.9579
16.5	1.0198	34.643	0.9688
18	1.0217	29.09	0.9761
19.5	1.0223	24.45	0.9825
21	1.0194	20.789	0.9873
22.5	1.0179	16.72	0.9913
24	1.0163	12.73	0.9944
25.5	1.0133	9.1053	0.9968
27	1.0095	5.7641	0.9986
28.5	1.005	2.6701	0.9997
30	1	1	1

Some of the SPT data are presented in **Table 6.6**. As observed, SPT-N values are missing at certain depths. To address this issue, interpolation methods have been employed to estimate the intermediate values at these depths.

Table 6.6: A portion of the SPT-N data.

[illegible]

According to the python code provided in below, all interpolated SPT-N values were utilized to calculate V_{s30} velocities for instances where the N values did not reach a

depth of 30 meters. In cases where the SPT-N values did not extend to 30 meters, the region-specific V_{sz} - V_{s30} relationship that we developed was employed to estimate V_{s30} . This method allowed us to calculate V_{s30} velocities from the interpolated SPT-N values for each station where the depth of the original SPT-N data was insufficient. By using this approach, we ensured more accurate and reliable V_{s30} estimates for each station within the region.

```
import pandas as pd
import os
from openpyxl import load_workbook
from openpyxl import Workbook

dosyaAdi = 'spt_1.5_30a_koda_gidecek.xlsx'

workbook = load_workbook(dosyaAdi, read_only=True, data_only=True)

result_workbook = Workbook()
result_writer = result_workbook.active

def vs30Hesapla(bottom_depth, vs_x):
    if bottom_depth == 1.5:
        vs = 0.9391 * vs_x + 25.593
    elif bottom_depth == 3:
        vs = 0.8033 * vs_x + 59.424
    elif bottom_depth == 4.5:
        vs = 0.7767 * vs_x + 65.342
    elif bottom_depth == 6:
        vs = 0.919 * vs_x + 113.58
    elif bottom_depth == 7.5:
        vs = 0.9357 * vs_x + 111.19
    elif bottom_depth == 9:
        vs = 0.9493 * vs_x + 95.412
    elif bottom_depth == 10.5:
        vs = 0.9534 * vs_x + 83.747
    elif bottom_depth == 12:
        vs = 0.973 * vs_x + 70.465
    elif bottom_depth == 13.5:
        vs = 0.9903 * vs_x + 59.384
    elif bottom_depth == 15:
        vs = 1.0047 * vs_x + 49.196
    elif bottom_depth == 16.5:
        vs = 1.0138 * vs_x + 44.691
    elif bottom_depth == 18:
        vs = 1.0198 * vs_x + 34.643
    elif bottom_depth == 19.5:
        vs = 1.0271 * vs_x + 29.489
    elif bottom_depth == 21:
        vs = 1.0223 * vs_x + 24.445
    elif bottom_depth == 22.5:
        vs = 1.0194 * vs_x + 20.789
    elif bottom_depth == 24:
        vs = 1.0179 * vs_x + 16.72
    elif bottom_depth == 25.5:
        vs = 1.0163 * vs_x + 12.737
    elif bottom_depth == 27:
        vs = 1.0133 * vs_x + 9.1053
```

```

elif bottom_depth == 28.5:
    vs = 1.0093 * vs_x + 5.7641
elif bottom_depth == 30:
    vs = 1.005 * vs_x + 2.6701
elif bottom_depth == 31.5:
    vs = 1 * vs_x + 1
else:
    vs = None
return vs

output_name = "Vs30_spt30.xlsx"

if os.path.exists(output_name):
    os.remove(output_name)

with pd.ExcelWriter(output_name, engine='openpyxl', mode='a' if os.path.exists(output_name) else
'w') as writer:

    output_rows = []

    for sayfaAdi in workbook.sheetnames:
        sayfa = workbook[sayfaAdi]
        sayfa_df = pd.DataFrame(sayfa.values)

        print("\n")
        print(f'Sayfa Adı: {sayfaAdi}')

        for index, row in sayfa_df.iterrows():
            if index == 0:
                continue
            count = 0
            total = 0
            sk_level_name = ""

            for column in sayfa_df.columns:
                if column == 0:
                    sk_level_name = row[column]
                    continue

                cell_value = row[column]
                if cell_value != "":
                    cell_value = float(cell_value)
                    result = 1.5/cell_value
                    total = total + result
                    count = count + 1

            bottom_depth = count * 1.5
            vs_x = 0
            vs_30 = 0

            if total > 0:
                vs_x = bottom_depth / total
                vs_30 = vs30Hesapla(bottom_depth, vs_x)
                print("SK level name:", sk_level_name)
                print("Bottom Depth:", bottom_depth)
                print("Toplam:", total)
                print("Vs_x:", bottom_depth, "=", round(vs_x, 2), "m/sn")
                print("Vs30:", round(vs_30, 2), "m/sn \n")

            output_rows.append({

```

```

        "SK Level": sk_level_name,
        "Bottom Depth": bottom_depth,
        "Total": total,
        "Vs X": vs_x,
        "Vs 30": vs_30
    })
    break

df = pd.DataFrame(output_rows)
df.to_excel(writer, index=False, header=True, sheet_name='Sheet1')

```

6.2. Geological-Based Proxy Model

6.2.1. Proxy Model Based on Geological Age

The Geology-Based Proxy Model is a method used to estimate V_{s30} (the time-averaged shear-wave velocity in the top 30 meters of a site), a crucial parameter in seismic hazard assessment. This model is particularly useful when direct measurements are not available, as it estimates V_{s30} values using geological and terrain-based indicators (proxies).

In their study, **(Stewart, et al., 2014)** highlight that V_{s30} can be estimated from proxy-based relationships developed for application on global or local scales when geophysical measurements are lacking. The method involves using proxies such as terrain type, surface geology, and surface gradients obtained from radar-based digital elevation models (DEMs). Their work in Greece demonstrated that utilizing these indicators can significantly enhance the accuracy of V_{s30} predictions by taking local geological conditions into account.

Similarly, **(Wills & Clahan, 2006)** emphasize the importance of the Geology-Based Proxy Model in their publication. They state, "Consideration of site conditions is a vital step in analyzing and predicting earthquake ground motion. The importance of amplification by soil conditions has long been recognized, but though many seismic-instrument sites have been characterized by their geologic conditions". This model aims to accurately determine local ground conditions, thereby minimizing potential damage during earthquakes. Their study in California used indicators like terrain slope and surface geology to estimate V_{s30} , showing that local geological conditions play a crucial role in improving the accuracy of these predictions.

The Geology-Based Proxy Model uses geological and terrain-based indicators to estimate V_{s30} values in a region, particularly when direct measurement data are insufficient. This model helps ensure accurate soil classification, which is essential for reducing earthquake-induced damage.

In our study, the relationship between the geological age, site conditions, and site classification of Kocaeli province with the obtained field data will be examined. The results of this analysis will be presented using histogram graphs.

The geological age and local soil characteristics of the region will be assessed to understand the correlation with the collected field data. This analysis aims to identify patterns and trends that are crucial for accurate site classification and ground motion prediction.

Histograms will visually represent the distribution and variability of the data, allowing for a clearer interpretation of the relationship between geological characteristics and site conditions. This approach is expected to enhance the understanding of the regional geology of Kocaeli and contribute to the development of more precise seismic hazard assessments.

In **Figure 6.10**, the map of the Kocaeli region, organized by geological age, shows the assigned borehole and V_s measurement points and **Figure 6.11** is the geological age map and its classification.

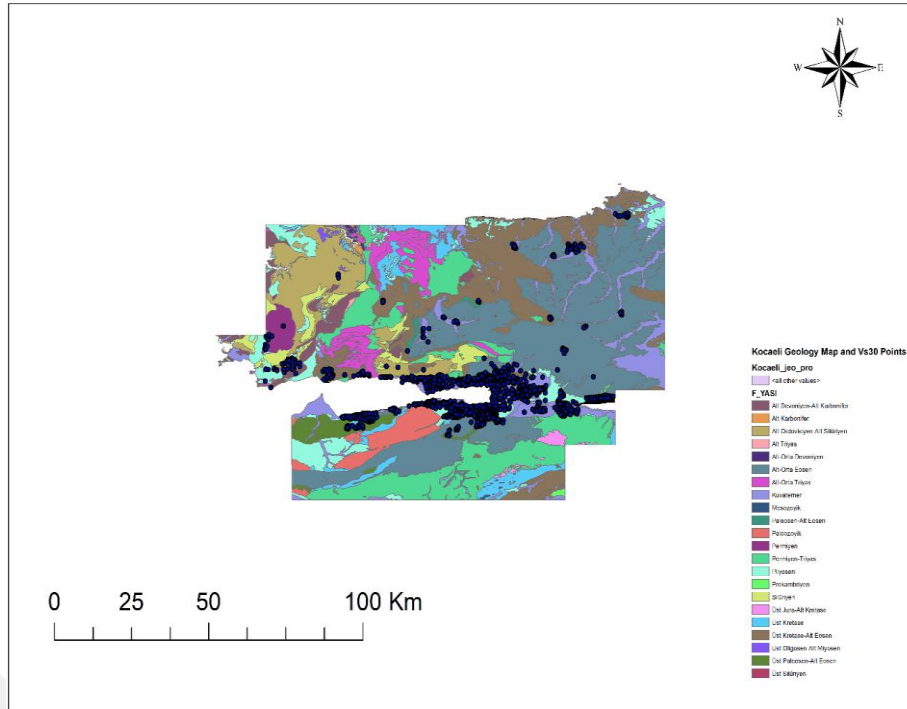


Figure 6.10: V_{s30} points in the Kocaeli province and the geological map of the Kocaeli province.

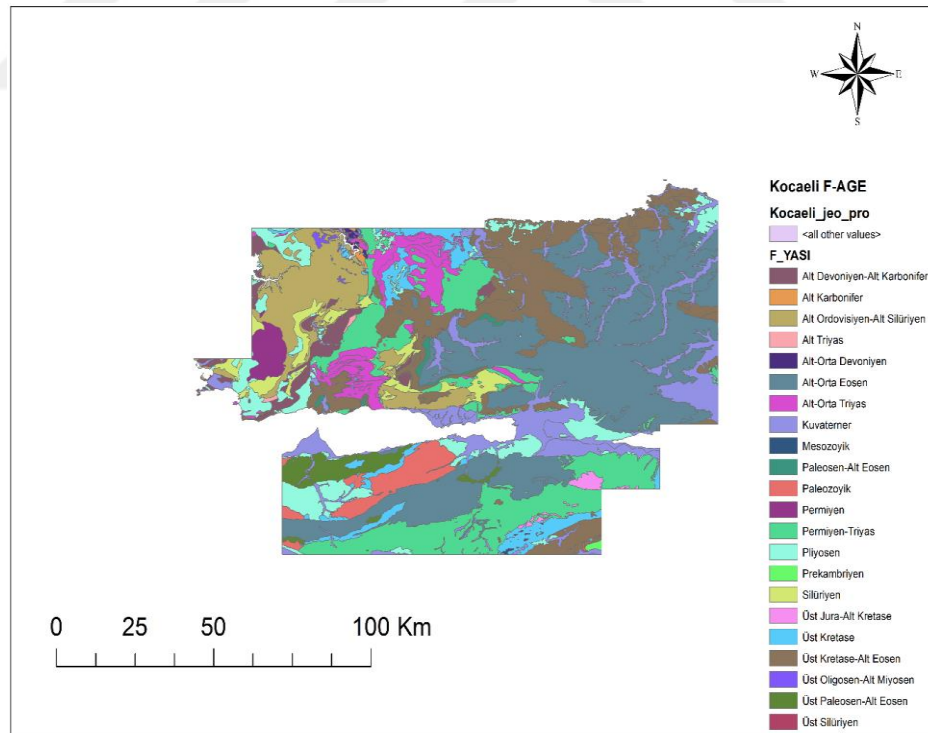


Figure 6.11: The map of the Kocaeli province according to its geological age.

Figure 6.12 illustrates the relationship between V_{s30} values and geological age in the Kocaeli province. This figure examines how V_{s30} values are distributed across different

geological age groups and their correlation. On the other hand, **Figure 6.13** presents histograms of Vs30 values by geological age in the Kocaeli province. These histograms show the frequency distribution of Vs30 values for each geological age group, helping to identify which value ranges are more common.

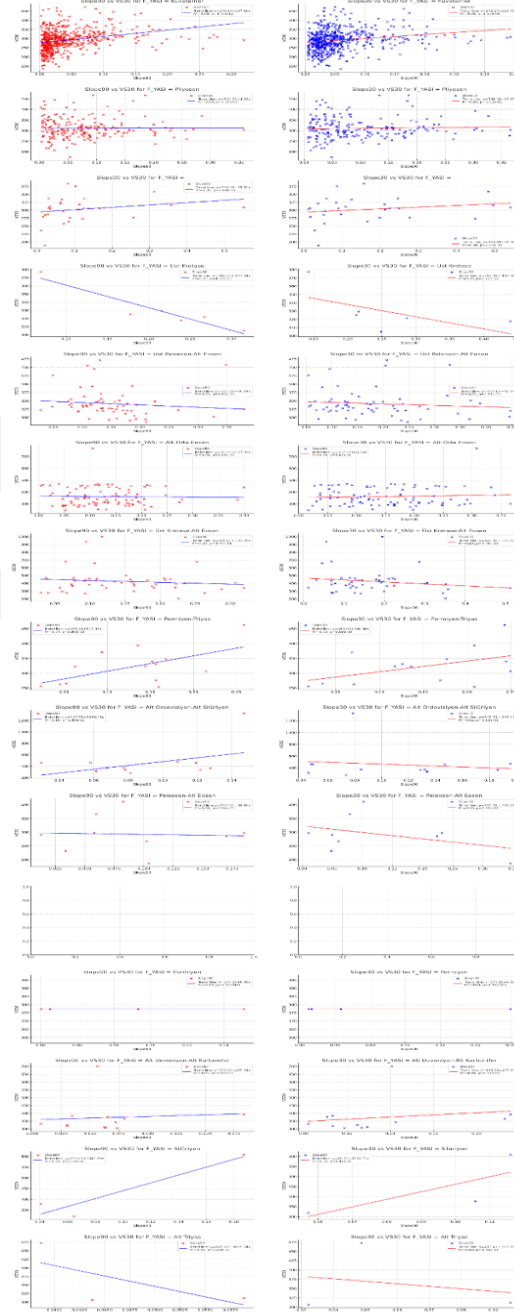


Figure 6.12: The relationship between Vs30 values and geological age in the Kocaeli province.

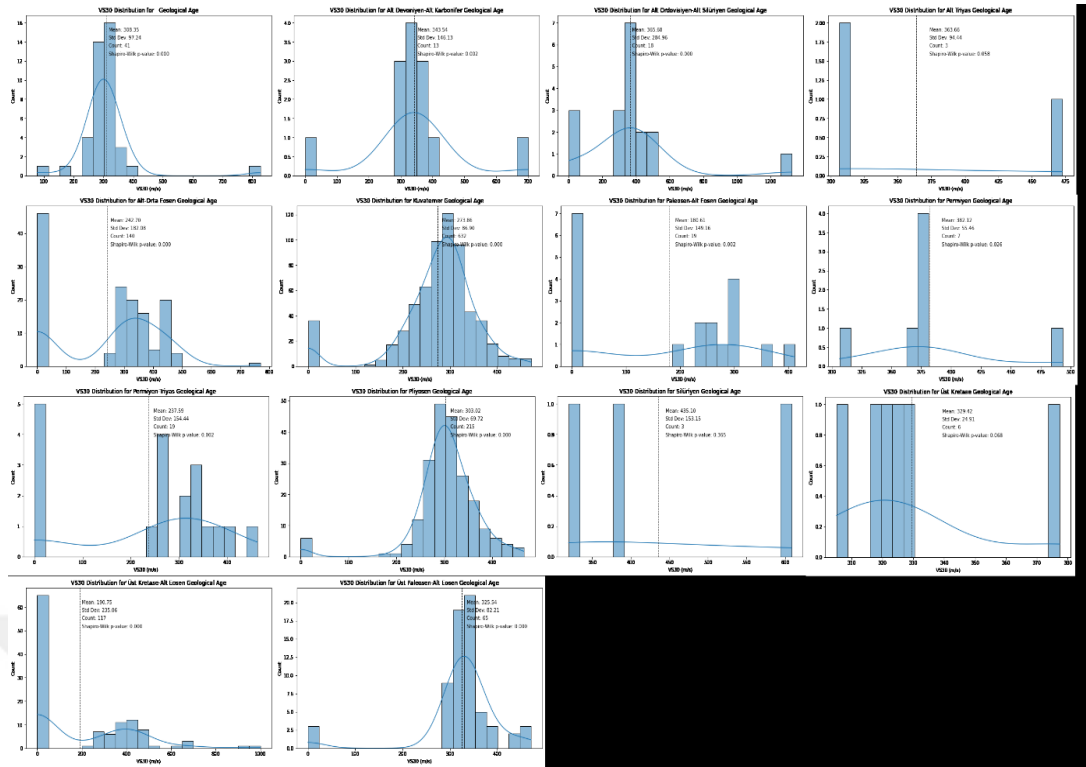


Figure 6.13: Histograms of V_{s30} values by geological age in the Kocaeli province.

6.2.1.1. Analysis and Interpretation of V_{s30} and Geological Age Data

The relationship between geological age classes and soil conditions in Kocaeli province was analyzed using field data. This analysis included evaluating the distribution of V_{s30} values according to geological age and their relationship with slope. Below are the results for each geological age class.

In the Lower Carboniferous (Ct) age class, V_{s30} values are widely scattered and show no distinct trend. The histogram reveals a highly heterogeneous distribution of V_{s30} values, indicating no specific pattern. The scatter plots also show no significant correlation, suggesting highly variable soil conditions. Due to the limited data, the reliability of analyses for this age class is low.

In the Permian (D13-Pzj-p) age class, V_{s30} values exhibit a more consistent distribution. The histogram shows V_{s30} values clustered within a narrower range and concentrated around a distinct mean. Scatter plots indicate a positive correlation between V_{s30} and geological age, suggesting more homogeneous soil characteristics for the Permian period. However, the limited data points reduce the generalizability of these findings.

In the Lower Devonian-Lower Carboniferous (d1d2c) age class, V_{s30} values tend to increase with geological age. The histogram shows higher V_{s30} values concentrated around the mean. Scatter plots confirm this positive trend, indicating that older soils are denser and more compact. The limited data available may affect the accuracy of these findings.

For Upper Cretaceous-Lower Eocene (D2-j2Q-e) soils, V_{s30} values are widely distributed without a clear correlation. The histogram shows a broad and heterogeneous distribution of V_{s30} values. Scatter plots reflect a wide range of data points, indicating no discernible trend. The limited data points suggest cautious interpretation of these results.

In the Lower-Middle Devonian (DCdb) age class, V_{s30} values show a tendency to increase with geological age. The histogram shows higher V_{s30} values concentrated within a narrow range. Scatter plots confirm this positive correlation, indicating more compact soils over time. However, the limited data may impact the reliability of these findings.

For Lower-Middle Eocene (e1e2, e1e2-V, sdtrgf) age classes, V_{s30} values exhibit a consistent distribution. Histograms show V_{s30} values clustered around a distinct mean with low variability. Scatter plots show data points clustered near the regression line, indicating more homogeneous soil characteristics. Nonetheless, the limited data affects the accuracy of these analyses.

In the Upper Jurassic-Lower Cretaceous (j2k1mr) age class, V_{s30} values tend to increase with geological age. The histogram shows higher V_{s30} values concentrated within a narrow range. Scatter plots confirm this positive correlation, indicating more compact soils over time. However, the limited data may reduce the reliability of these findings.

V_{s30} values in the Upper Cretaceous (k2-s, k2-V, k2e1-V, k2e1s, k2vm, O9-Mz-k2) age class are widely scattered and show no distinct trend. Histograms reveal a broad distribution of V_{s30} values with no specific concentration. Scatter plots indicate no discernible trend due to the wide range of data points. The limited data points reduce the generalizability of these results.

In the Mesozoic (of-Mz-Mz) age class, V_{s30} values tend to increase with geological age. The histogram shows higher V_{s30} values concentrated within a narrow range.

Scatter plots confirm this positive trend, indicating denser soils. However, the limited data may affect the accuracy of these findings.

For Lower Ordovician-Lower Silurian (OS) soils, V_{s30} values are widely scattered without a clear correlation. The histogram shows a broad and heterogeneous distribution of V_{s30} values. Scatter plots indicate no significant trend, suggesting highly variable soil conditions. The limited data points suggest cautious interpretation of these results.

In the Precambrian (pE-M1m) age class, V_{s30} values exhibit a more consistent distribution. The histogram shows V_{s30} values clustered within a narrow range and concentrated around a distinct mean. Scatter plots confirm this consistency, indicating more homogeneous soil characteristics. However, the limited data points affect the reliability of these analyses.

In the Pliocene (pls) age class, V_{s30} values tend to increase with geological age. The histogram shows higher V_{s30} values concentrated within a narrow range. Scatter plots confirm this positive correlation, indicating more compact soils over time. Nevertheless, the limited data affects the generalizability of these findings.

For Upper Paleocene-Lower Eocene (pn2e1-10-ks, pne1-7-sy) soils, V_{s30} values are widely scattered and show no distinct correlation. The histograms show a broad distribution of V_{s30} values. Scatter plots reflect no significant trend due to the wide range of data points, indicating heterogeneous soil conditions. The limited data points reduce the reliability of these results.

In the Permian-Triassic (pts) age class, V_{s30} values exhibit a more consistent distribution. The histogram shows V_{s30} values clustered within a narrow range and concentrated around a distinct mean. Scatter plots confirm this consistency, indicating more homogeneous soil characteristics. However, the limited data points affect the reliability of these analyses.

In the Paleozoic (Pzm) age class, V_{s30} values are widely scattered and show no distinct trend. The histogram reveals a broad distribution of V_{s30} values with no specific concentration. Scatter plots indicate no discernible trend due to the wide range of data points. The limited data points suggest cautious interpretation of these results.

In the Quaternary (Q-21-k, Q-22-k, Q-24-k, Q-29-k) age class, V_{s30} values exhibit a consistent distribution. Histograms show V_{s30} values clustered within a narrow range

and concentrated around a distinct mean. Scatter plots confirm this consistency, indicating more homogeneous soil characteristics. However, the limited data points affect the reliability of these analyses.

In the Upper Silurian (SDy) age class, V_{s30} values tend to increase with geological age. The histogram shows higher V_{s30} values concentrated within a narrow range. Scatter plots confirm this positive correlation, indicating more compact soils over time. The limited data points affect the reliability of these findings.

In the Silurian (Ss) age class, V_{s30} values are widely scattered and show no distinct correlation. The histogram shows a broad distribution of V_{s30} values. Scatter plots indicate no significant trend due to the wide range of data points, suggesting heterogeneous soil conditions. The limited data points suggest cautious interpretation of these results.

In the Lower-Middle Triassic (t1t2-s, t1t2k) age class, V_{s30} values exhibit a consistent distribution. Histograms show V_{s30} values clustered within a narrow range and concentrated around a distinct mean. Scatter plots confirm this consistency, indicating more homogeneous soil characteristics. However, the limited data points affect the reliability of these analyses.

In the Lower Triassic (ta-V) age class, V_{s30} values are widely scattered and show no distinct correlation. The histogram shows a broad distribution of V_{s30} values. Scatter plots indicate no significant trend due to the wide range of data points, suggesting heterogeneous soil conditions. The limited data points reduce the reliability of these results.

In the Upper Oligocene-Lower Miocene (Tom) age class, V_{s30} values exhibit a consistent distribution. Histograms show V_{s30} values clustered within a narrow range and concentrated around a distinct mean. Scatter plots confirm this consistency, indicating more homogeneous soil characteristics. However, the limited data points affect the reliability of these analyses.

Overall, the relationship between V_{s30} values and geological age classes in Kocaeli province varies across different age classes. Some classes show strong correlations and low variability, while others exhibit weak correlations and high variability. Particularly for classes with limited data points, the reliability of the results is reduced.

These findings provide important insights for accurate site classification and seismic hazard assessment.

6.2.2. Proxy Model Based on Site Classification

Figure 6.14 illustrates the site classification map of the Kocaeli province. This figure depicts the distribution of different site classes throughout the region, based on Vs30 values and other relevant criteria. On the other hand, **Figure 6.15** presents histograms of Vs30 values by site classification in the Kocaeli province. These histograms show the frequency distribution of Vs30 values for each site class, helping to identify which value ranges are more prevalent within each classification.

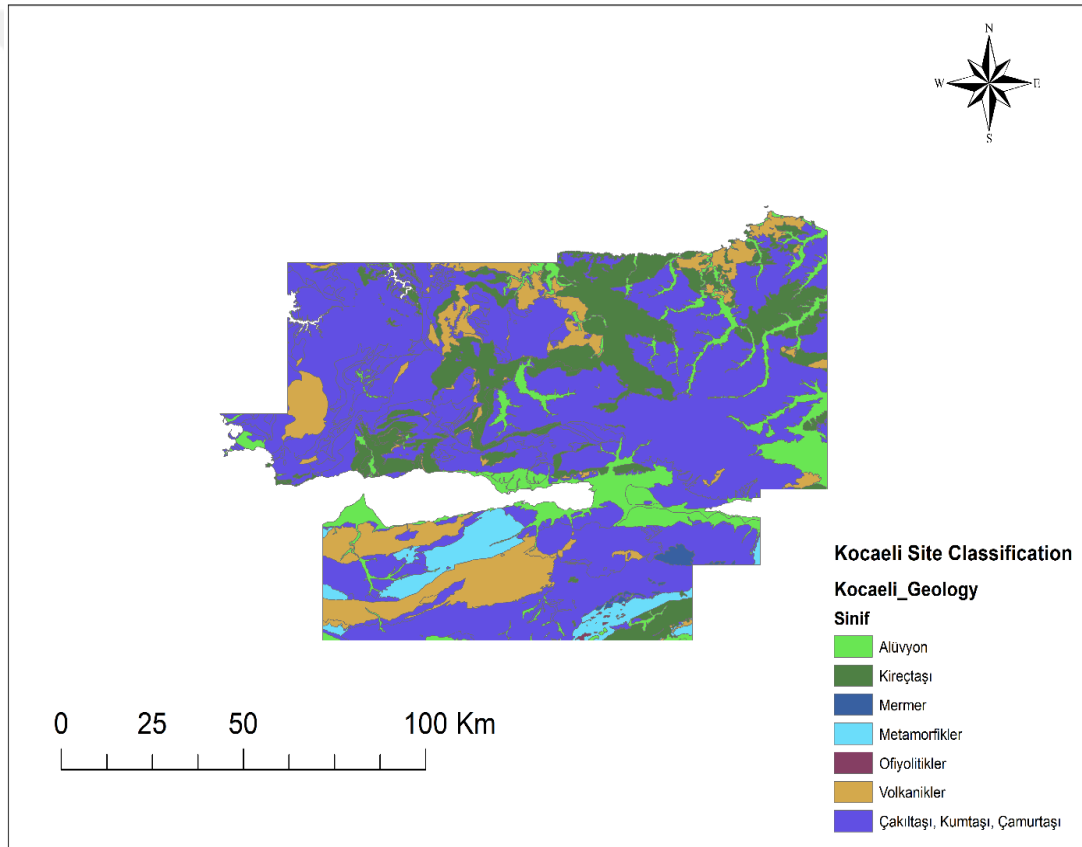


Figure 6.14: The site classification map of the Kocaeli province.

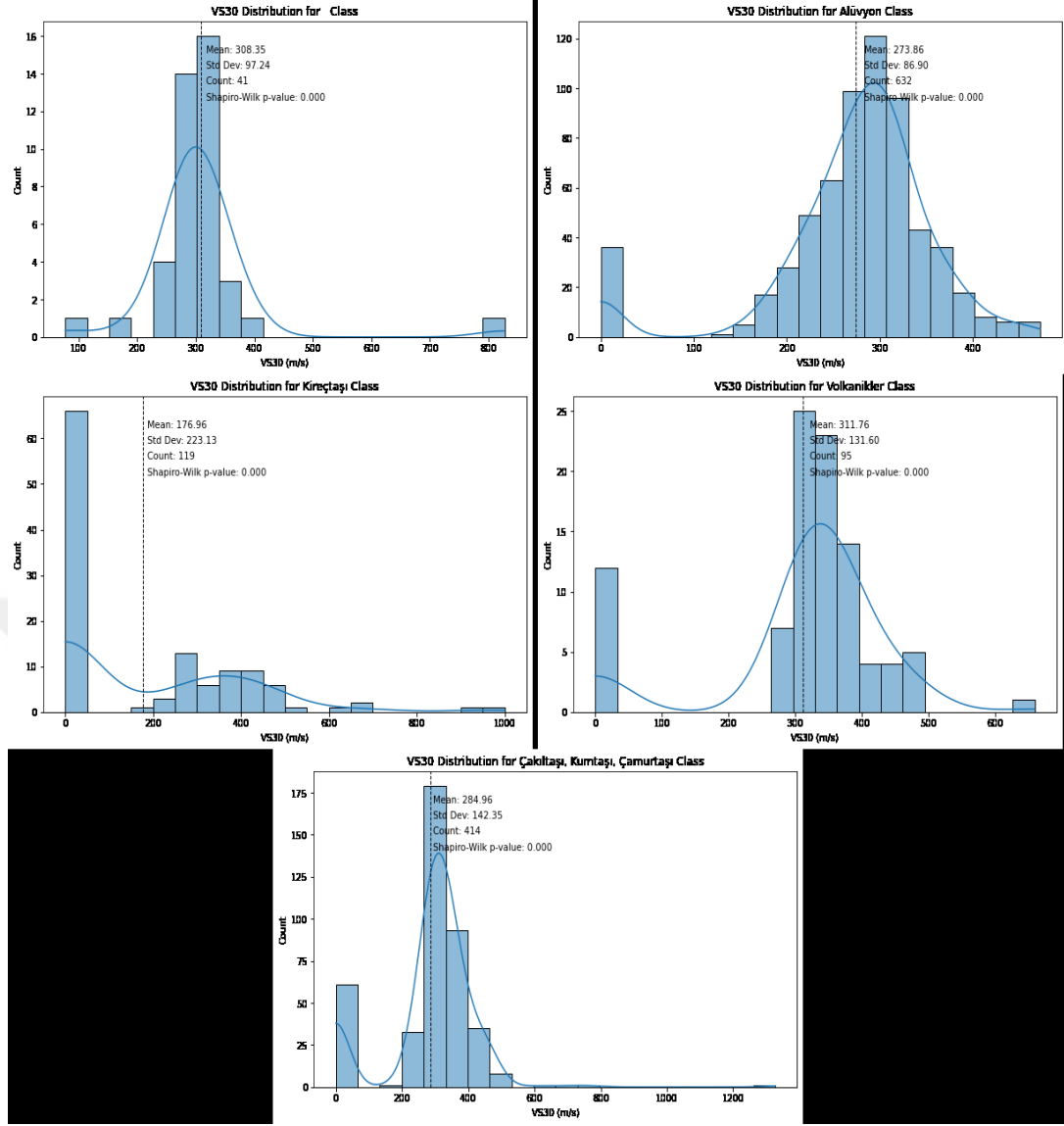


Figure 6.15: Histograms of V_{s30} values by site classification in the Kocaeli province.

6.2.2.1. Analysis of V_{s30} Distribution by Geological Classes

The V_{s30} (shear-wave velocity in the top 30 meters) distributions for different geological classes provide significant insights into the homogeneity and heterogeneity of soil conditions. For the first class, the V_{s30} values are concentrated within a narrow range with a mean of 303.58 m/s and a standard deviation of 97.4. This indicates relatively homogeneous soil conditions with a clear central tendency. However, the Shapiro-Wilk test yielded a p-value of 0.000, suggesting significant deviation from normal distribution.

In the alluvium class, the V_{s30} values show a wider range of distribution with a mean of 277.86 m/s and a standard deviation of 62.5, indicating moderate variability and somewhat heterogeneous soil conditions. The Shapiro-Wilk test p-value of 0.000 also indicates significant deviation from normality.

For the limestone class, V_{s30} values exhibit a broad range and high variability, with a mean of 176.56 m/s and a standard deviation of 129.31. This class displays highly heterogeneous soil conditions with substantial differences in V_{s30} values. The Shapiro-Wilk test p-value of 0.000 confirms the deviation from normal distribution.

The volcanic class, on the other hand, shows a more homogeneous distribution of V_{s30} values, with a mean of 211.76 m/s and a standard deviation of 73.56. This indicates relatively uniform soil conditions. The Shapiro-Wilk test p-value of 0.000 suggests that the data significantly deviates from normality.

Finally, for the gravelstone, sandstone, and sandy mudstone class, V_{s30} values are widely distributed, showing a significant range with a mean of 284.56 m/s and a standard deviation of 142.45. This indicates highly variable soil conditions. The Shapiro-Wilk test p-value of 0.000 again indicates a significant deviation from normal distribution.

Overall, the distribution of V_{s30} values by geological classes highlights the varying degrees of soil homogeneity and heterogeneity across different geological formations. Classes with more homogeneous soil conditions have V_{s30} values concentrated within narrower ranges, whereas classes with heterogeneous conditions exhibit wider distributions. The consistent p-values from the Shapiro-Wilk tests across all classes suggest that the V_{s30} data significantly deviates from normal distribution, warranting careful consideration in analysis.

6.2.3. Proxy Model Based on Site Condition

Figure 6.16 illustrates the site condition map of the Kocaeli province. This figure depicts the distribution of different site conditions throughout the region, based on V_{s30} values and other relevant criteria. On the other hand, **Figure 6.17** presents histograms of V_{s30} values by site condition in the Kocaeli province. These histograms show the frequency distribution of V_{s30} values for each site condition, helping to identify which value ranges are more prevalent within each condition.

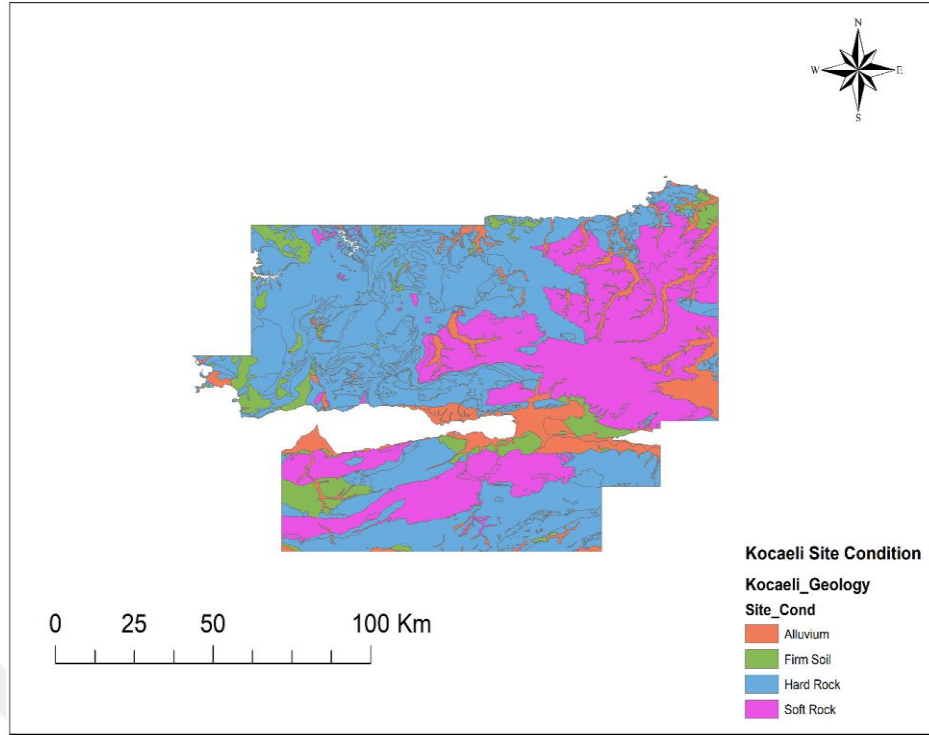


Figure 6.16: The site condition map of the Kocaeli province.

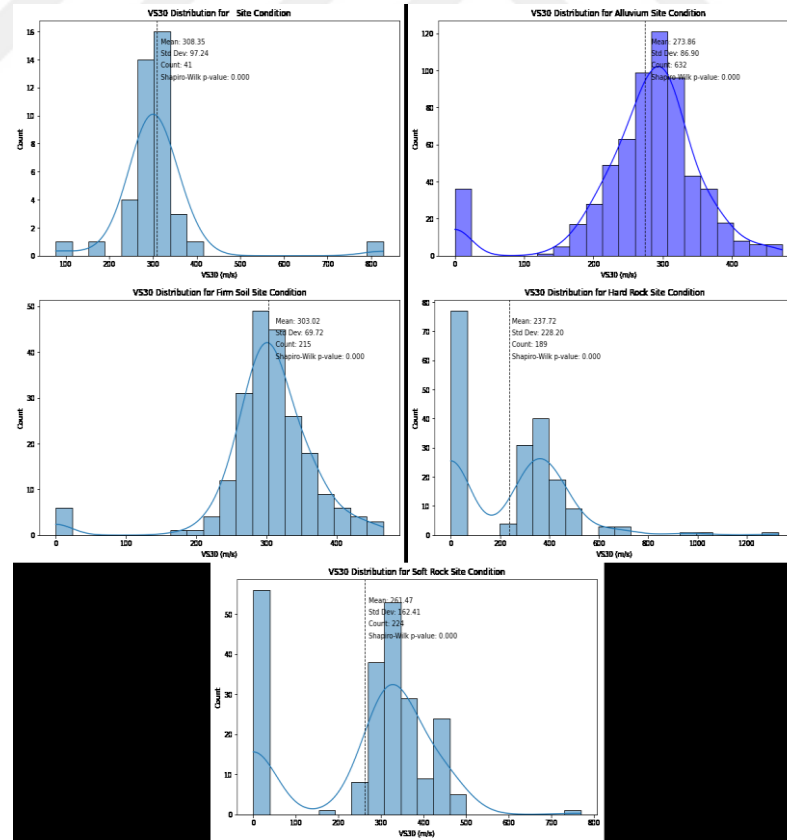


Figure 6.17: Histograms of V_{s30} values by site condition in the Kocaeli province.

6.2.3.1. Analysis of V_{s30} Distribution by Site Conditions

The analysis of V_{s30} (shear-wave velocity in the top 30 meters) distributions for different site conditions provides significant insights into the homogeneity and heterogeneity of soil properties. For the first site condition, V_{s30} values are concentrated within a narrow range, with a mean of 303.58 m/s and a standard deviation of 97.4. This indicates relatively homogeneous soil conditions with a clear central tendency. The Shapiro-Wilk test yielded a p-value of 0.000, suggesting significant deviation from normal distribution.

In the alluvium site condition, V_{s30} values show a wider range of distribution, with a mean of 277.86 m/s and a standard deviation of 62.5, indicating moderate variability and somewhat heterogeneous soil properties. The Shapiro-Wilk test p-value of 0.000 also indicates significant deviation from normality.

For the firm soil site condition, V_{s30} values exhibit a more consistent distribution, with a mean of 303.62 m/s and a standard deviation of 97.76, concentrated within a narrow range. This suggests that firm soil conditions are more homogeneous and show a clear central tendency. The Shapiro-Wilk test p-value of 0.000 confirms significant deviation from normal distribution.

In the hard rock site condition, V_{s30} values are widely distributed and exhibit high variability, with a mean of 237.12 m/s and a standard deviation of 73.56. This site condition shows highly heterogeneous soil properties, with large differences in V_{s30} values. The Shapiro-Wilk test p-value of 0.000 confirms significant deviation from normal distribution.

For the soft rock site condition, V_{s30} values are widely distributed, showing a significant range with a mean of 299.47 m/s and a standard deviation of 124.41. This site condition indicates highly variable soil properties, with substantial differences in V_{s30} values. The Shapiro-Wilk test p-value of 0.000 again indicates significant deviation from normal distribution.

Overall, the distribution of V_{s30} values by site conditions highlights the varying degrees of soil homogeneity and heterogeneity across different site types. Classes with more homogeneous soil conditions have V_{s30} values concentrated within narrower ranges, while classes with heterogeneous conditions exhibit wider distributions. The

Shapiro-Wilk test results across all site conditions suggest that the V_{s30} data significantly deviates from normal distribution, warranting careful consideration in analysis.

6.3. Terrain Categories

6.3.1. V_{s30} Proxy Model Based on Terrain Categories

The V_{s30} proxy model based on terrain categories is a method used to estimate the shear-wave velocity (V_{s30}) in the top 30 meters of the Earth's surface by utilizing terrain attributes. Terrain categories are typically derived from digital elevation models (DEMs) and can include parameters such as slope, curvature, and surface roughness. These attributes are used to classify the terrain into different categories, each of which is associated with specific V_{s30} values based on empirical relationships.

In this model, terrain categories serve as proxies for subsurface geological conditions. The underlying assumption is that certain terrain features correlate with specific soil or rock types, which in turn influence shear-wave velocities. For example, flat and low-lying areas might correspond to soft soils with lower V_{s30} values, while steep, rugged terrains might indicate the presence of hard rocks with higher V_{s30} values. By mapping these terrain categories across a region, it is possible to generate a V_{s30} map that provides critical information for seismic hazard assessment and engineering applications.

This approach offers a cost-effective alternative to direct measurements of V_{s30} , which can be expensive and logistically challenging, especially in large or inaccessible areas. The use of terrain categories leverages readily available topographic data to predict V_{s30} values with reasonable accuracy, facilitating better-informed decision-making in geotechnical and seismic risk analyses.

(Iwahashi & Pike, 2007) developed a method based on three main parameters to identify 16 terrain types using digital elevation models (DEMs). The study focused on slope gradient, local convexity, and surface texture. Slope was calculated using the slope subroutine of ArcInfo, which determines slope angles in degrees with a 3x3 cell matrix. Local convexity was used to identify positive (convex), negative (concave), and zero (flat) areas, expressed as the percentage of convex-upward cells within a

specific radius. Surface texture was determined using a spatial convolution filtering technique that captures differences between the original DEM and a median-filtered DEM, measuring the number of surface pits and peaks within an optimal radius. These three parameters were classified using an unsupervised nested-means algorithm, generating binary grayscale images based on average values and categorizing them into 8, 12, or 16 classes. This method was applied globally at a 1 km resolution, providing more detailed and accurate classification when high-resolution data sets were used. The classes were calibrated and defined by comparing them with existing topographic maps and geological structures (Iwahashi & Pike, 2007).

(Yong, Hough, Iwahashi, & Braverman, 2012) developed a geomorphometry-based approach to identify 16 terrain types. This classification was performed using an automated terrain classification scheme based on taxonomic criteria such as slope gradient, local convexity, and surface texture. The 16 terrain types were systematically identified from 1 km resolution Shuttle Radar Topography Mission digital elevation models **(Farr, et al., 2007)**. A simulation-based statistical method was applied to determine the mean V_{s30} values for each terrain type. This method was compared with models based on individual proxies such as mapped surface geology and topographic slope, demonstrating that the systematic terrain-based approach performed better than semi-empirical estimates based on individual proxies.

The mean values of slope, texture, and curvature were recalculated and reclassified, and these data were combined to form 8 terrain classes. This classification was performed by optimizing the categories representing specific ranges of each parameter, resulting in more homogeneous and distinct categories. The creation of these 8 terrain classes allows for a clearer and more practical analysis of terrain types.

6.3.2. DEM Data, Slope, Curvature, and Texture Concepts

Digital Elevation Model (DEM) is a dataset that numerically represents the topographic surface of the terrain, containing elevation data. DEM data are obtained by measuring the elevation of the terrain at a specific resolution and are used in various applications such as geomorphological analysis, land classification, and environmental modeling.

Concepts of Slope, Curvature, and Texture

- **Slope:** Slope is the angle or steepness of a surface relative to the horizontal plane. Slope derived from DEM data shows the rate of change in elevation across the terrain surface. It has significant implications for environmental processes such as water flow, soil erosion, and vegetation growth.
- **Curvature:** Curvature refers to the degree of bending of a surface and is divided into profile curvature and plan curvature. Profile curvature indicates the rate of change in slope, while plan curvature affects the direction of water flow. Curvature is used to determine the shape of the topography and drainage patterns.
- **Texture:** Surface texture represents the roughness and heterogeneity of the terrain surface. Texture measures the complexity and variations of the surface and plays an important role in land classification and determining soil properties.

DEM Resolutions and SRTM Data

DEM data can be obtained at different resolutions, which determine how detailed the representation of the terrain surface is:

- **1 Arc-Second DEM:** Provides approximately 30-meter resolution and high-detail terrain data. This resolution is suitable for small-scale studies and detailed analyses.
- **3 Arc-Second DEM:** Provides approximately 90-meter resolution and medium-detail terrain data. It is suitable for broader-scale studies. Data at this resolution are typically provided by the SRTM (Shuttle Radar Topography Mission) and are used in extensive topographic analyses worldwide.
- **30 Arc-Second DEM:** Provides approximately 900-meter resolution and low-detail terrain data. This resolution is suitable for large-scale regional or global studies.

SRTM (Shuttle Radar Topography Mission), conducted by NASA and NGA (National Geospatial-Intelligence Agency) in 2000, has provided high-resolution DEM data for much of the Earth's surface. SRTM data are available at 1 arc-second (approximately 30 meters) and 3 arc-second (approximately 90 meters) resolutions, offering high accuracy and detail. These data are widely used for global terrain analyses and are particularly valuable for slope, curvature, and texture analyses.

The slope, curvature, and texture information derived from SRTM data are crucial for various applications such as land classification, natural hazard risk assessment, and environmental modeling. These data provide a fundamental component for understanding and modeling the physical characteristics of the terrain surface and enable detailed examination of geomorphological processes.

6.3.3.1 Arc-Second Gradient Terrain Categories for Kocaeli Province

6.3.3.1. Description of Maps and Analysis

Figure 6.18 presents the DEM data for Kocaeli province at a resolution of 1 arc-second, equivalent to 30 meters. This high-resolution DEM data was utilized to perform various terrain analyses using ArcMap 10.3.

Figure 6.19 illustrates the slope analysis derived from the DEM data. Slope represents the steepness or incline of the terrain surface, which is critical for understanding water flow, erosion potential, and other environmental processes.

Figure 6.20 depicts the curvature analysis, which includes both profile and plan curvature. Curvature analysis helps in understanding the topographic shape and drainage patterns of the terrain.

Figure 6.21 shows the texture analysis of the terrain. Texture analysis measures the roughness and heterogeneity of the surface, providing insights into the complexity and variation of the terrain features.

Figure 6.22 demonstrates the reclassification analysis. Reclassification involves categorizing the terrain into different classes based on specific criteria, such as slope, curvature, and texture. This process is essential for various applications, including land use planning, risk assessment, and environmental management.

These analyses, conducted using ArcMap 10.3, provide a comprehensive understanding of the terrain characteristics in Kocaeli province, leveraging high-resolution DEM data to support detailed geomorphological and environmental studies.

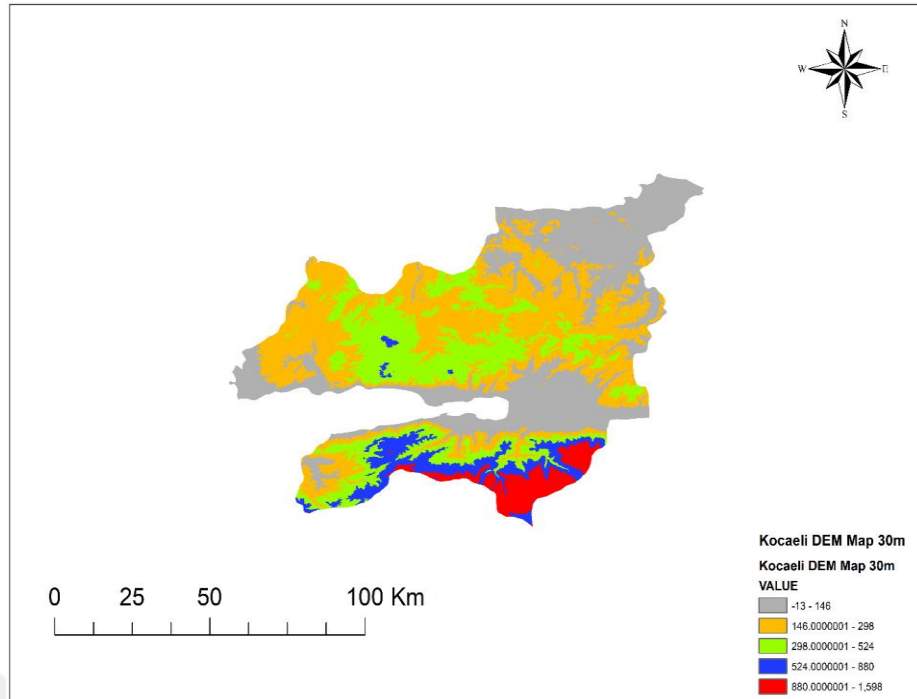


Figure 6.18: 1 arc-sec Digital Elevation Map (DEM).

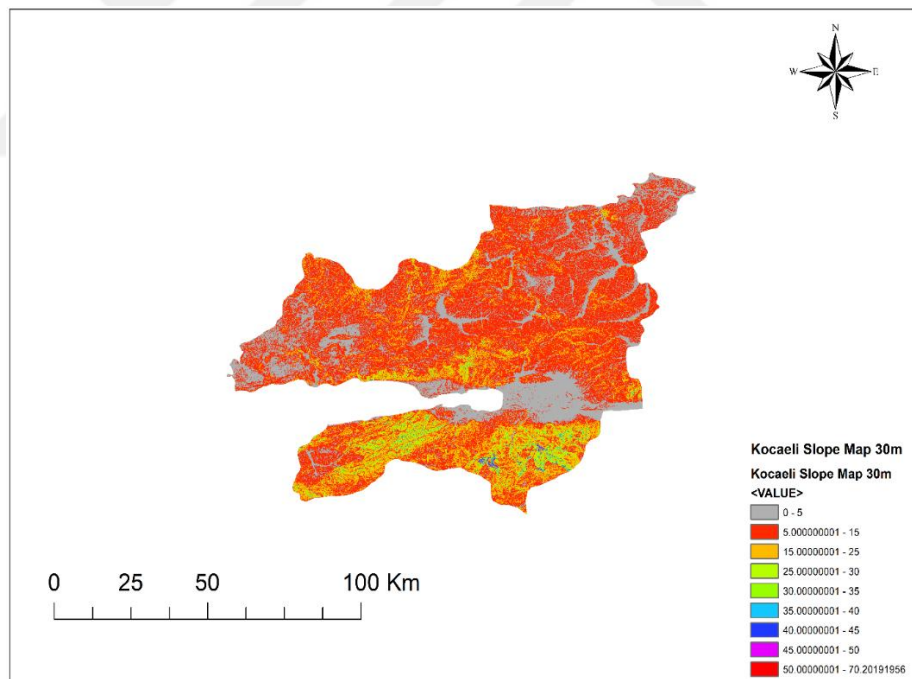


Figure 6.19: 1 arc-sec Slope Map.

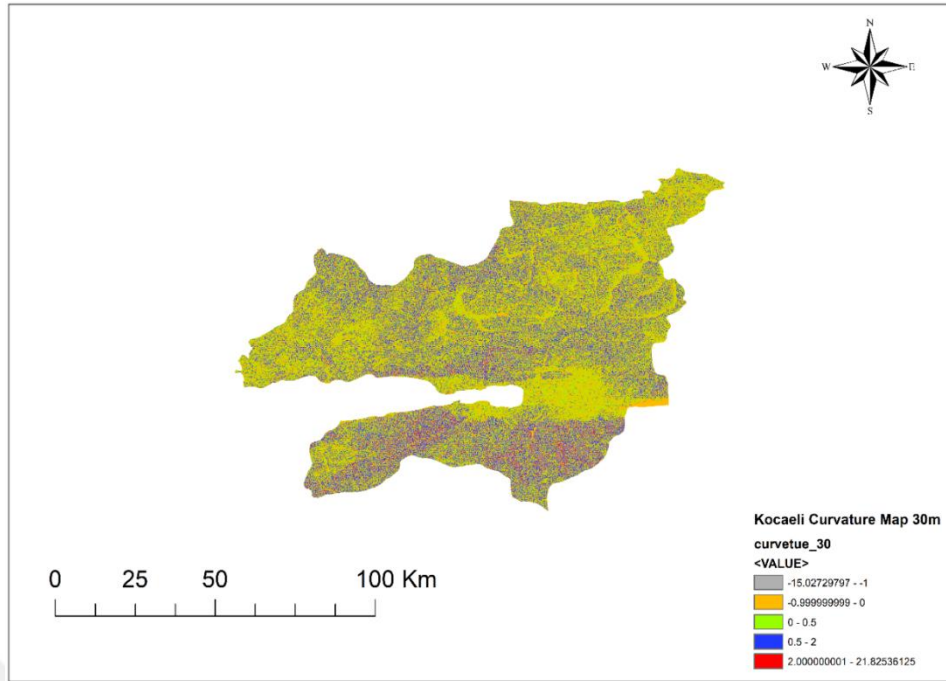


Figure 6.20: 1 arc-sec Curvature Map.

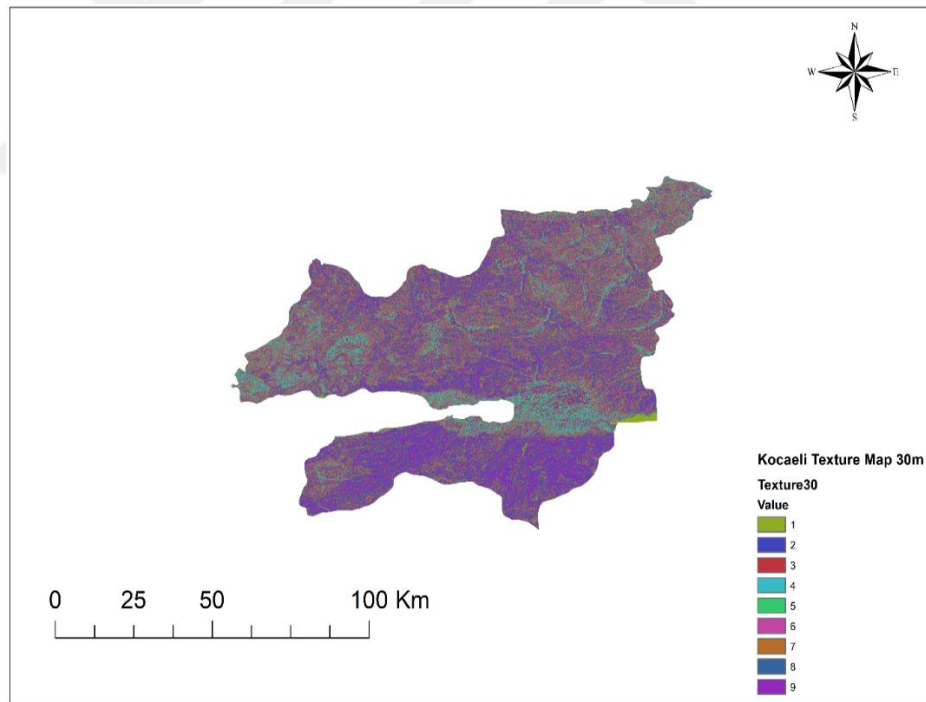


Figure 6.21: 1 arc-sec Texture Map.

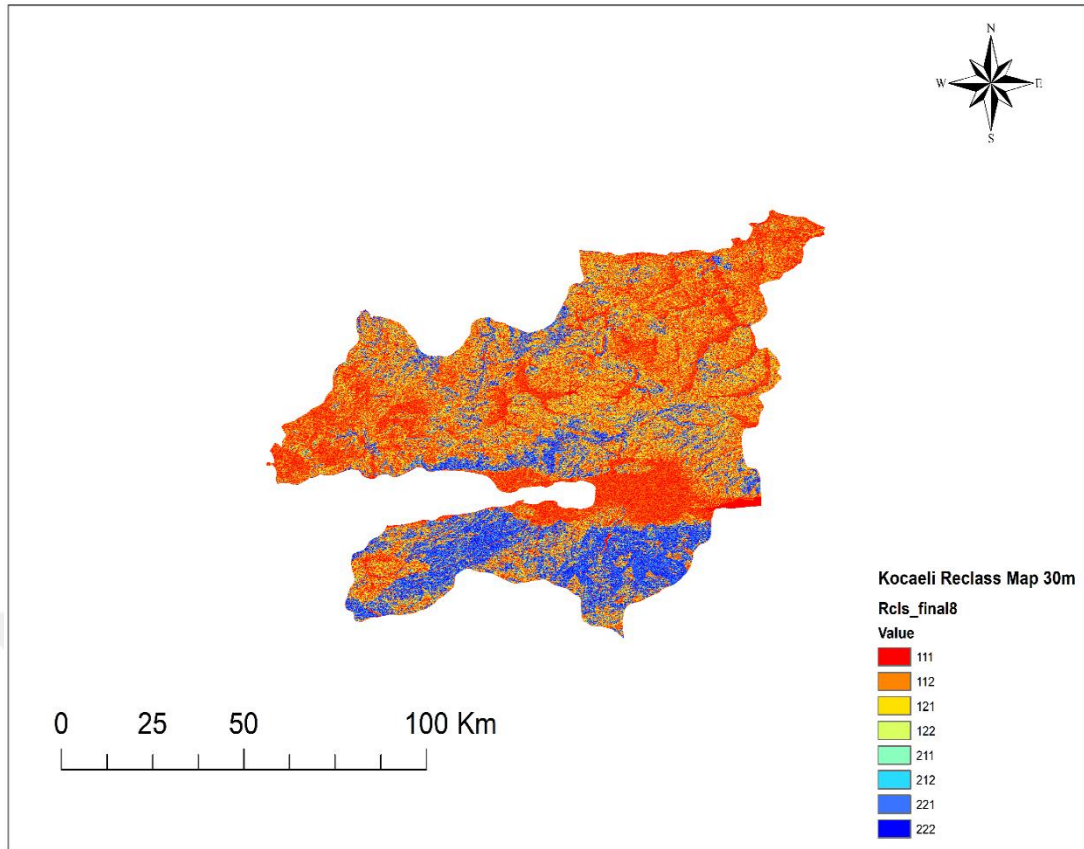


Figure 6.22: 1 arc-sec Reclass Map.

6.3.3.2. Definitions of Terrain Categories

Terrain categories are classified based on slope, curvature, and texture characteristics as follows:

- **111:** Low slope, low curvature, and fine texture
- **112:** Low slope, low curvature, and coarse texture
- **121:** Low slope, high curvature, and fine texture
- **122:** Low slope, high curvature, and coarse texture
- **211:** High slope, low curvature, and fine texture
- **212:** High slope, low curvature, and coarse texture
- **221:** High slope, high curvature, and fine texture
- **222:** High slope, high curvature, and coarse texture

This classification plays a crucial role in the detailed analysis of terrain characteristics and the identification of different terrain types. Low slope and low curvature typically

represent flatter and less rugged areas, while high slope and high curvature indicate steeper and more complex topographic features. Fine and coarse textures provide information about the surface roughness and heterogeneity, which are critical for assessing soil properties and land use potential.

6.3.3.3. Analysis

Table 6.7: 1 arc-sec map regression analysis.

ÖZET ÇIKIŞI									
<i>Regresyon İstatistikleri</i>									
Çoklu R	0.037560037								
R Kare	0.001410756								
Ayarlı R Kare	0.000640933								
Standart Hata	302.2204838								
Gözlem	1300								
ANOVA									
	<i>df</i>	<i>SS</i>	<i>MS</i>	<i>F</i>	<i>Anlamlılık F</i>				
Regresyon	1	167618.549	167618.549	1.835161476	0.175754853				
Fark	1299	118647049.9	91337.22083						
Toplam	1300	118814668.4							
	<i>Katsayılar</i>	<i>Standart Hata</i>	<i>t Stat</i>	<i>P-değeri</i>	<i>Düşük %95</i>	<i>Yüksek %95</i>	<i>Düşük 95.0%</i>	<i>Yüksek 95.0%</i>	
Kesişim	0	#YOK	#YOK	#YOK	#YOK	#YOK	#YOK	#YOK	
269.936188	-0.006736467	0.004972732	-1.354681319	0.175754672	-0.016491931	0.003018998	-0.016491931	0.003018998	

As shown in **Table 6.7**, the regression analysis results indicate that the R Square value is 0.0014, meaning only 0.14% of the variability in the dependent variable (V_{s30}) is explained by the independent variable (slope). This low R square value suggests that the slope is not a strong predictor of V_{s30} in this model. Additionally, the P-value for the F-statistic is 0.176, which is greater than the commonly used significance level of 0.05. This indicates that the regression model is not statistically significant, meaning there is insufficient evidence to suggest that the slope has a meaningful linear relationship with V_{s30} . The linear equation derived from the regression analysis is:

$$V_{s30}=269.936188-0.006736467\times\text{slope}$$

This equation represents the predicted V_{s30} value based on the slope, where the intercept (269.936188) indicates the expected V_{s30} value when the slope is zero, and the slope coefficient (-0.006736467) represents the change in V_{s30} for a one-unit increase in the slope.

The results were not reasonable; therefore, the V_{s30} proxy model map was not created.

6.3.4.3 Arc-Second Gradient Terrain Categories for Kocaeli Province

6.3.4.1. Description of Maps and Analysis

Figure 6.13 presents the DEM data for Kocaeli province at a resolution of 3 arc-second, equivalent to 90 meters. This high-resolution DEM data was utilized to perform various terrain analyses using ArcMap 10.3.

Figure 6.14 illustrates the slope analysis derived from the DEM data. Slope represents the steepness or incline of the terrain surface, which is critical for understanding water flow, erosion potential, and other environmental processes.

Figure 6.15 depicts the curvature analysis, which includes both profile and plan curvature. Curvature analysis helps in understanding the topographic shape and drainage patterns of the terrain.

Figure 6.16 shows the texture analysis of the terrain. Texture analysis measures the roughness and heterogeneity of the surface, providing insights into the complexity and variation of the terrain features.

Figure 6.17 demonstrates the reclassification analysis. Reclassification involves categorizing the terrain into different classes based on specific criteria, such as slope, curvature, and texture. This process is essential for various applications, including land use planning, risk assessment, and environmental management.

These analyses, conducted using ArcMap 10.3, provide a comprehensive understanding of the terrain characteristics in Kocaeli province, leveraging high-resolution DEM data to support detailed geomorphological and environmental studies.

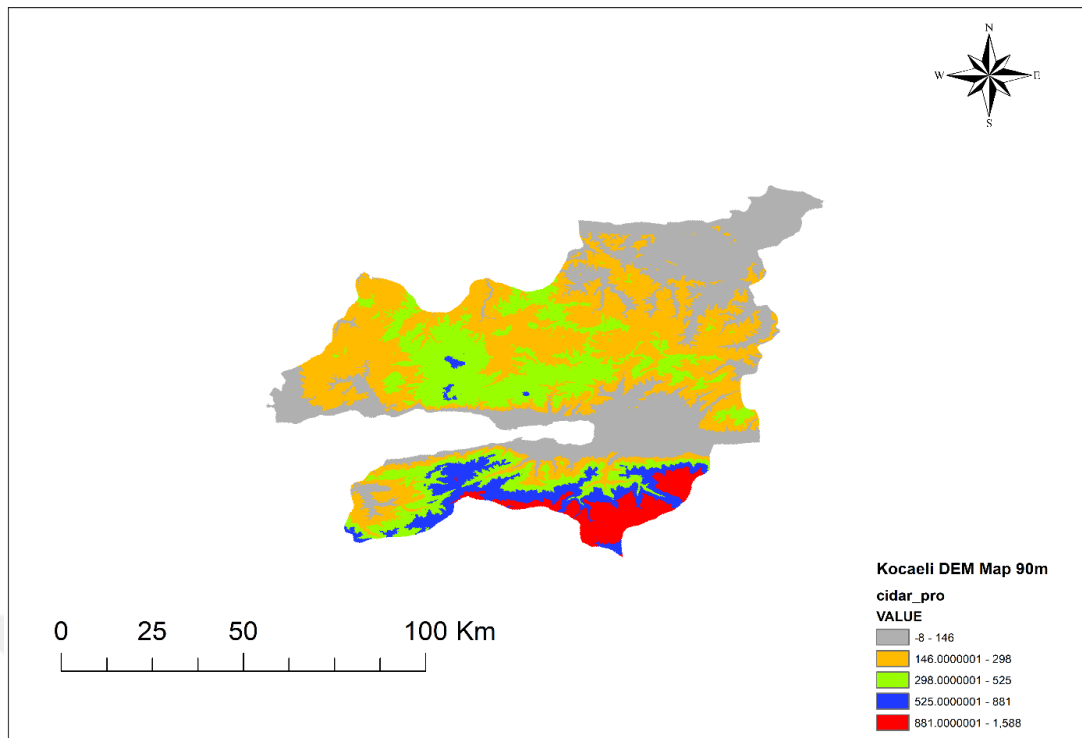


Figure 6.23: 3 arc-sec Digital Elevation Map (DEM)

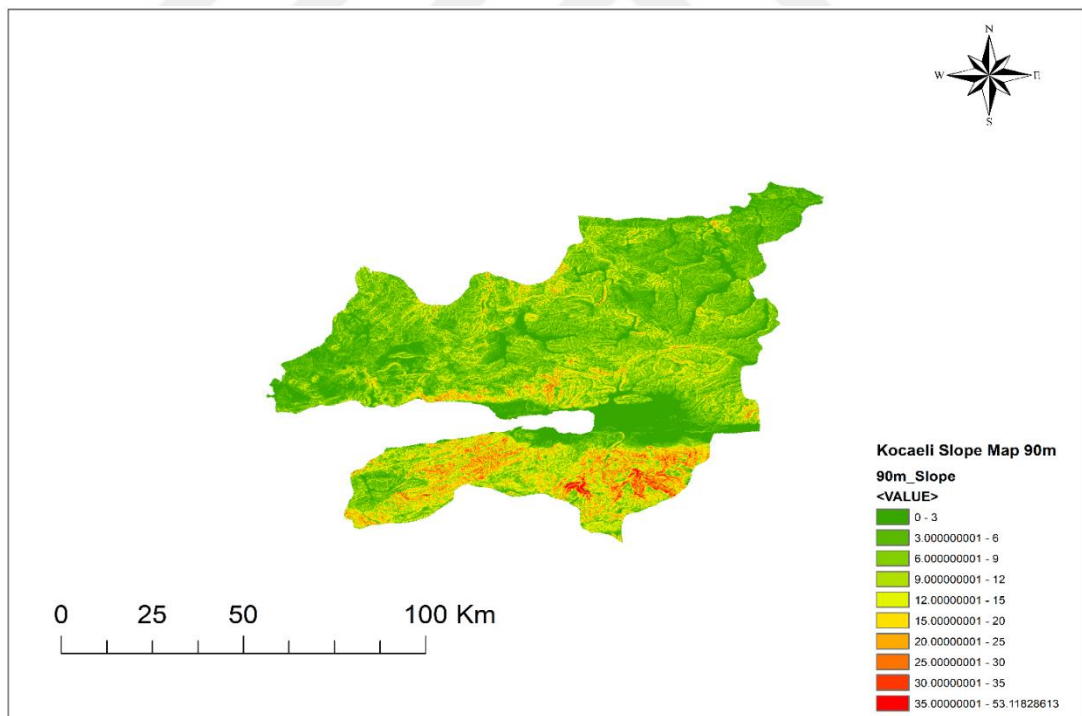


Figure 6.24: 3 arc-sec Slope Map

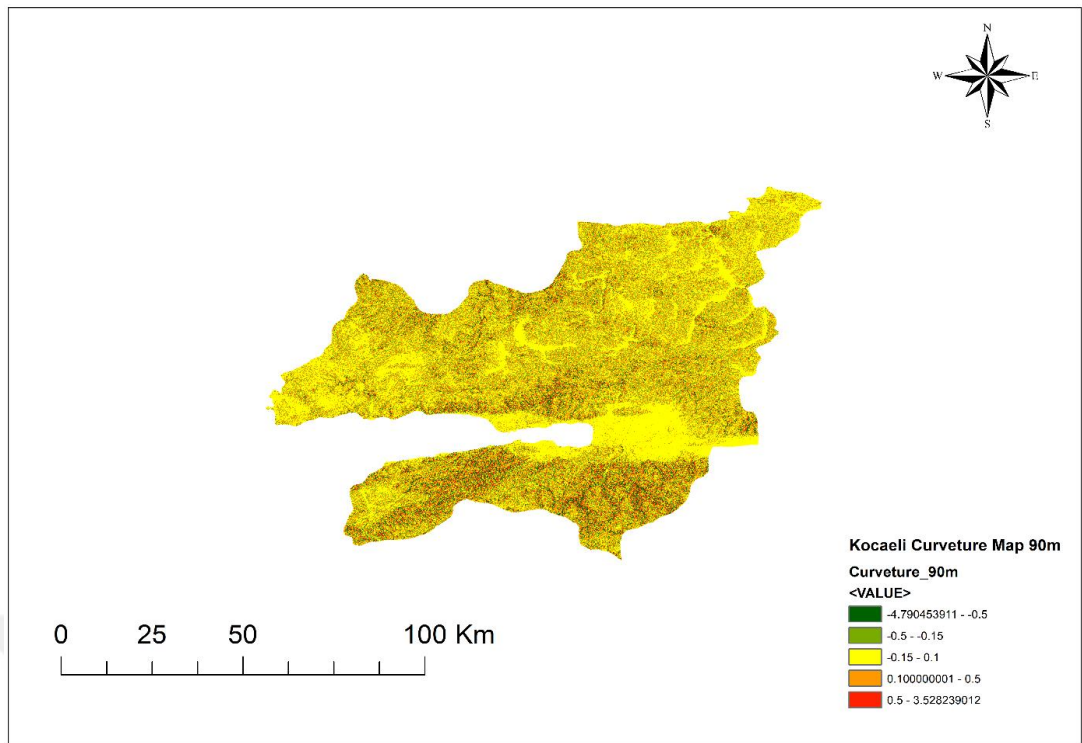


Figure 6.25: 3 arc-sec Curvature Map.

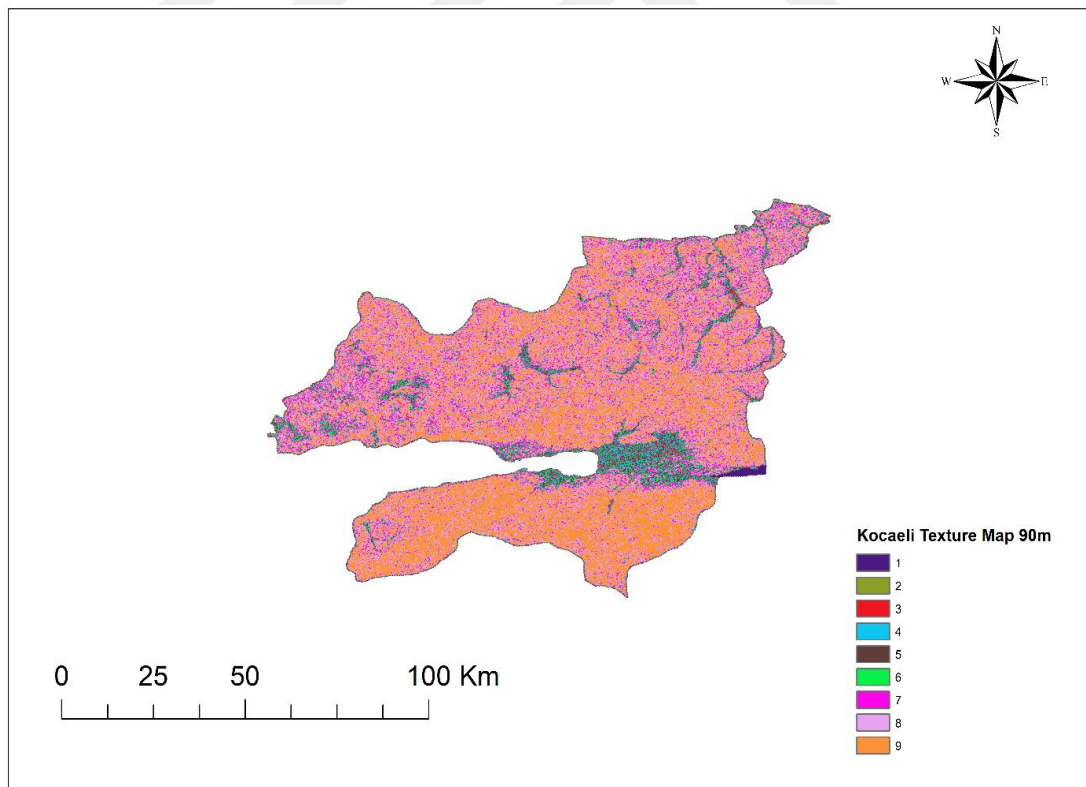


Figure 6.26: 3 arc-sec Texture Map.

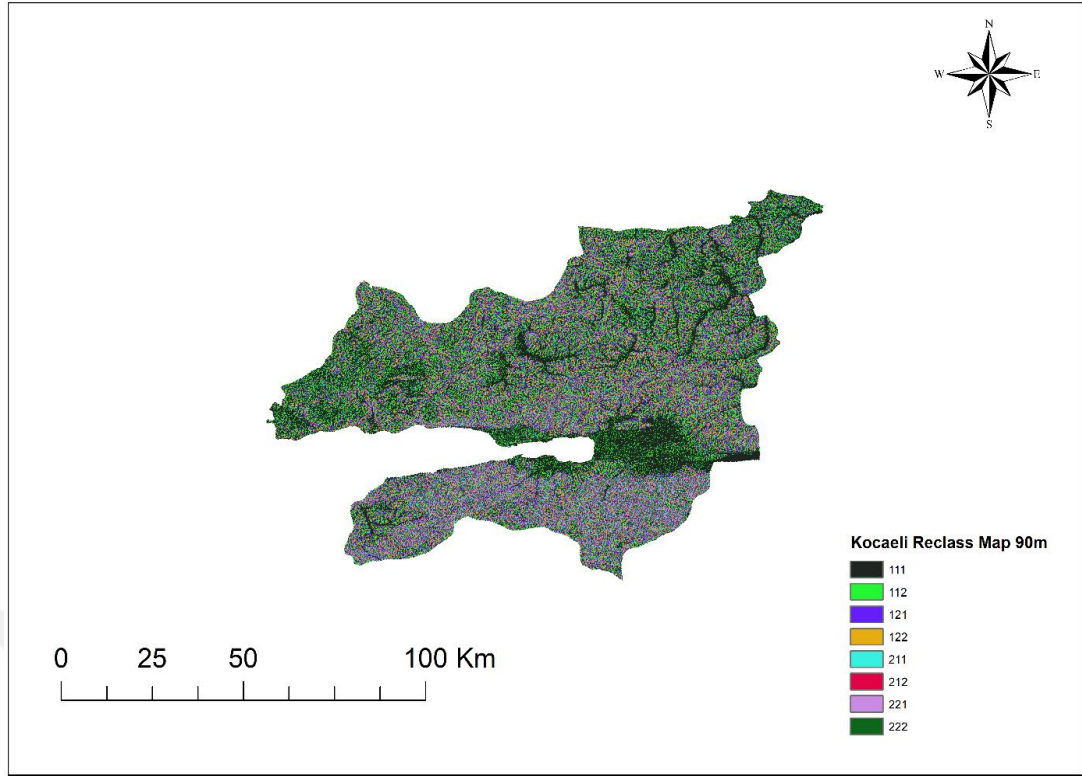


Figure 6.27: 3 arc-sec Reclass Map.

Table 6.8: 3 arc-sec map regression analysis.

ÖZET ÇIKIŞI									
<i>Regresyon İstatistikleri</i>									
Çoklu R	0.884789462								
R Kare	0.782852391								
Ayarlı R Kare	0.782082568								
Standart Hata	140.9314694								
Gözlem	1300								
ANOVA									
	<i>df</i>	<i>SS</i>	<i>MS</i>	<i>F</i>	<i>Anlamlılık F</i>				
Regresyon	1	93014347.29	93014347.29	4683.105943	0				
Fark	1299	25800321.12	19861.67907						
Toplam	1300	118814668.4							
	<i>Katsayılar</i>	<i>Standart Hata</i>	<i>t Stat</i>	<i>P-değeri</i>	<i>Düşük %95</i>	<i>Yüksek %95</i>	<i>Düşük 95.0%</i>	<i>Yüksek 95.0%</i>	
Kesişim	0	#YOK	#YOK	#YOK	#YOK	#YOK	#YOK	#YOK	
281.44	0.986216115	0.014411365	68.43322251	0	0.957944017	1.014488213	0.957944017	1.014488213	

As shown in **Table 6.8**, the regression analysis results indicate that the R Square value is 0.7829, meaning 78.29% of the variability in the dependent variable (V_{s30}) is explained by the independent variable (slope). This high R Square value suggests that the slope is a strong predictor of V_{s30} in this model. Additionally, the P-value for the F-statistic is 0, which is less than the commonly used significance level of 0.05. This indicates that the regression model is statistically significant, meaning there is

sufficient evidence to suggest that the slope has a meaningful linear relationship with V_{s30} . The linear equation derived from the regression analysis is:

$$V_{s30}=281.44+0.986216115\times\text{slope}$$

This equation represents the predicted V_{s30} value based on the slope, where the intercept (281.44) indicates the expected V_{s30} value when the slope is zero, and the slope coefficient (0.986216115) represents the change in V_{s30} for a one-unit increase in the slope. **Figure 6.28** shows the V_{s30} proxy model based on terrain categories.

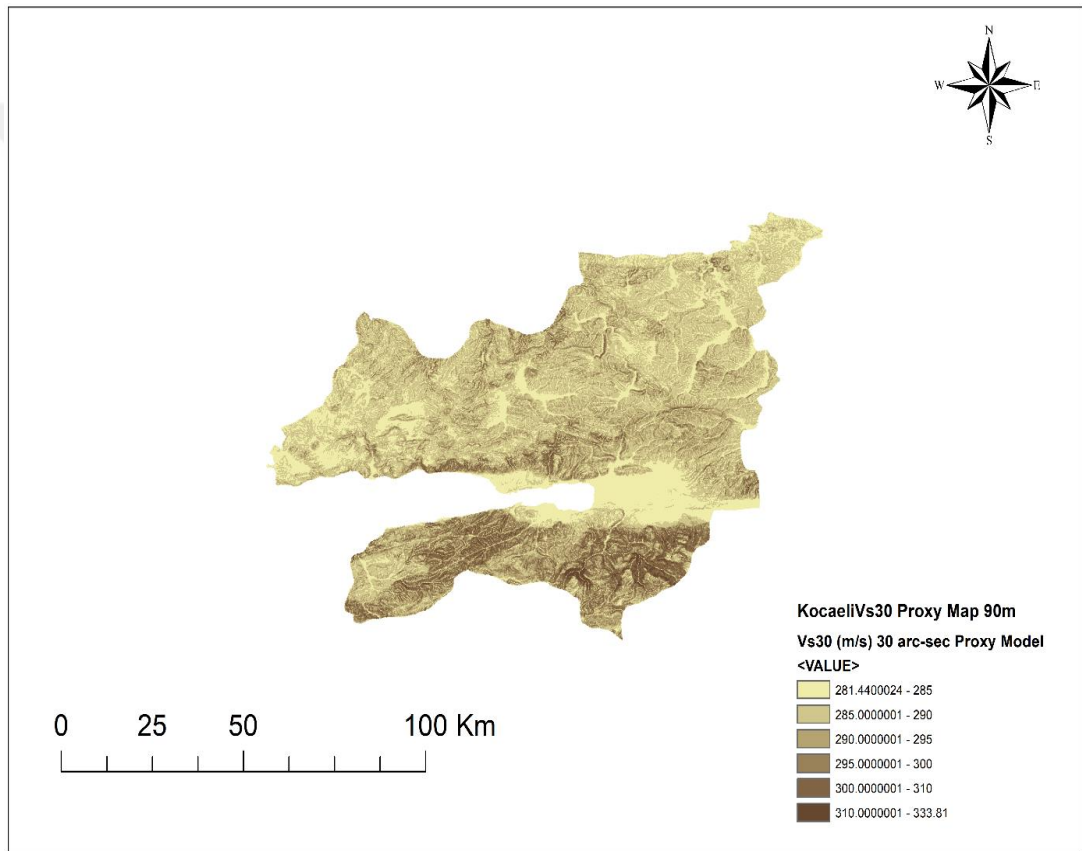


Figure 6.28: 3 arc-sec V_{s30} proxy model terrain categories.

6.3.5.30 Arc-Second Gradient Terrain Categories for Kocaeli Province

6.3.5.1. Description of Figures and Analysis

Figure 6.29 presents the DEM data for Kocaeli province at a resolution of 30 arc-second, equivalent to 1000 meters. This high-resolution DEM data was utilized to perform various terrain analyses using ArcMap 10.3.

Figure 6.30 illustrates the slope analysis derived from the DEM data. Slope represents the steepness or incline of the terrain surface, which is critical for understanding water flow, erosion potential, and other environmental processes.

Figure 6.31 depicts the curvature analysis, which includes both profile and plan curvature. Curvature analysis helps in understanding the topographic shape and drainage patterns of the terrain.

Figure 6.32 shows the texture analysis of the terrain. Texture analysis measures the roughness and heterogeneity of the surface, providing insights into the complexity and variation of the terrain features.

Figure 6.33 demonstrates the reclassification analysis. Reclassification involves categorizing the terrain into different classes based on specific criteria, such as slope, curvature, and texture. This process is essential for various applications, including land use planning, risk assessment, and environmental management.

These analyses, conducted using ArcMap 10.3, provide a comprehensive understanding of the terrain characteristics in Kocaeli province, leveraging high-resolution DEM data to support detailed geomorphological and environmental studies.

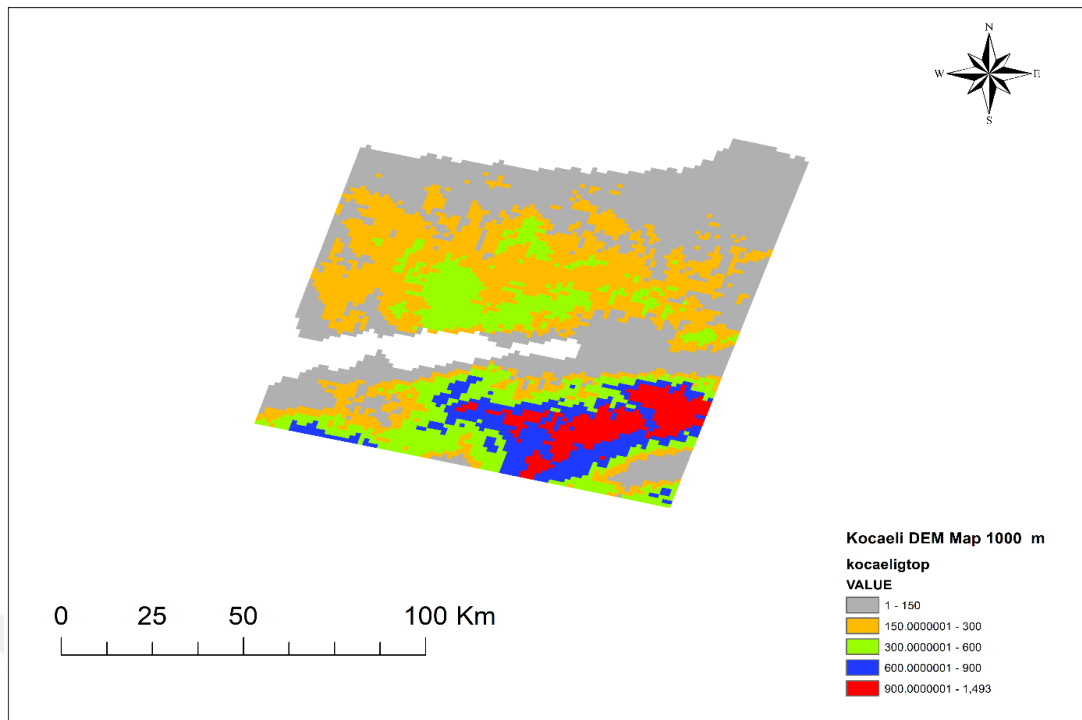


Figure 6.29: 30 arc-sec Digital Elevation Map (DEM).

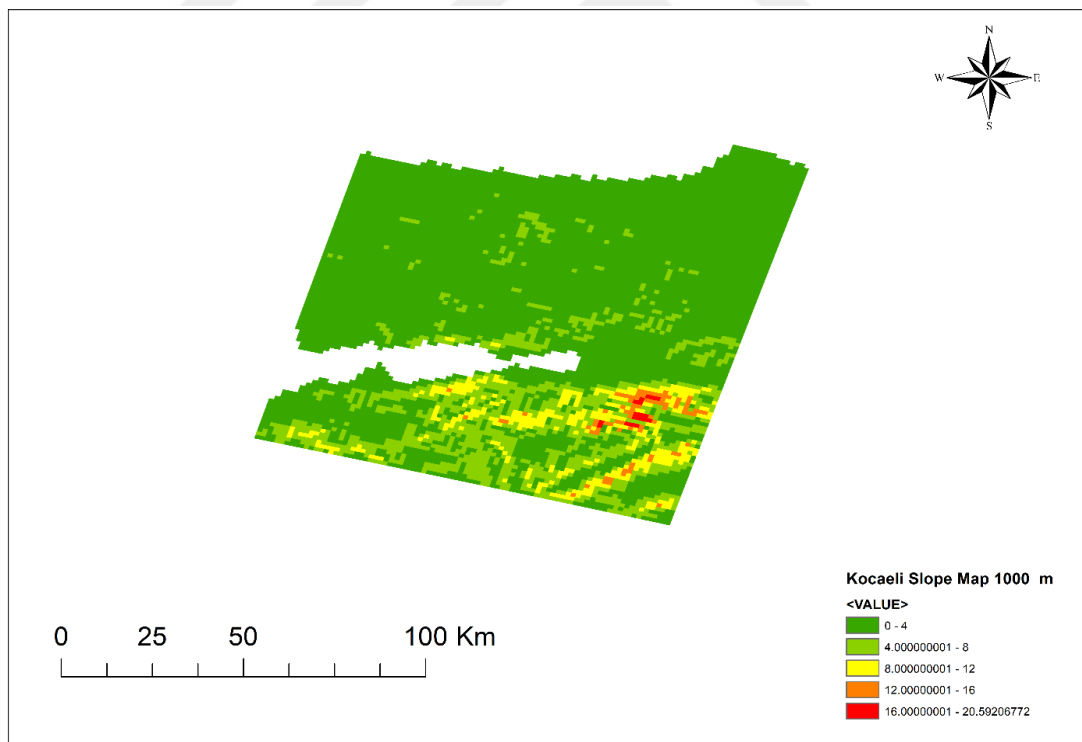


Figure 6.30: 30 arc-sec Slope Map.

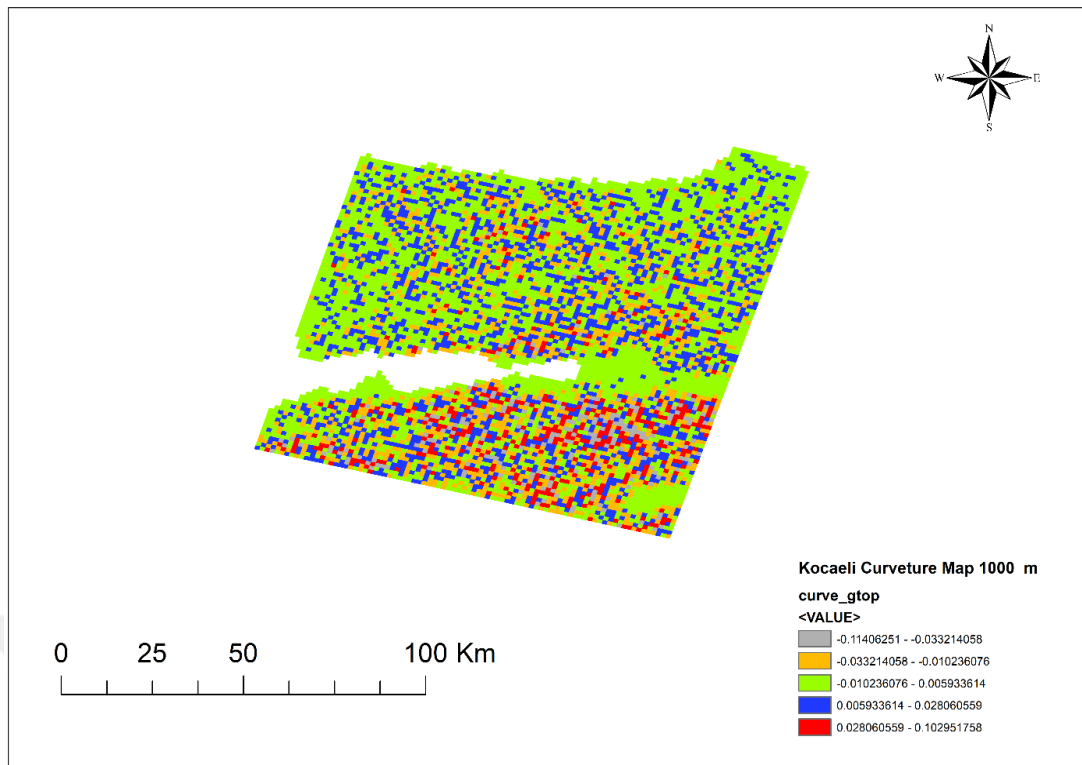


Figure 6.31: 30 arc-sec Curvature Map.

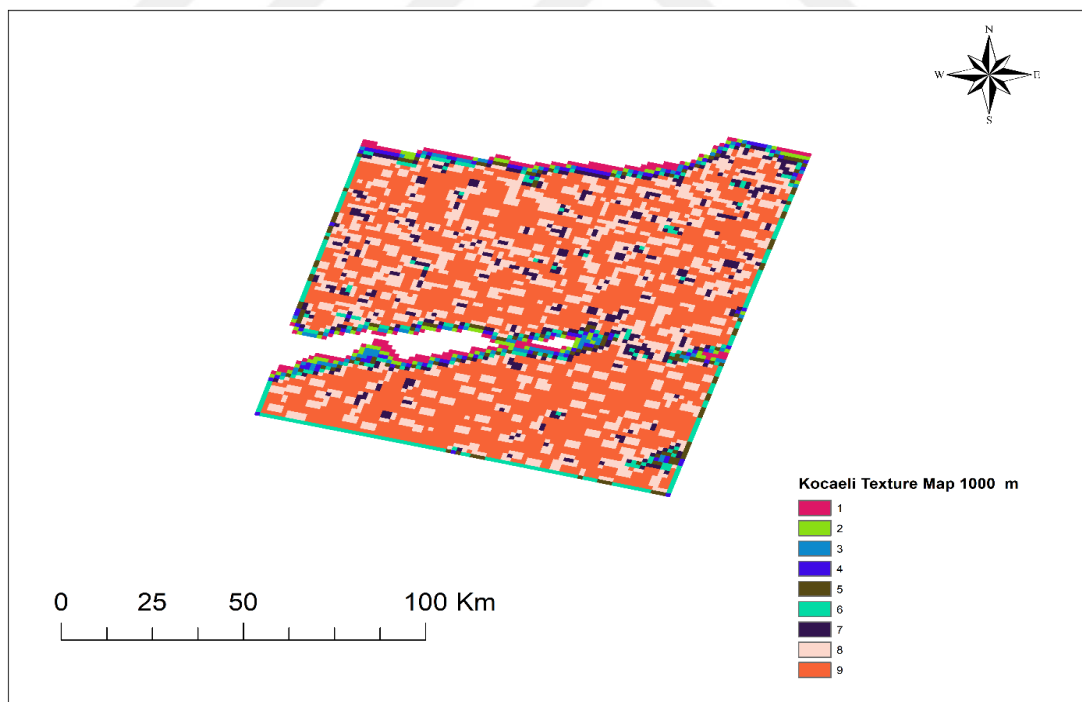


Figure 6.32: 30 arc-sec Texture Map.

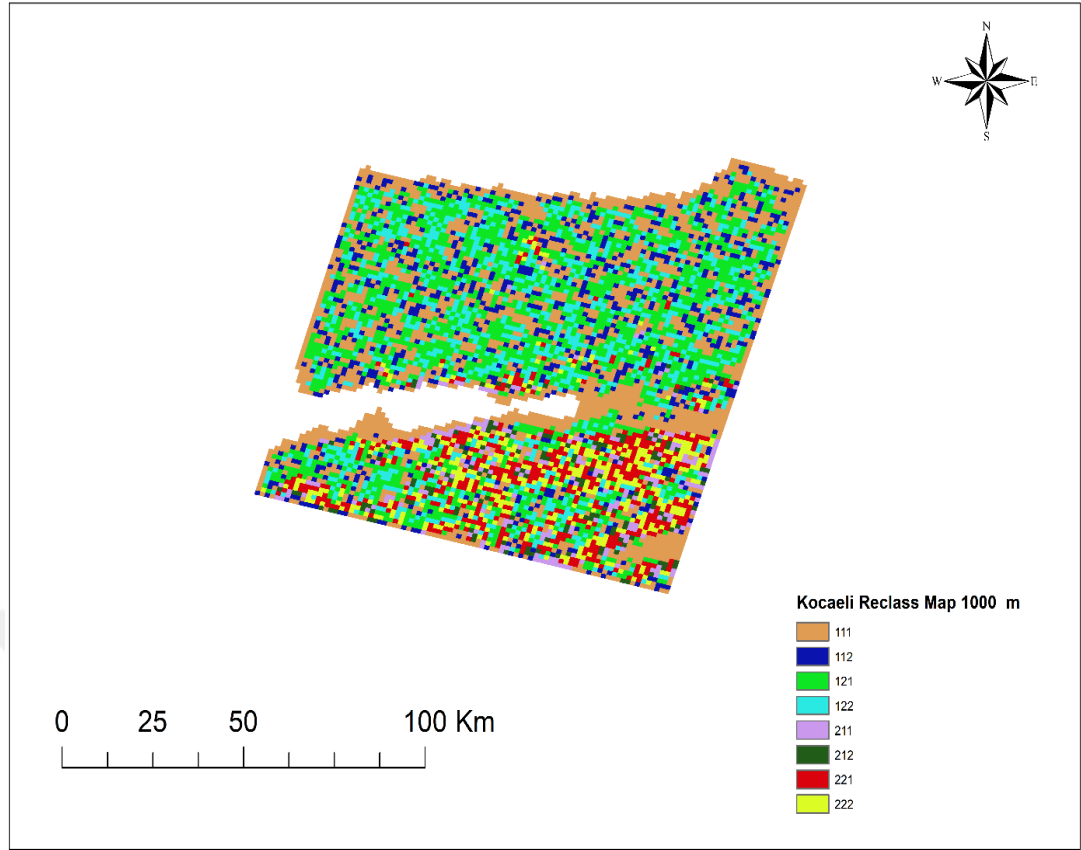


Figure 6.33: 30 arc-sec Reclass Map.

Table 6.9: 30 arc-sec map regression analysis

ÖZET ÇIKIŞI								
<i>Regresyon İstatistikleri</i>								
Çoklu R	0.868459727							
R Kare	0.754222297							
Ayarlı R Kare	0.753452474							
Standart Hata	149.9345413							
Gözlem	1300							
ANOVA								
	<i>df</i>	<i>SS</i>	<i>MS</i>	<i>F</i>	<i>Anlamlılık F</i>			
Regresyon	1	89612672.1	89612672.1	3986.263809	0			
Fark	1299	29201996.31	22480.36668					
Toplam	1300	118814668.4						
	<i>Katsayılar</i>	<i>Standart Hata</i>	<i>t Stat</i>	<i>P-değeri</i>	<i>Düşük %95</i>	<i>Yüksek %95</i>	<i>Düşük 95.0%</i>	<i>Yüksek 95.0%</i>
Kesişim	0	#YOK	#YOK	#YOK	#YOK	#YOK	#YOK	#YOK
269.435	0.989175444	0.015667161	63.13686569	0	0.958439735	1.019911154	0.958439735	1.019911154

As demonstrated in **Table 6.9**, the regression analysis results indicate that the R square value is 0.7542, meaning 75.42% of the variability in the dependent variable (V_{s30}) is explained by the independent variable (slope). This high R Square value suggests that the slope is a strong predictor of V_{s30} in this model. Additionally, the P-value for the

F-statistic is 0, which is less than the commonly used significance level of 0.05. This indicates that the regression model is statistically significant, meaning there is sufficient evidence to suggest that the slope has a meaningful linear relationship with VS30. The linear equation derived from the regression analysis is: $V_{s30}=269.435+0.989175444\times\text{slope}$.

This equation represents the predicted V_{s30} value based on the slope, where the intercept (269.435) indicates the expected V_{s30} value when the slope is zero, and the slope coefficient (0.989175444) represents the change in V_{s30} for a one-unit increase in the slope. **Figure 6.34** shows the V_{s30} proxy model based on terrain categories.

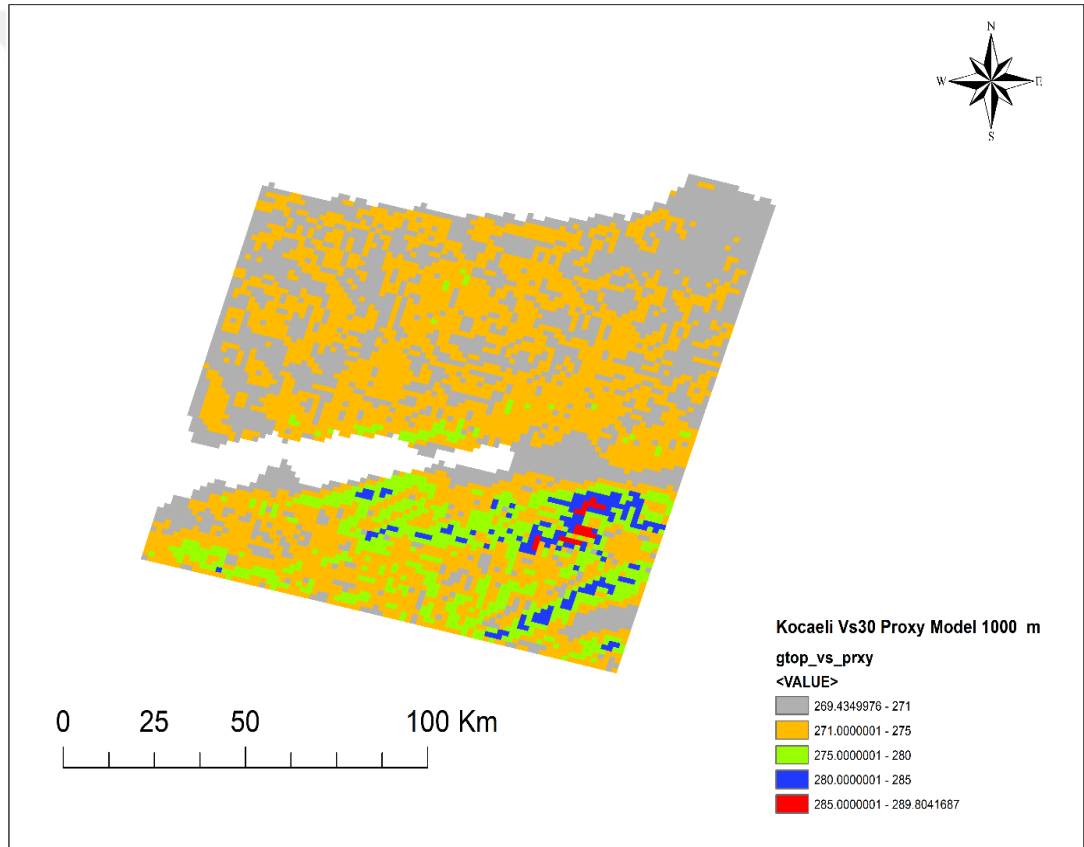


Figure 6.34: 30 arc-sec Vs30 proxy model terrain categories.

6.4. Slope-Based Proxy Model for Kocaeli Province

The relationship between topographic slope and V_{s30} is a significant area of research for assessing soil characteristics and seismic responses. V_{s30} represents the average shear wave velocity down to 30 meters below the surface and is a critical parameter

widely used in seismic analysis. Topographic slope is determined using data obtained from digital elevation models (DEMs) and serves as an indicator of ground conditions. Understanding the relationship between V_{s30} and topographic slope is particularly important in regions where geotechnical and geological data are limited. Various empirical models estimate V_{s30} values using topographic slope data. Steeper slopes are generally associated with higher V_{s30} values, indicating rocky or hard soil conditions. Conversely, gentler slopes are typically linked to lower V_{s30} values, reflecting softer or looser soil conditions.

The model developed by **(Wald & Allen, 2007)** demonstrated the reliability of using slope data for estimating V_{s30} across different regions globally. This study used slope data to classify soil conditions and provided critical information for seismic risk assessments. Similarly, **(Stewart, et al., 2014)** developed V_{s30} estimates for Greece using local geological and topographic data, showing that this approach effectively predicts local soil conditions more accurately.

The practical applications of understanding the relationship between topographic slope and V_{s30} are extensive. It is crucial for seismic risk assessments, emergency planning, and engineering designs. Accurate determination of soil conditions is essential for post-earthquake emergency responses and evaluating the seismic resilience of structures.

In conclusion, the relationship between topographic slope and V_{s30} is a valuable tool for evaluating seismic responses. Modeling and understanding this relationship provide reliable soil condition estimates for various engineering and planning applications, filling a critical gap in regions where geotechnical data are limited.

6.4.1. Analysis of Topographic Slope and V_{s30} Proxy Model for 1 Arc-Second DEM Map

Figure 6.35 illustrates the 1 arc-second Slope Map (in radians), which shows the gradient of the terrain at a high resolution. This map is essential for understanding the steepness and variations in the slope of the region. On the other hand, **Figure 6.36** presents the 1 arc-second V_{s30} Slope Proxy Map. This map uses slope data as a proxy to estimate V_{s30} values, providing a detailed representation of the seismic shear wave velocity across the terrain.

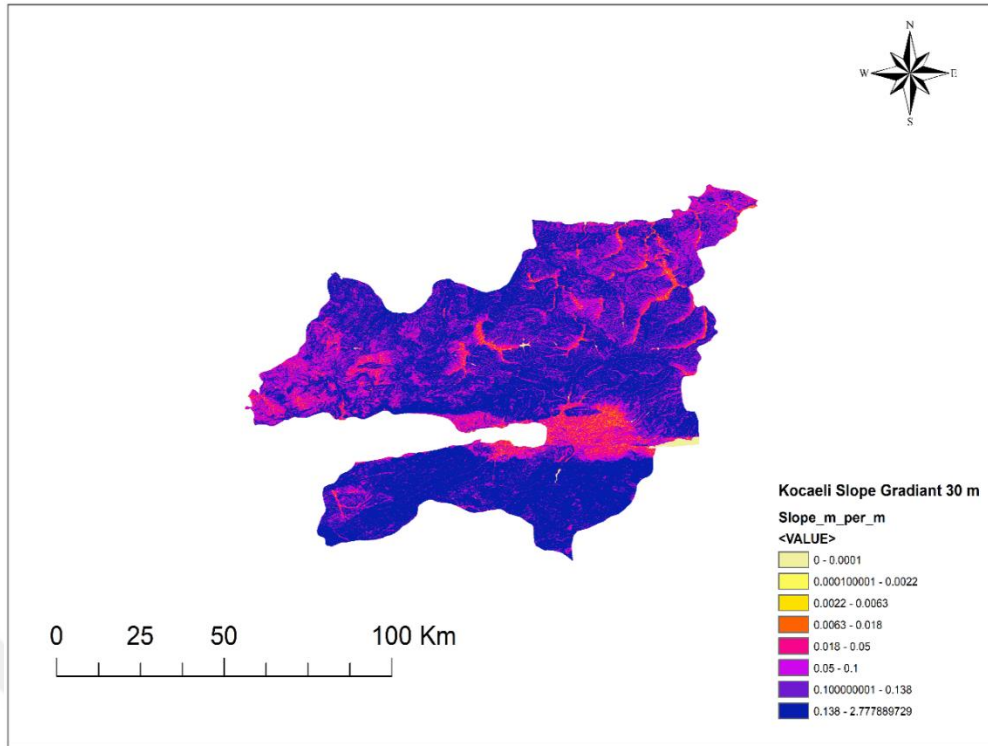


Figure 6.35: 1 arc-sec Slope Map (rad).

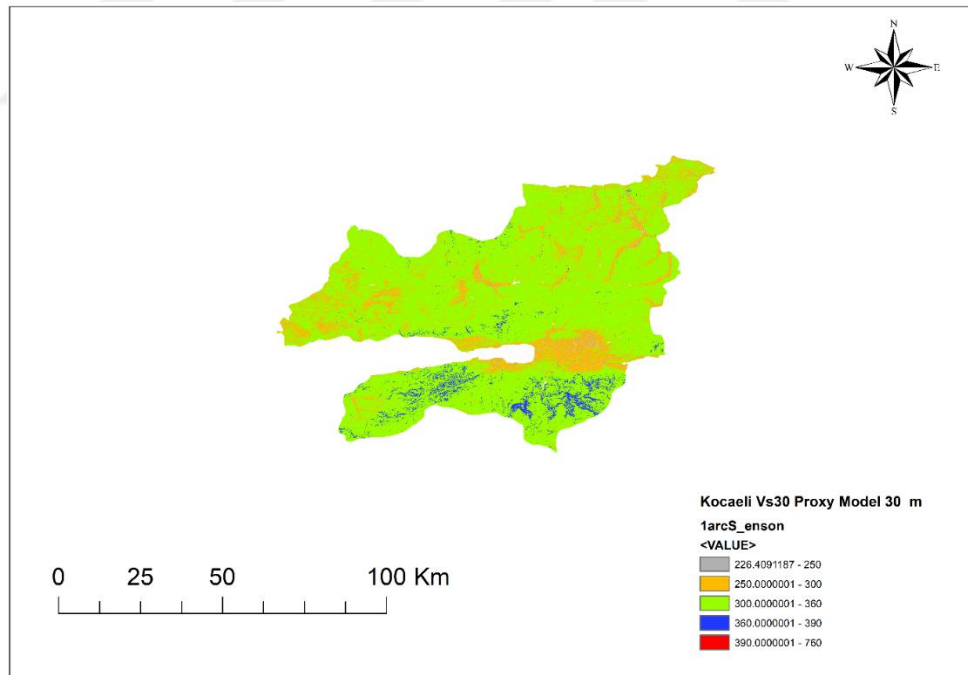


Figure 6.36: 1 arc-sec V_{s30} Slope Proxy Map.

6.4.2. Analysis of Topographic Slope and Vs30 Proxy Model for 3 Arc-Second DEM Map

Figure 6.37 shows the 3 arc-second Slope Map (in radians). This map visualizes the slope angle of the terrain at a broader resolution, highlighting slope variations and degrees. On the other hand, **Figure 6.38** presents the 3 arc-second V_{s30} Slope Proxy Map. This map uses slope data to estimate V_{s30} values, providing a comprehensive representation of the seismic shear wave velocity across the terrain.

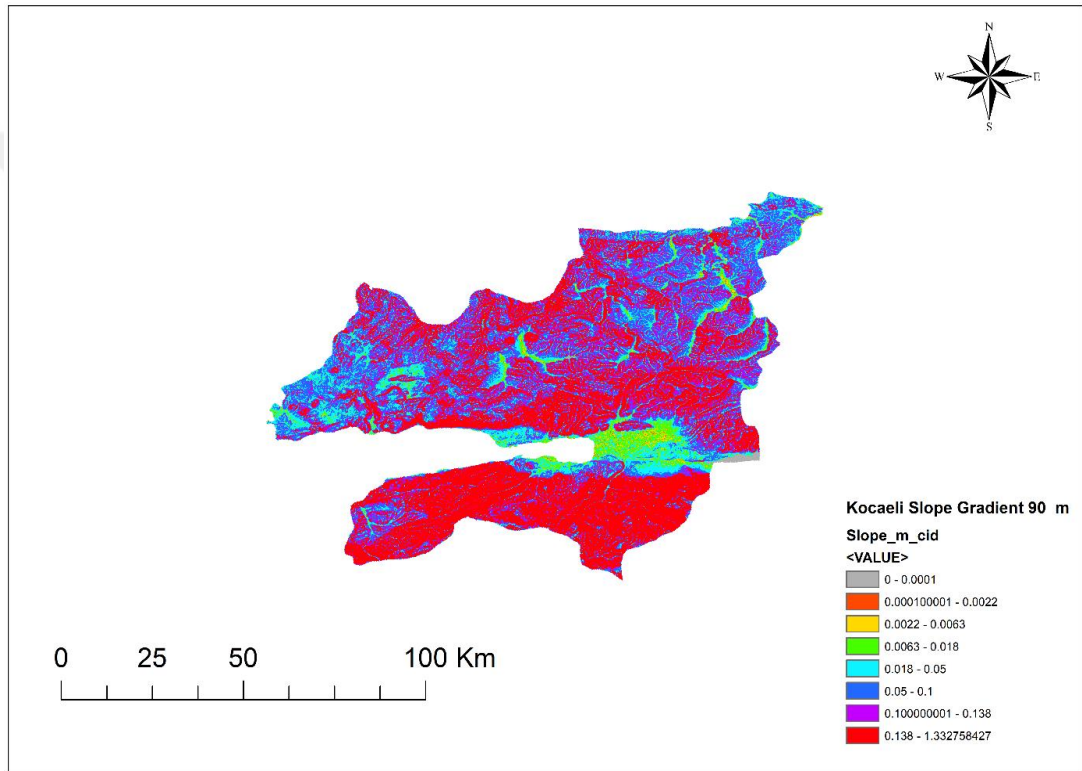


Figure 6.37: 3 arc-sec Slope Map (rad).

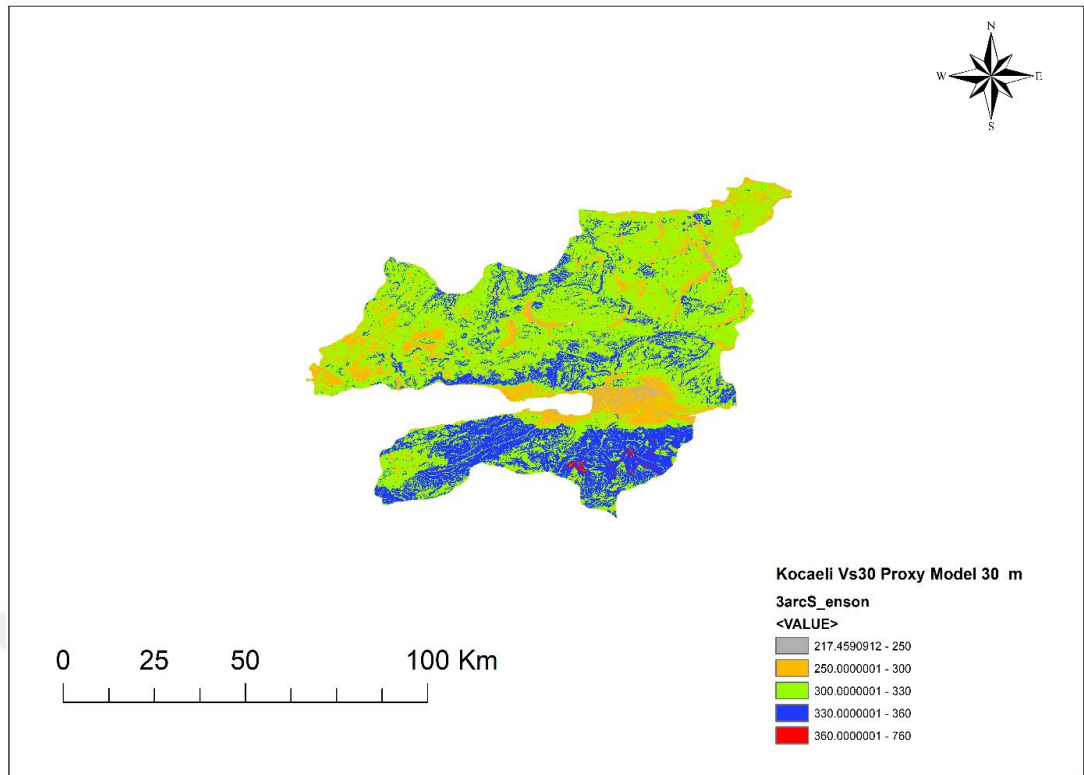


Figure 6.38: 3 arc-sec Vs30 Slope Proxy Map.

6.4.3. Analysis of Topographic Slope and V_{s30} Proxy Model for 30 Arc-Second DEM Map

Figure 6.39 shows the 30 arc-second Slope Map (in radians). This map provides a broader view of the terrain's slope angle, illustrating slope variations and degrees at a coarse resolution. On the other hand, **Figure 6.40** presents the 30 arc-second V_{s30} Slope Proxy Map. This map uses slope data to estimate V_{s30} values, offering a detailed representation of the seismic shear wave velocity across the terrain at a wider scale.

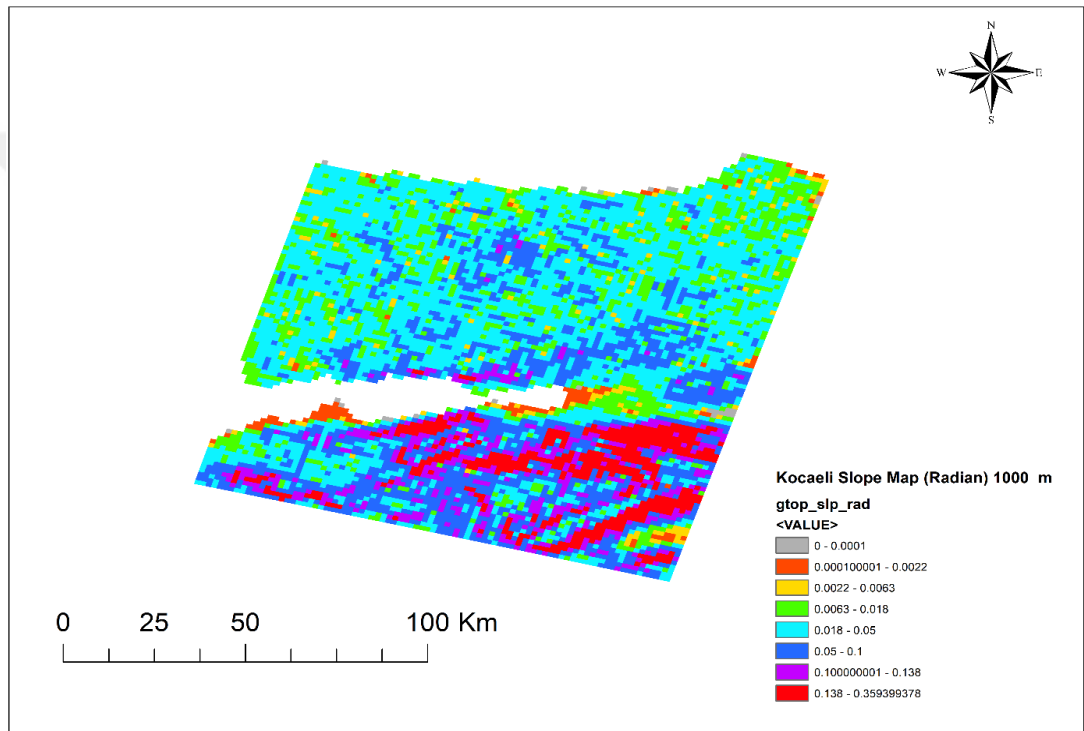


Figure 6.39: 30 arc-sec Slope Map (rad).

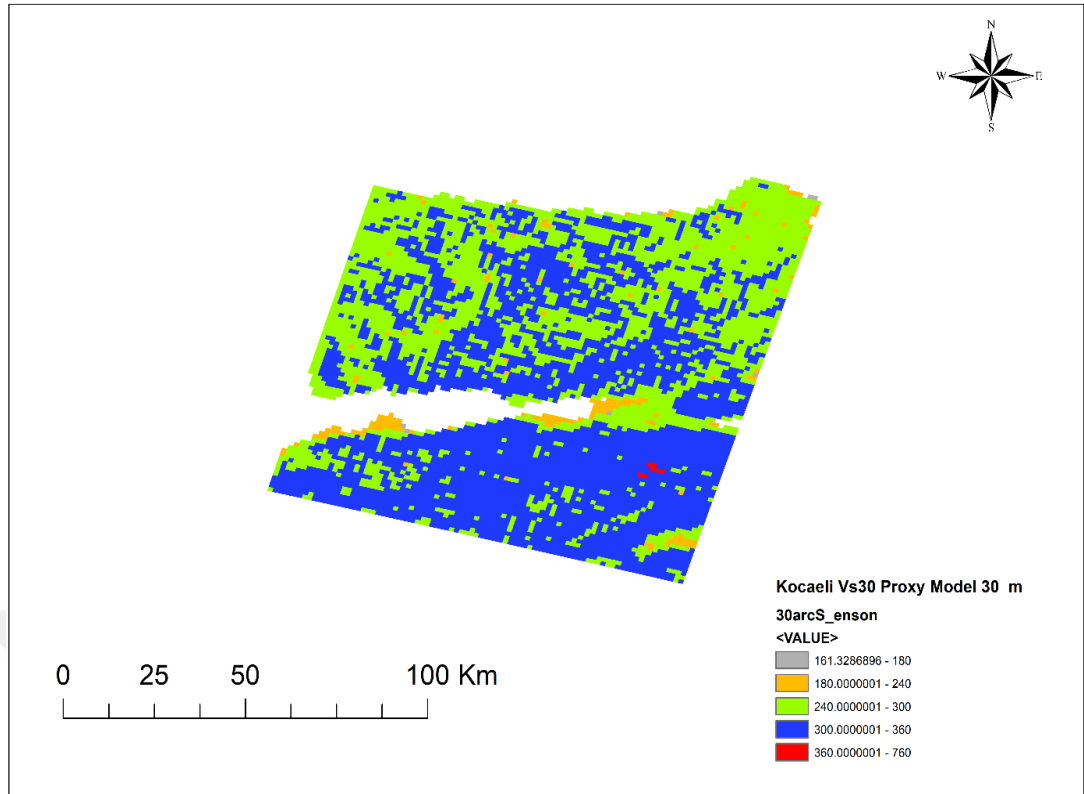


Figure 6.40: 30 arc-sec Vs30 Slope Proxy Map.

6.5. Comparison of 1 Arc-Second, 3 Arc-Second, and 30 Arc-Second DEM Data for V_{s30} Proxy Model

In the study by (Wald & Allen, 2007), a relationship between topographic slope and V_{s30} values was established. By utilizing this relationship, we can estimate the V_{s30} value of a location with known slope information through interpolation. The following Python code performs this interpolation using data derived from the (Wald & Allen, 2007) graph.

(Wald & Allen, 2007) slope- V_{s30} relationship:

```
import pandas as pd

file_path = 'slopelar_rad1.xlsx'
data = pd.read_excel(file_path)

data['Slope_H'] = data.iloc[:, 7]
data['Slope_I'] = data.iloc[:, 8]

slope_vs30_relationship = {
    'active': {
        'A': {'slope_range': (0, 0.1e-4), 'vs30_range': (0, 180)},
        'B': {'slope_range': (0.1e-4, 2.2e-3), 'vs30_range': (180, 240)},
        'C': {'slope_range': (2.2e-3, 9e-3), 'vs30_range': (240, 300)},
```

```

'D1': {'slope_range': (9e-3, 0.01), 'vs30_range': (300, 360)},
'D2': {'slope_range': (0.01, 0.05), 'vs30_range': (360, 490)},
'E': {'slope_range': (0.05, 0.133), 'vs30_range': (490, 620)},
'F': {'slope_range': (0.133, float('inf')), 'vs30_range': (620, 760)},
'G': {'slope_range': (0.133, float('inf')), 'vs30_range': (760, float('inf'))}
},
'stable': {
'A': {'slope_range': (0, 2.0e-5), 'vs30_range': (0, 180)},
'B': {'slope_range': (2.0e-5, 9e-4), 'vs30_range': (180, 240)},
'C': {'slope_range': (9e-4, 0.005), 'vs30_range': (240, 300)},
'D1': {'slope_range': (0.005, 0.01), 'vs30_range': (300, 360)},
'D2': {'slope_range': (0.01, 0.015), 'vs30_range': (360, 490)},
'E': {'slope_range': (0.015, 0.025), 'vs30_range': (490, 620)},
'F': {'slope_range': (0.025, float('inf')), 'vs30_range': (620, 760)},
'G': {'slope_range': (0.025, float('inf')), 'vs30_range': (760, float('inf'))}
}
}

def interpolate_vs30(slope, region_type='active'):
    for category, ranges in slope_vs30_relationship[region_type].items():
        slope_min, slope_max = ranges['slope_range']
        vs30_min, vs30_max = ranges['vs30_range']

        if slope_min <= slope < slope_max:
            if vs30_max == float('inf'):
                return vs30_min
            return vs30_min + (vs30_max - vs30_min) * (slope - slope_min) / (slope_max - slope_min)

    return None

data['vs30_H'] = data['Slope_H'].apply(lambda x: interpolate_vs30(x, region_type='active'))
data['vs30_I'] = data['Slope_I'].apply(lambda x: interpolate_vs30(x, region_type='active'))

output_file_path = 'vs30_degerleri.xlsx'
data.to_excel(output_file_path, index=False)

```

The accuracy of estimating the average shear-wave velocity to a depth of 30 meters (V_{s30}) is crucial in seismic site classification. This analysis examines the relationship between V_{s30} values and topographic slope gradients. Two graphs are provided to illustrate this relationship and compare the current model with the **(Wald & Allen, 2007)** study.

Figure 6.41: The graph showing the relationship between the 1 arc-second gradient and V_{s30} values is represented by a logarithmic regression model $y=29.055\ln(x)+378.73$ with an $R^2=0.3232$, indicating the model's explanatory power. The accuracy of the model is moderate, and there is a significant relationship between slope gradient and V_{s30} .

Figure 6.42: The graph depicting the relationship between the 1 arc-second gradient and the residuals from the (Wald & Allen, 2007) study shows that the current model's predictions yield lower residuals compared to the (Wald & Allen, 2007) model. The blue points represent the current data, while the orange points represent the residuals calculated based on the (Wald & Allen, 2007) model. The results indicate that, particularly at lower slope values, the current model demonstrates better prediction accuracy than the (Wald & Allen, 2007) model.

The analysis reveals that the current model is more successful in estimating V_{s30} compared to the (Wald & Allen, 2007) model. The lower residuals, especially in the lower slope ranges, indicate that the current model's predictions are more accurate. This finding suggests that V_{s30} estimates can be improved by using topographic slope information and that the current model provides a more reliable tool for seismic site classification.

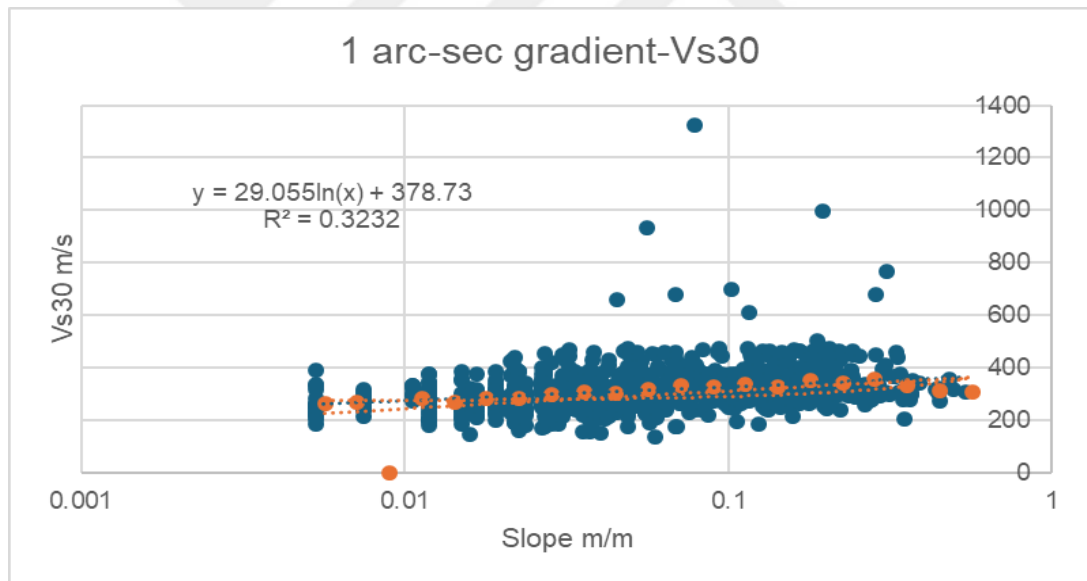


Figure 6.41: The relationship between 1 arc-second slope gradient and Vs30 values, represented by a logarithmic regression model.



Figure 6.42: The residuals of the 1 arc-second slope gradient model compared to the residuals from the (Wald & Allen, 2007) study.

Figure 6.43: The graph showing the relationship between the 3 arc-second gradient and V_{s30} values is represented by a logarithmic regression model $y=23.895\ln(x)+368.98$ with an $R^2=0.2902$ indicating the model's explanatory power. The accuracy of the model is moderate, and there is a significant relationship between slope gradient and V_{s30} .

Figure 6.44: The graph depicting the relationship between the 3 arc-second gradient and the residuals from the (Wald & Allen, 2007) study shows that the current model's predictions yield lower residuals compared to the (Wald & Allen, 2007) model. The blue points represent the current data, while the orange points represent the residuals calculated based on the (Wald & Allen, 2007) model. The results indicate that, particularly at lower slope values, the current model demonstrates better prediction accuracy than the (Wald & Allen, 2007) model.

The analysis reveals that the current model is more successful in estimating V_{s30} compared to the (Wald & Allen, 2007) model. The lower residuals, especially in the lower slope ranges, indicate that the current model's predictions are more accurate. This finding suggests that V_{s30} estimates can be improved by using topographic slope information and that the current model provides a more reliable tool for seismic site classification.

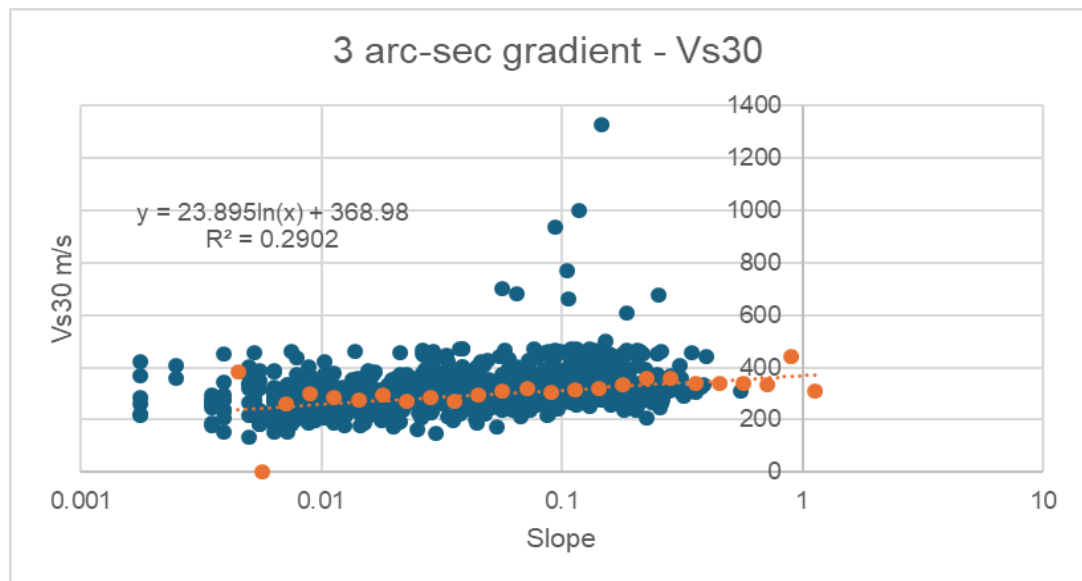


Figure 6.43: The relationship between 3 arc-second slope gradient and Vs30 values, represented by a logarithmic regression model.

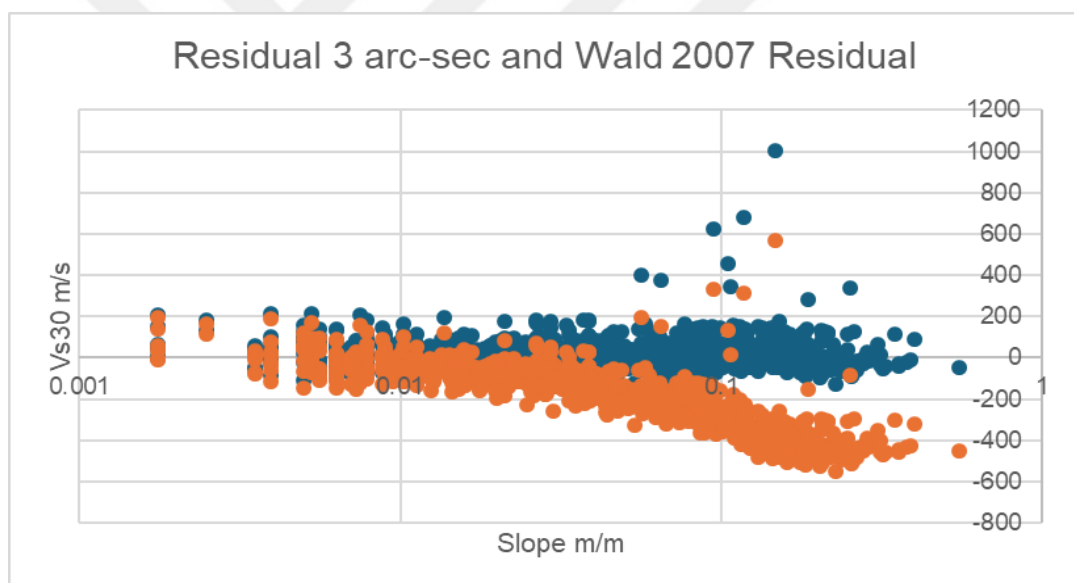


Figure 6.44: The residuals of the 3 arc-second slope gradient model compared to the residuals from the (Wald & Allen, 2007) study.

Figure 6.45: The graph showing the relationship between the 30 arc-second gradient and V_{s30} values is represented by a logarithmic regression model $y = 26.978 \ln(x) + 392.18$ with an $R^2 = 0.5752$. This indicates that the model has a moderate to strong explanatory power. There is a significant positive relationship between the slope gradient and V_{s30} , with higher slopes generally corresponding to higher V_{s30} values. The data points exhibit a considerable spread, suggesting variability in the V_{s30} values at similar slope gradients.

Figure 6.46: The graph depicting the residuals of the 30 arc-second gradient model compared to the residuals from the (Wald & Allen, 2007) study shows that the current model's predictions yield lower residuals compared to the (Wald & Allen, 2007) model. The blue points represent the current data residuals, while the orange points represent the residuals calculated based on the (Wald & Allen, 2007) model. The results indicate that, particularly at lower slope values, the current model demonstrates better prediction accuracy than the (Wald & Allen, 2007) model. The residuals are generally lower across a wide range of slopes, highlighting the improved fit of the current model.

These findings suggest that the current model is more successful in estimating V_{s30} compared to the (Wald & Allen, 2007) model. The lower residuals, especially in the lower slope ranges, indicate that the current model's predictions are more accurate. This demonstrates that V_{s30} estimates can be enhanced by using topographic slope information and that the current model provides a more reliable tool for seismic site classification.

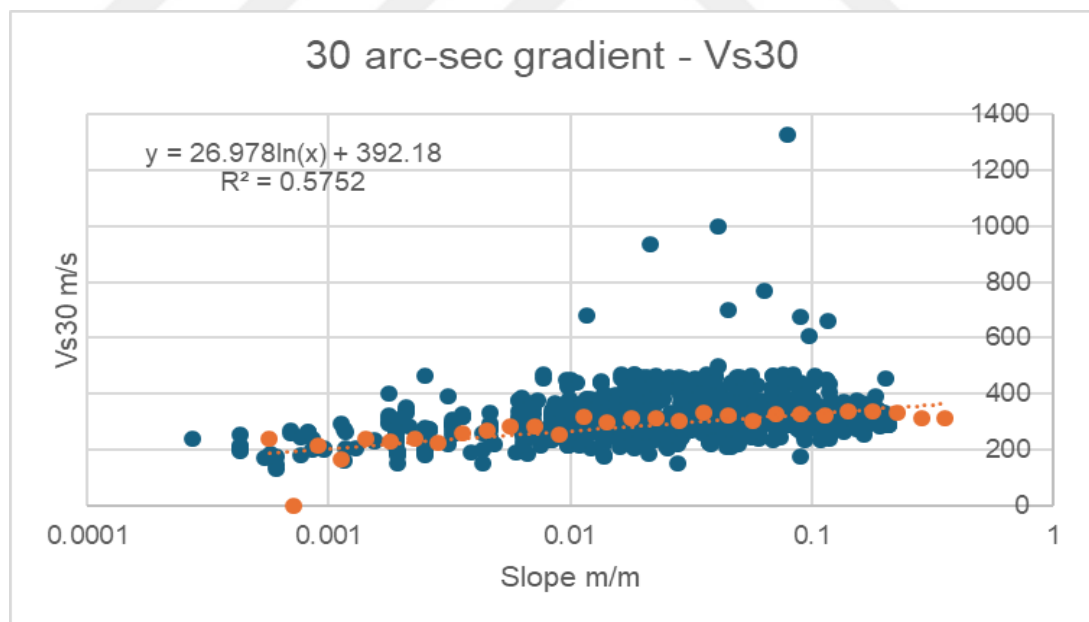


Figure 6.45: The relationship between 30 arc-second slope gradient and V_{s30} values, represented by a logarithmic regression model.



Figure 6.46: The residuals of the 30 arc-second slope gradient model compared to the residuals from the (Wald & Allen, 2007) study.

6.6. Comparative Conclusion

Comparing the three gradient scales, the 30 arc-second gradient model emerges as the most reliable for estimating V_{s30} values. This model demonstrates the highest explanatory power ($R^2=0.5752$) and provides lower residuals compared to both the 1 arc-second and 3 arc-second gradient models.

In comparison with the (Wald & Allen, 2007) study, the 30 arc-second gradient model yields lower residuals, particularly at lower slope values. This indicates that the current model's predictions are more accurate than those of the (Wald & Allen, 2007) model.

The 30 arc-second model proves to be superior, especially in making accurate predictions at lower slope values, thereby establishing itself as a valuable tool for seismic site classification. The findings suggest that incorporating topographic slope information at the 30 arc-second scale significantly enhances V_{s30} estimates, offering a more robust and reliable method for seismic site classification.

7. CONCLUSIONS

This study provides significant findings for soil classification and earthquake response assessment in the Kocaeli region. The primary objective of the study is to accurately predict the local soil classes and accordingly plan construction activities. Given Kocaeli's high industrial and population density and its location on the North Anatolian Fault line, minimizing potential earthquake damage is of paramount importance.

Correlations between V_{s30} values obtained from geophysical measurements and SPT-N data were established using three different methods: Terrain Category, Slope Method, and Geological Category. These correlations were utilized to determine the dynamic properties of soils in the Kocaeli region, and V_{s30} shear wave velocity maps were created. These maps were then evaluated concerning the region's geological characteristics to assess their accuracy.

The research findings demonstrate the usability of the relationship between topographic slope and V_{s30} in soil classification. The 30 arc-second slope model, in particular, was identified as having the highest explanatory power for estimating V_{s30} values. This model provides lower residuals, thereby enhancing the accuracy of V_{s30} predictions and enabling the accurate classification of the region's soil types.

Analysis of the distribution of V_{s30} values according to geological age classes in the Kocaeli region revealed that some classes exhibit more homogeneous soil characteristics, while others show heterogeneous soil properties. For classes with limited data points, the reliability of results may be low. However, the findings provide valuable insights for accurate site classification and seismic hazard assessment.

The Slope Method employed in this study facilitated the estimation of V_{s30} values using topographic slope data. Integrating slope data with geophysical measurements proved highly beneficial for soil classification and seismic hazard assessments.

V_{s30} values obtained based on Standard Penetration Test (SPT-N) data played a significant role in determining the soil characteristics of the region. Correlations derived from SPT-N data enabled accurate classification of different soil types in the area.

Additionally, the Terrain Category method provided an effective approach for estimating V_{s30} values using surface topography and other terrain features. This method was particularly useful for determining the dynamic soil properties of various terrain categories and assessing soil response. Identifying terrain categories played a crucial role in soil classification and seismic hazard assessments.

The results of this study will serve as a foundation for future construction projects and engineering applications, contributing to the reduction of potential earthquake damage. Accurate determination of Kocaeli's soil characteristics is essential for establishing reliable settlement areas.



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PUBLICATIONS AND PRESENTATIONS FROM THE THESIS

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