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Full Length Research Paper

Urban microzonation study for Esenler district, Istanbul, Turkey

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It is necessary to prepare the microzonation maps and determine the better soil sites in settlement areas which are located on active tectonic regions. In this study, the geological, geophysical and geotechnical conditions of the Esenler district (Istanbul) were investigated and a small scales microzonation study was carried out. The northern sides of the study area generally represented by Lower Carboniferous aged graywacke (sandstone) and some areas in the southern parts represented by Upper Miocene aged limestone. The soil units consist of high plastic, hard-solid consistency and overconsolidated thick clay layers. The earthquake hazard of the study area is determined by using deterministic and probabilistic approaches. The probabilistic hazard analysis indicated that the occurrence probability of a 7 magnitude (M_w=7) earthquake is 7.42% in 10 years and 32% in 50 years (Poisson probability dispersion). The deterministic earthquake hazard analysis is also performed for Adalar Fault in Marmara Sea and accelerations were estimated for study area by several attenuation relations. Soil amplification factors and site characteristic periods were determined and estimated by seismic measurements. Shear wave velocity (V_{s30}) values, soil amplification values and site characteristic periods are changing between 257 to 1255 m/s, 1 to 2.4 and 0.46 to 0.1 s in the study area, respectively.

Key words: Microzonation, seismic hazard, soil amplification, soil condition.

INTRODUCTION

Seismic microzonation is the preliminary phase of earthquake risk mitigation studies. It requires multi-disciplinary approach with major contributions from geology, seismology and geotechnical engineering. The final output should include proper recommendations for application by local managers, city planners and engineers (Ansal and Biro, 2004). Using the geological and geotechnical, data is gaining much importance in the microzonation in particular the planning of city urban infrastructure, which can identify, control and avoid geological hazards (Bell et al., 1987; Legget, 1987; Hake, 1987; Rau, 1994; Dai et al., 1994, 2001; Van Rooy and Stiff, 2001). Seismic microzonation studies generally consists of three stages: the assessment of seismicity and estimation of the regional seismic hazard, determination of the local geological and geotechnical site conditions and assessment of the probable ground response and ground motion parameters on the ground surface.

Microzonation is the most widely accepted technique in seismic hazard assessment and risk evaluations and it is defined as the zonation with respect to ground motion characteristics taking into consideration source and field conditions (TC4-ISSMGE, 1999). Seismic microzonation is known to subdivide a region into separate areas having different potentials hazardous earthquake effects, describing their specific seismic behavior for engineering design and land-use planning (Sitharam and Anbazhagan, 2008).

Esenler district is located on european part of Istanbul province and within a second-degree earthquake zone of Turkey according to the seismic design code (GDDA, 1996) (Figure 1). The seismicity of the study area and its

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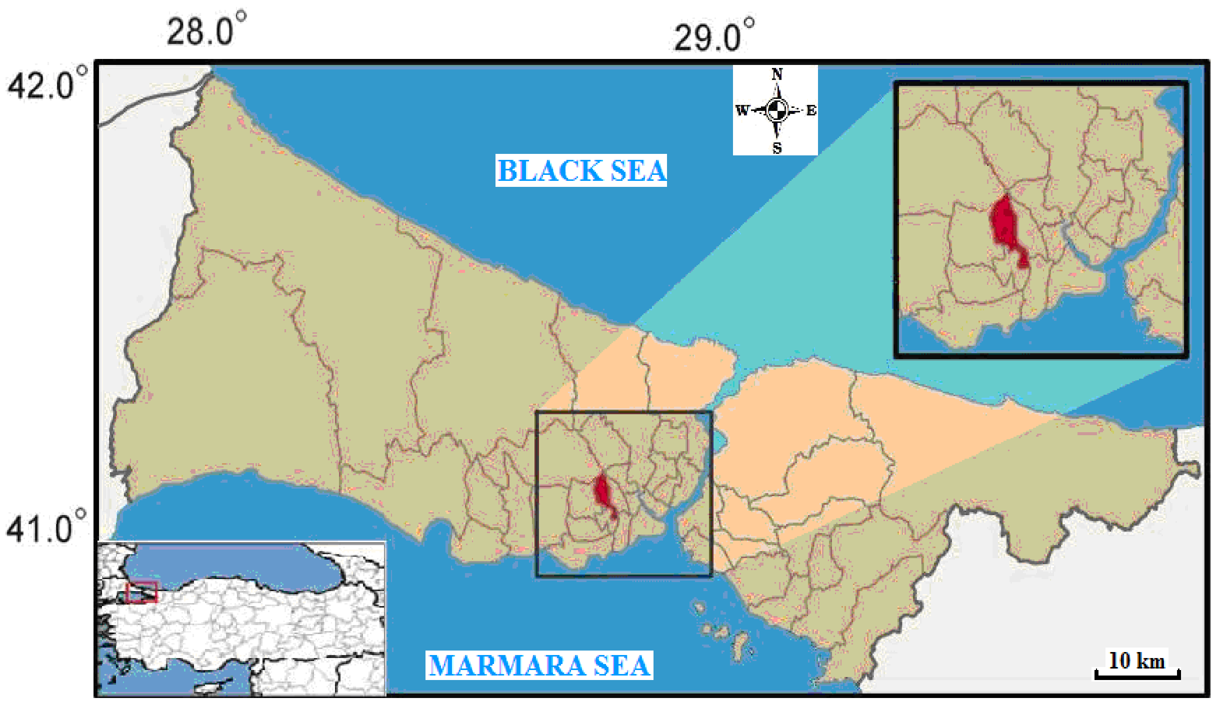

Figure 1. The location of the study area.

vicinity is mainly controlled by the north Anatolian fault zone (NAFZ). The August 17, 1999 Kocaeli earthquake (Mw = 7.4), caused extensive structural damage and the loss of almost 18,000 lives in the Marmara region. After the August 17, 1999 earthquake, geological and geotechnical investigations and also microzonation studies becoming very important in urban planning for all municipalities in Turkey.

In this study, the geological, geophysical and geotechnical conditions of the study area were investigated and the results are shown on microzonation maps. This paper describes the stages and details of the investigation of the urban geology aiming at the preparation of a microzonation map of Esenler district.

GEOLOGICAL SETTINGS

The geology and soil profile of the study area have been investigated using 225 boreholes data and various source materials. The northern parts of the study area are dominated by Paleozoic bedrock. The bedrock consists of Lower Carboniferous aged Trakya Formation represented by interbedded claystone, sandstone and greywacke (Kaya, 1971; Vardar and Bayraktar, 1993). The Oligocene and Upper Miocene sediments and sedimentary rocks that extend over the Paleozoic bedrock. The geological map of the study area is shown in Figure 2.

Gürpınar Formation is Oligocene aged and dominant lithology is a greyish green clay of high plasticity (CH), overconsolidated and of stiff to hard consistency. Güngören Formation (Sayar, 1976) is Miocene aged and composed of green colored fissured clay, highly plastic, thin laminated clays with a considerable organic content and swelling potential. Bakırköy Formation is Upper Miocene aged and composed of lacustrine, off-white-cream colored, flat-bedded, moderately strong to strong Mactra bearing limestone and weak to moderately strong marl, usually with interbeds of green clay. Alluvial deposits are Quaternary aged and consisting of unconsolidated sediments composed of gravel, sand, silt and clay, which overlay the other formations and are the result of fluvial activity. Besides, there are some artificial fill fields in the study area and the thickness of them are changing between 2 to 34.5 m.

GROUNDWATER

The study area is located on a poor region in terms of groundwater. Groundwater is just a few meters deep, only center parts of the study area. These local areas are situated on the valley extension and have an impermeable layer. However, in the south sides of the study area, both the fluviatile alluvial deposits, limestones in the Bakırköy Formation and sand lenses in Gürpınar Formation have groundwater potential in the average depth of 10 to 15 m. The north side of the study area, do not contain groundwater. The variation of the groundwater

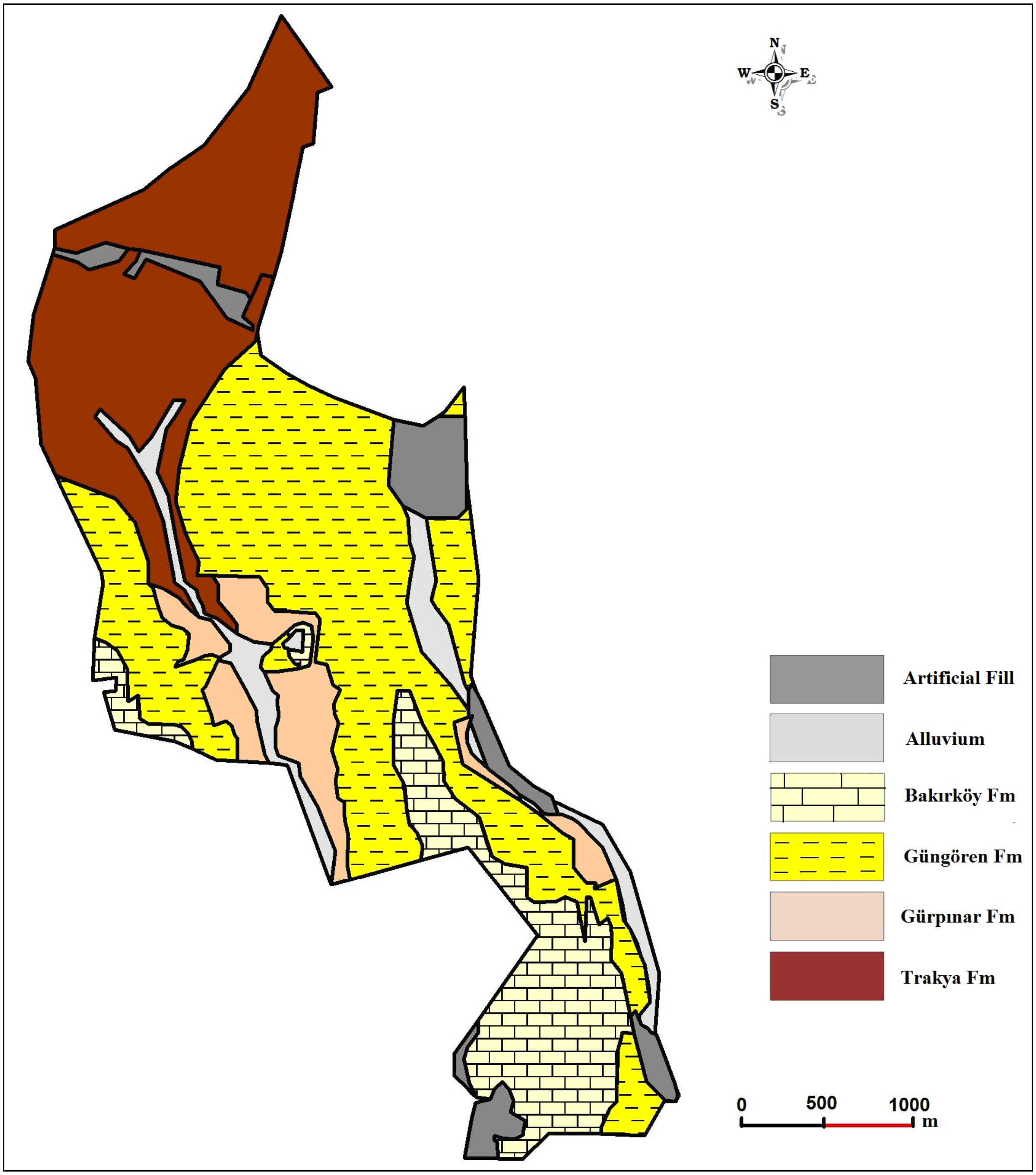

Figure 2. The geological map of the study area.

level depth in the study area is shown in Figure 3.

Soil classification

The site classification of the study area was established using data from 150 seismic measurements and 225 boreholes drilled and applied by different agencies and companies. The borehole logs include the description and thickness of soil layers and SPT values. The site soil classification was determined according to both the Turkish earthquake code (TEC, 2007) and NEHRP (BSSC 2001) by taking into consideration the soil profile and soil properties defined for each boring (Figures 4 and 5). The areas where the Trakya Formation outcrops can be classified as Z1-Z2/B, while zones of Z1-Z2/C-D are found where the Bakırköy Formation outcrops. The Gürpınar and Güngören Formation outcrops and alluvial

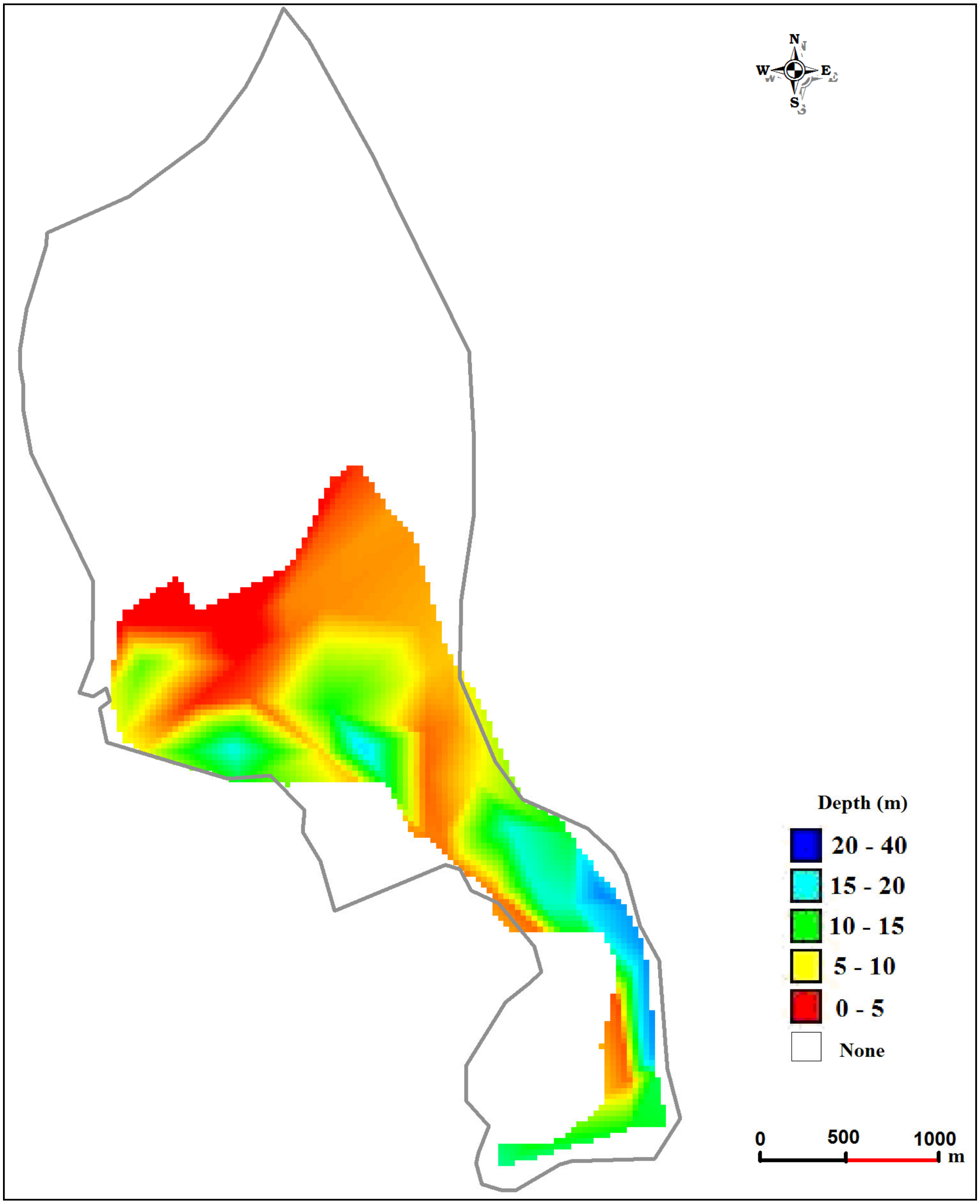

Figure 3. The variation of the groundwater level depth in the study area.

deposits are classified as Z2-Z3/C-D.

EARTHQUAKE HAZARD ASSESSMENT

There are two methods commonly used in the evaluation of earthquake hazard. One of them is the probabilistic seismic hazard analysis, which combines the probabilities of all earthquake scenarios with different magnitudes and distances that could affect a site in order to determine the seismic hazard. The other one is the deterministic earthquake hazard assessment that preceded probabilistic seismic hazard analysis as the prevalent form of hazard assessment for maximum (worst case) earthquake

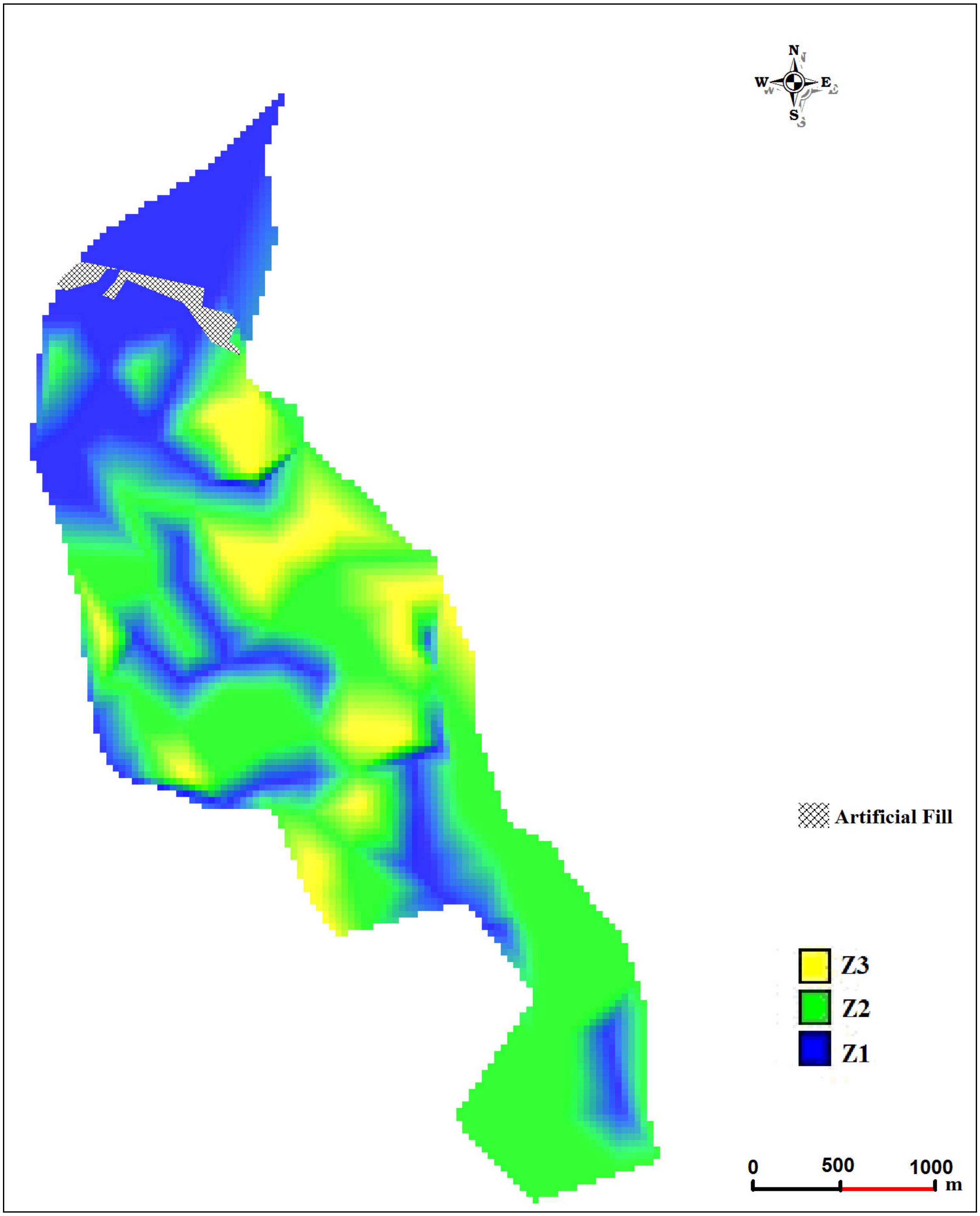

Figure 4. Soil classification according to Turkish earthquake code (TEC, 2007).

shaking. It involves development of a seismic scenario and define the hazard at the site by the controlling earthquake. In this study, a fundamental probabilistic seismic hazard analysis was carried out for the region and deterministic seismic hazard analysis was used to evaluate the earthquake hazard of the study area.

PROBABILISTIC SEISMIC HAZARD ANALYSIS OF REGION

Seismicity of the Marmara Sea region is controlled by the North Anatolian Fault Zone (NAFZ). NAFZ originated 10 Ma ago in eastern Anatolia and propagated westward

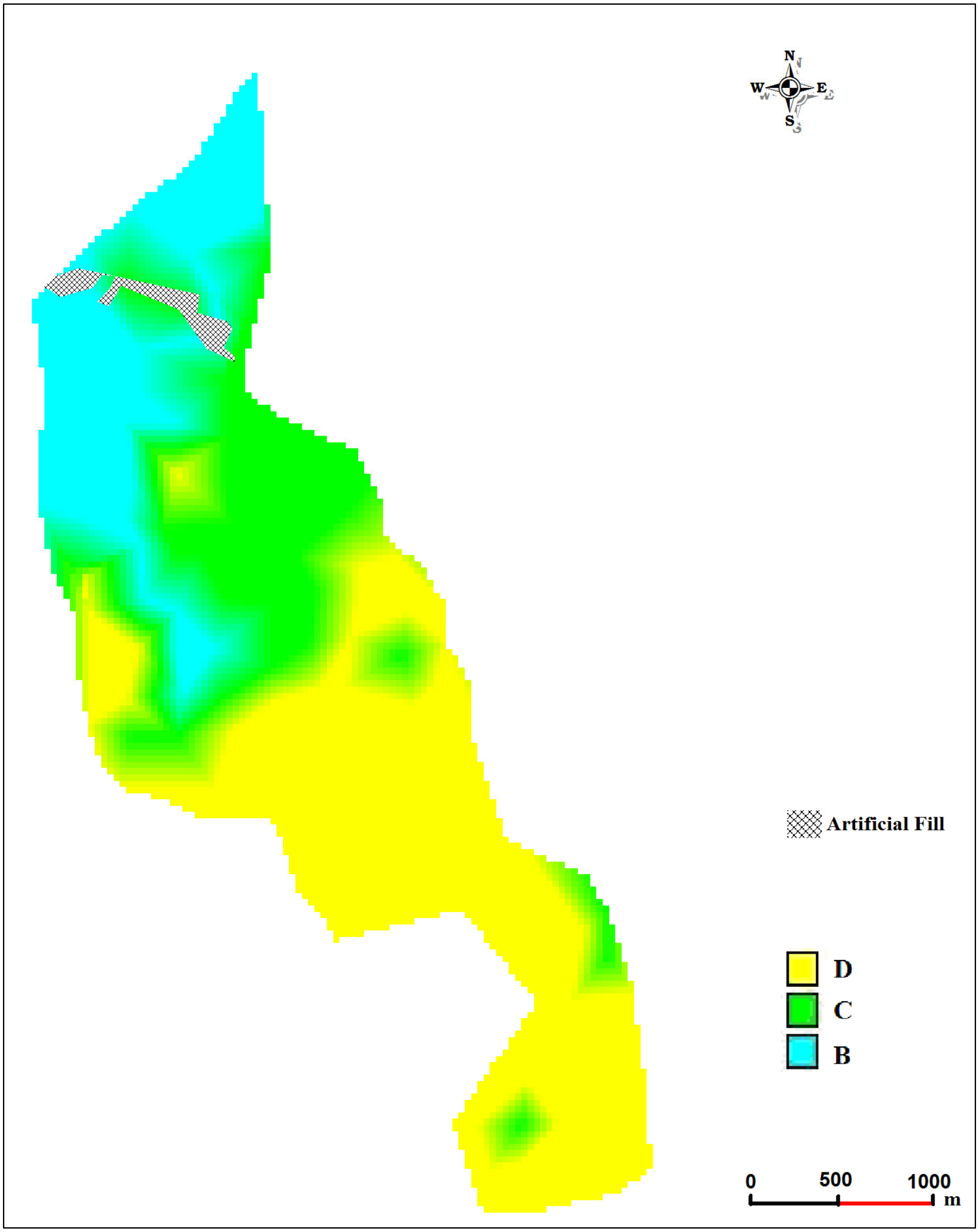

Figure 5. Soil classification according to NEHRP (2001, BSSC).

over the past 10 Ma according to geological and morphological evidences (Şengör et al., 1985; Barka, 1992; Armijo et al., 1999, 2002; Hubert-Ferrari et al., 2002). The fault zone extends for about 900 km between Karlıova in the east and Mudurnu town in the west with a single fault trace character (Ketin, 1969; Dewey and Şengör, 1979; Barka and Kadinsky-Cade, 1988; Koçyiğit, 1988; Stein et al., 1997; Gürer et al., 2003). NAFZ caused a broad distributed zone of deformation in the Marmara sea region (Barka and Kadinsky-Cade, 1988; Suzanne et al., 1990; Okay et al., 1999, 2000; Le Pichon et al., 2001a, b; İmren et al., 2001). There were five destructive earthquakes

Table 1. Earthquakes in research area about 150 km radius.

Magnitudes	4.0 ≤M <5.0	5.0 ≤M<5.5	5.5 ≤M <6.0	6.0 ≤M <6.5	6.5 ≤M <7.0	7.0 ≤M <7.5
Numbers	111	12	6	1	0	2

Table 2. Earthquake occurrence probability for region.

Magnitude	For D = 10 years probability (%)	For D = 30 years probability (%)	For D = 50 years probability (%)	For D = 70 years probability (%)	For D = 100 years probability (%)
5.0	75	99	99.91	99.99	100
5.5	49.30	87	97	99.14	99.89
6.0	28.03	62.72	80.69	90	96
6.5	14.72	37.98	54.90	67.20	79.66
7.0	7.42	20.65	31.99	41.71	53.74
7.2	5.61	15.89	25.06	33.22	43.83
7.5	3.66	10.59	17.03	23	31.15

of M_s >= 7.0 (9.8.1912 M_s = 7.3, 18.3.1953 M_s = 7.1, 26.5.1957 M_s = 7.2, 22.7.1967 M_s = 7.2 and 17.8.1999 M_s = 7.4) occurred in Marmara region in the last century. The occurrence probability of an M_w >= 7.0 magnitude earthquake is about 65% according to recent studies conducted after the 1999 Kocaeli (M_w = 7.4) and Düzce (M_w = 7.2) earthquakes (assuming that the stress regime in the Marmara Sea remains unchanged) (Parsons et al., 2000).

In order to determine the probabilistic earthquake risk of the region, primarily 4 and the larger magnitude earthquakes which occurred in 1900 to the present within a radius of 150 km were obtained from KOERİ (Kandilli Observatory and Earthquake Research Institute). In Table 1, earthquakes were given in research area as about 150 km radius. Gutenberg-Richter recurrence relationships were determined as:

$$\text{Log (N)} = 4.50 - 0.63\text{ M} \quad (1)$$

Probabilistic seismic hazard of the study area and its surroundings were determined for different magnitude and durations according to Poisson probability distribution and was given in Table 2 by using:

$$Rm = 1 - e^{-(N(M)D)} \quad (2)$$

where Rm = Risk value (%); D, duration; N(M) for M magnitude Equation 1 value

DETERMINISTIC SEISMIC HAZARD ANALYSIS FOR THE STUDY AREA

Deterministic seismic hazard assessment was performed for the Adalar Fault which is the closest fault segment to the study area in Marmara region (Figure 6). Adalar Fault is approximately 105 km rupture length. Magnitudes were estimated for Adalar Fault by using several equations as shown in Table 3. Design earthquake magnitude is selected as 7.4 for the deterministic seismic hazard analysis.

Ground motion effects due to the estimated earthquake magnitude were determined by using Boore et al. (1997) and Gülkan and Kalkan (2002) attenuation relationships. Both attenuation relationships are widely used in earthquake hazard assessments and there are similarities between the mechanisms of San Andreas fault and NAF originated earthquakes. The ground motion estimation equation (Boore et al., 1997) is shown as;

$$\ln Y = b_1 + b_2\,(Mw - 6) + b_3\,(Mw - 6)^2 + b_5 \ln r + bv \ln (Vs/V_A) \quad (3)$$

$$r = \sqrt{rjb^2 + h^2}$$

and (Gülkan and Kalkan, 2002) is shown as;

$$\ln Y = b_1 + b_2\,(M - 6) + b_3\,(M - 6)^2 + b_5 \ln r + bv \ln (Vs/ V_A) \quad (4)$$

$$r = \sqrt{rcl^2 + h^2}$$

where Y is the ground motion parameter (peak horizontal acceleration (PGA) or pseudo spectral acceleration (PSA) in g); M is (moment) magnitude; rcl is closest horizontal distance from the station to a site of interest in km; rjb is the Joyner-Boore distance (km); Vs is the average shear wave velocity to 30.0 m (m/s); b_1, b_2, b_3, b_5, h, bv, and V_A are the parameters to be determined by

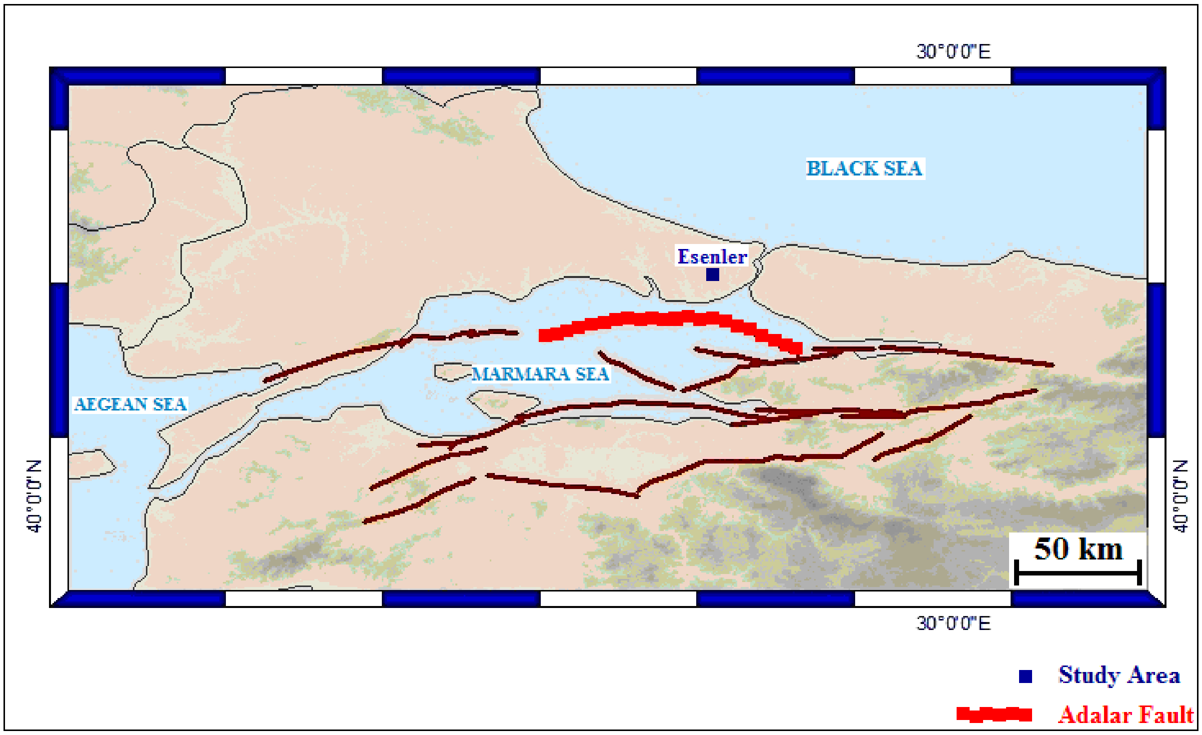

Figure 6. Fault segmentation model for the Marmara region (Barka and Cadinsky, 1988; Armijo et al., 2005).

Table 3. Equations for rupture length and magnitude estimations.

Researcher	Equation	Magnitude type	M (Magnitude)
(Ambraseys and Zatopek,1968)	M = (0.881 LOG(L)) + 5.62	Ms	7.4
(Douglas and Ryall, 1975)	M = (LOG(L) + 4.673)/0.9	Ms	7.4
(Ezen, 1981)	M = (LOG(L) + 2.19)/0.577	Ms	7.3
(Matsuda, 1975)	M = (LOG(L) + 2.9)/0,6	Ms	8.2
(Toksöz et al., 1979)	M = (LOG(L) + 3.62)/0.78	Ms	7.2
(Wells and Coppersmith, 1994)	M = 5.16 + (1.12 LOG(L))	Mw	7.4
(Wells and Coppersmith, 1994)	M = 5.08 + (1.16 LOG(L))	Mw	7.4

Table 4. Coefficients of attenuation equation (Boore et al., 1997).

Index	b_1	b_2	b_3	b_5	bv	V_A (m/s)	h (km)
PGA (g)	-0.313	0.527	0.000	-0.778	-0.371	1396	5.57

regression. The coefficients related to the attenuation relationships are presented in Table 4 and Table 5.

In this study, during the determination of the ground motion effects of the study area, used average of the estimated peak horizontal accelerations according to Boore et al. (1997) and Gülkan and Kalkan (2002) attenuation relationships. Figure 7 represents the seismic hazard map prepared by the average of the estimated peak horizontal accelerations.

GEOPHYSICAL ANALYSIS OF SOIL AMPLIFICATIONS

While planning the settlement areas, to determine the possible soil amplifications caused by earthquakes is very important in terms of earthquake-resistant design. It is known that the soft soils enlarge the earthquake waves during an earthquake and have a large share on the earthquake damages. In this study, shear wave velocity

Table 5. Coefficients of attenuation equation (Gülkan and Kalka, 2002).

Index	b_1	b_2	b_3	b_5	bv	V_A (m/s)	h (km)
PGA (g)	-0.682	0.253	0.036	-0.562	-0.297	1381	4.48

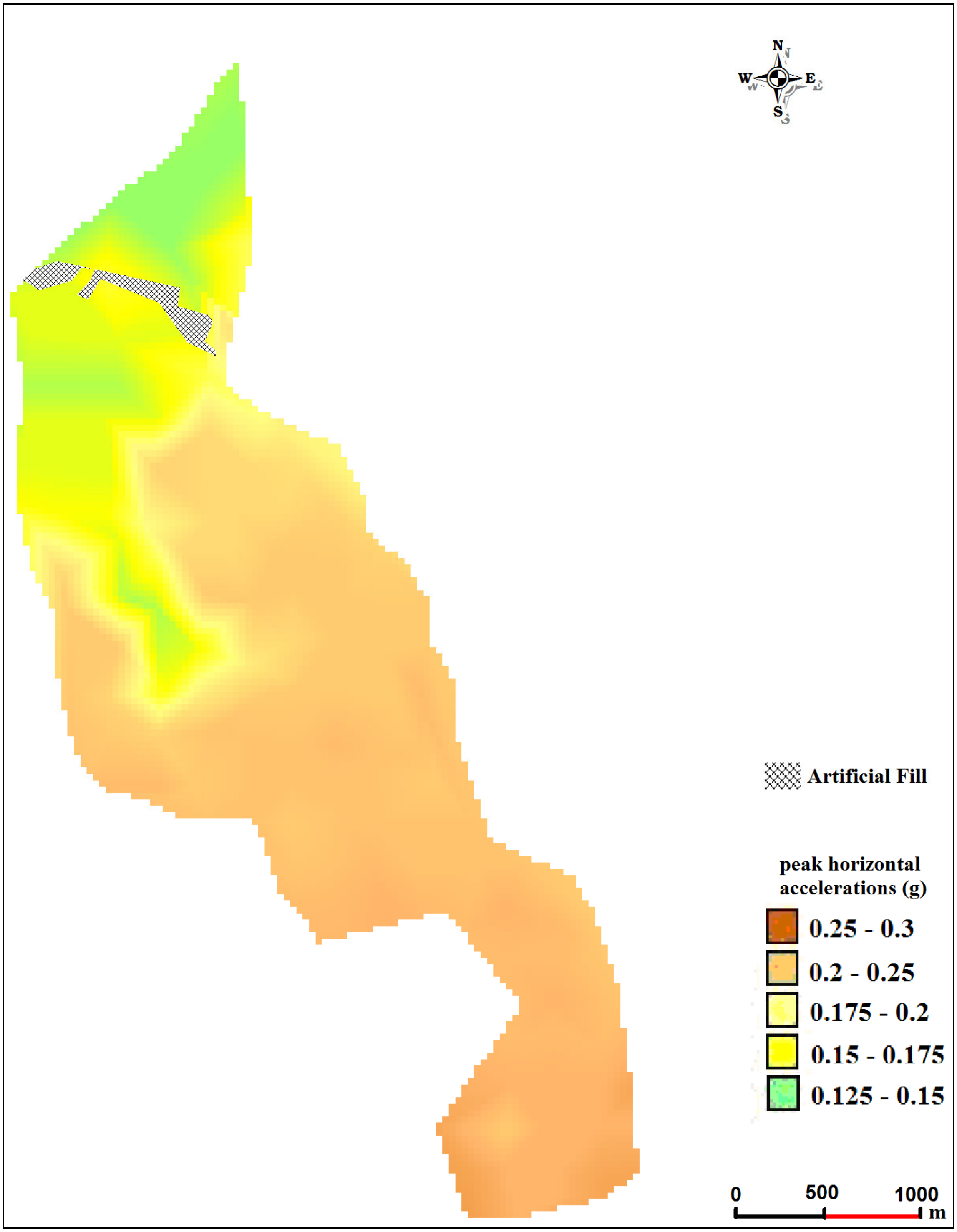

Figure 7. Variation of average peak horizontal accelerations estimated attenuation relationships (Boore et al., 1997; Gülkan and Kalkan, 2002).

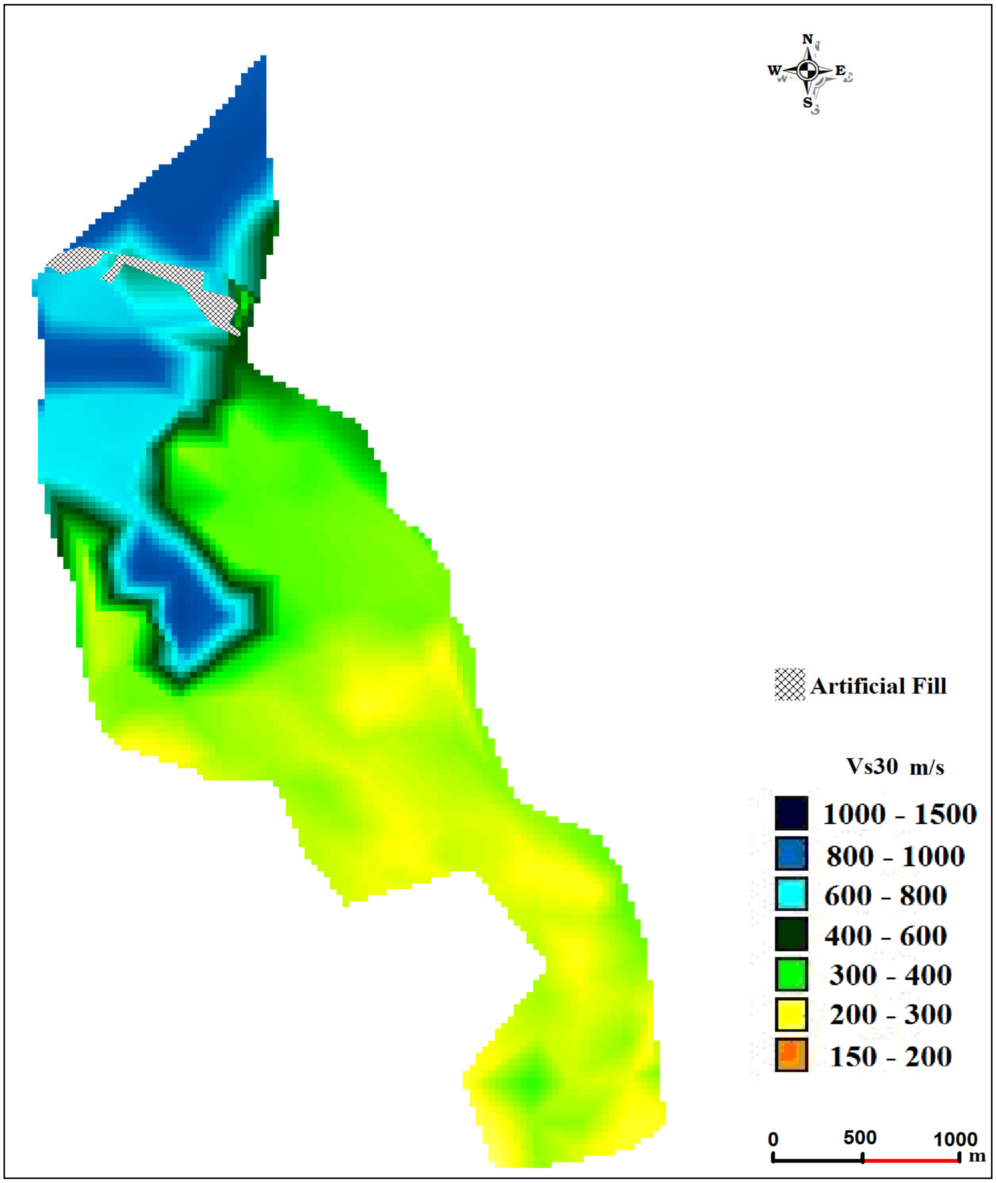

Figure 8. V_{s30} values in the study area.

data obtained by seismic measurements were used to determine the probable soil amplifications and characteristic site periods. As it is known, shear wave velocity is an index property to evaluate the soil amplifications. In equations 5 and 6, the shear wave and soil amplification relations were given (Midorikawa, 1987).

$$A = 68\ V_1^{-0.6} \quad (V_1 < 1100 m/s) \qquad (5)$$

$$A = 1\ (V_1 > 1100\ m/s) \qquad (6)$$

where V_1 is average shear wave velocity to 30.0 m.

The characteristic site period, which only depends on the soil thickness and average shear wave velocity of the soil, provides already a very useful indication of the period of vibration at which the most significant amplification can be expected. The period of vibration corresponding to the fundamental frequency is called the site period (T) and for multi-layered soil can be computed as;

$$T = 4h/Vs \qquad (7)$$

where T is characteristic site period in seconds, Vs is the average shear wave velocity of the layer and h is the total thickness of the sedimentary layers.

Figures 8, 9 and 10 show V_{s30} values, characteristic site period values and soil amplification values of the study area, respectively. V_{s30} values are generally ranged

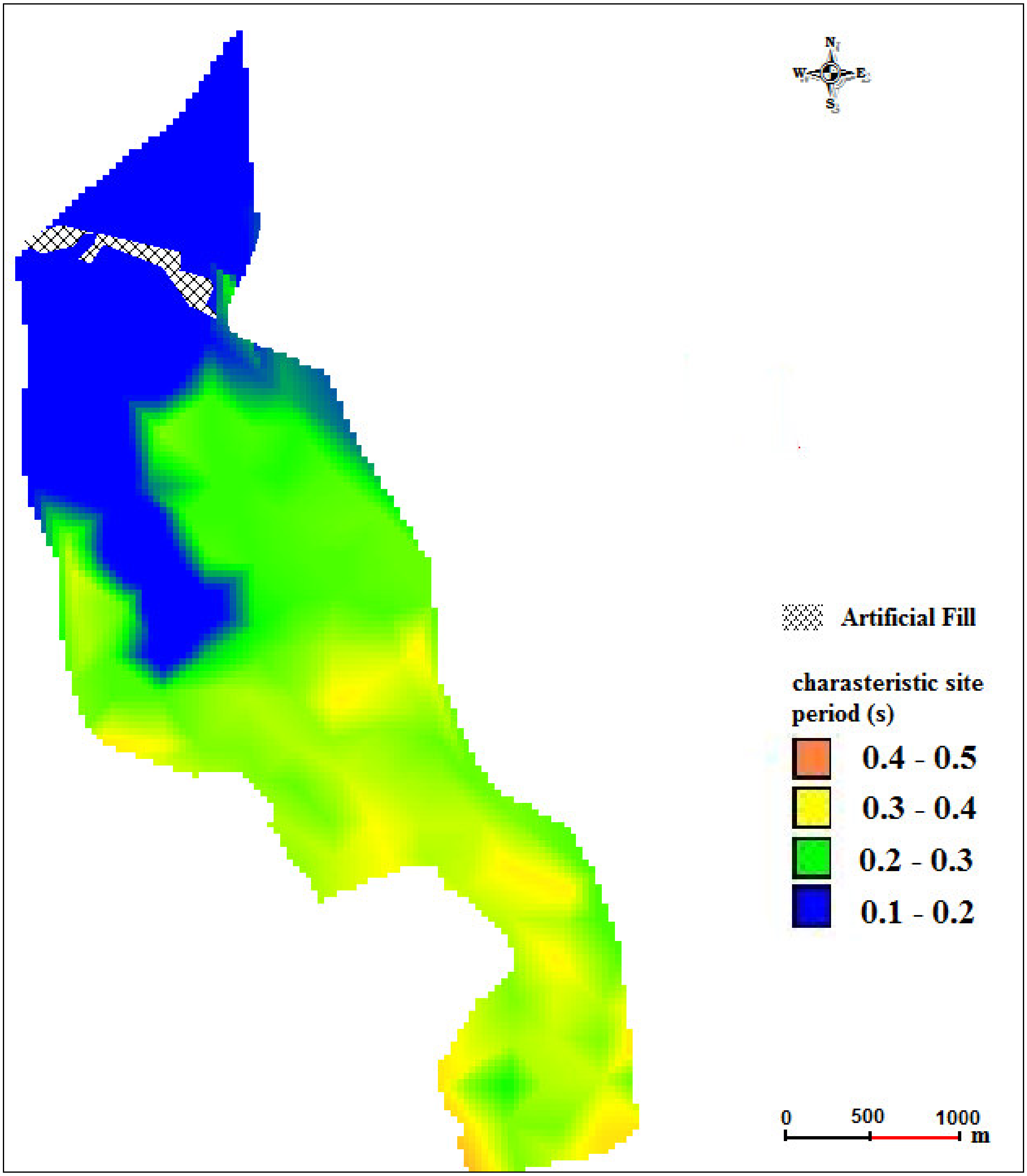

Figure 9. Characteristic site period values in the study area.

from 600 to 1000 m/s on the Trakya Formation outcrops at the northern sides and generally ranged from 200 to 400 m/s on the other sides in the study area. Therefore, the northern sides of the study area have low characteristic site period and soil amplification values.

RESULTS AND CONCLUSIONS

In this study, small scales microzonation was carried out for Esenler district located on European side of Istanbul by using geological, geophysical and geotechnical data

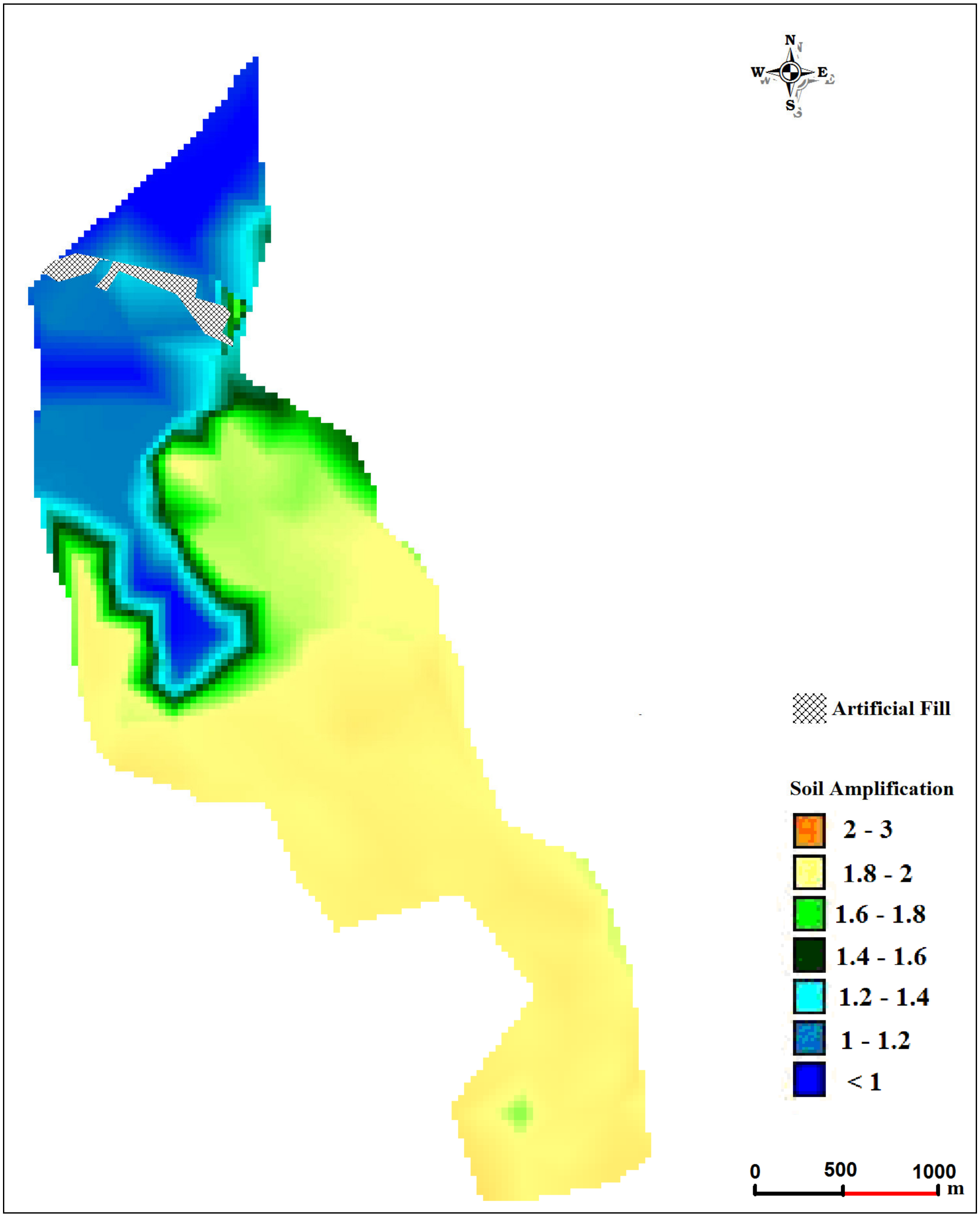

Figure 10. Soil amplification values in the study area according to Midorikawa (1987) relation.

together. Geological and geotechnical data were used to prepare detailed geological map which indicates the local geological characteristics of the site. The study area has a deep slope in N-S direction. The soil classes are generally determined as CH and CL according to USCS in study area. The SPT-N values are generally changing between 30 and 50 at the weathered rock units and generally changing between 20 and 40 at the soil units in the study area. According to seismic measurements, the shear wave velocities are generally changing between 200 and 400 m/s in the study area in the depth of 30 m. The shear wave velocity increases to 800 to 1200 m/s in the northern parts of the study area due to the sandstone and greywacke effects. The soil boring studies indicate that there is no groundwater level in many areas in the study area.

Site classification was conducted for each boring with respect to Turkish earthquake code (TEC, 2007) and the site was classified as Z1, Z2 and Z3. For the site classification with respect to NEHRP (BSSC, 2001), shear wave velocities in the upper most 30 m were utilized and NEHRP site classification have indicated that the investigated area could be classified as D, C and B. According to the evaluations of site classification maps together with geology maps, the zones where graywacke and limestones with varying strengths of Trakya and Bakırköy Formations are outcropping and are mapped as Z1 and Z2 and B and C with respect to TEC and NEHRP, respectively. The majority of the Gürpınar and Güngören Formations and alluvial sites are classified as Z2 and Z3 according to TEC and as C and D according to NEHRP. As a result of the evaluations made based on the local soil conditions, the site classification maps are seen to be compatible with the geological structures.

The earthquake hazard of the study area is determined by using deterministic and probabilistic approaches. The probabilistic analysis indicated that the occurrence probability of a 7 magnitude (M_w=7) earthquake is 7.42% in 10 years and 32% in 50 years for Istanbul and its surroundings. Deterministic earthquake hazard analysis is also performed for Adalar Fault in Marmara region and the design earthquake magnitude is selected as 7.4. Deterministic earthquake hazard analysis indicates that the peak horizontal accelerations ranged from 0.20 to 0.30 g in the southern parts and ranged from 0.15 to 0.20 g in the northern parts of the study area.

Soil amplification values and characteristic site periods are estimated by shear wave velocities for the depth of 30 m in the study area. Characteristic site periods determined as 0.1 to 0.2 s grades in the northern sides and 0.2 to 0.4 s in the other sides. In addition the northern sides of the study area are not risky in terms of soil amplification due to the sandstone and greywacke effects (Midorikawa, 1987).

Microzonation is of great importance for urban planning. It is possible to evaluate the seismic hazard and to determine the local soil parameters in urban microzonation studies by using geological, geophysical and geotechnical data together. This study indicated that the northern sides of the study area represented by Trakya Formation are more suitable for the settlements in Esenler district. Considering the earthquake potential of the area, the design stage must include geotechnical investigations for detailed assessment of the foundation conditions.

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