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GIS-BASED SOIL LIQUEFACTION HAZARD MAPPING WITH GEOTECHNICAL DATA ALONG MAJOR COASTAL HIGHWAY ARTERIES OF IZMIR BAY AREA

İZMİR KÖRFEZ BÖLGESİ'NİN ANA SAHİL OTOYOLU ARTERLERİ BOYUNCA GEOTEKNİK VERİLERLE CBS TABANLI ZEMİN SIVILAŞMA TEHLİKESİNİN HARİTALANDIRILMASI

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ÖZET

Sıvılaşma en önemli geoteknik tehlikelerden biri olup, deprem esnasında suya doygun gevşek kumlu zeminlerde ve plastik olmayan killerin su basıncının artmasıyla dayanımını kaybederek sıvı benzeri davranış göstermesi olarak tanımlanır. Bu olay binalara barajlara, köprülere ve altyapıya hasar vermekte olup, en önemlisi insan hayatı için büyük tehlike arz etmektedir. Bu kavram 1964 yılında meydana gelen Niagata ve Alaska depremlerinden sonra geoteknik camiası tarafından dikkat kazanmış ve bu alanda çalışmalar yoğunlaşmıştır. Bu çalışmanın konusu olan bölge İzmir, şiddetli depremlere maruz kalmış ve fay zonlarına yakınlığından dolayı deprem sırasında sıvılaşma tehlikesi barındırmaktadır. Bu maksatla İzmir kıyısındaki yollarda, ana arter olarak nitelendirilen, coğrafi bilgi sistemleri araçlarıyla sondaj logları ve laboratuvar sonuçlarından elde edilen geoteknik veriler entegre edilerek sıvılaşma tehlikesi incelenmiştir. Toplamda 82 sondaj kaydı dahil edilmiş ve sıvılaşmaya karşı güvenlik faktörü üç farklı deprem seviyesi (DD1, DD2 ve DD3) için hesaplanmıştır. Sonuçlar, bölgenin sismik risklere karşı hassasiyetini değerlendirmek ve böyle bir tehlikeye karşı bölgenin dayanıklılığını artırmak için geoteknik mühendisleri ve karar vericiler için değerli bilgiler sağlamayı amaçlamaktadır.
Anahtar Kelimeler: Sıvılaşma, Güvenlik katsayısı, PGA, CBS, Hayati yol

ABSTRACT

Liquefaction, one of the most important geotechnical hazards, occurs when saturated sandy soils and non-plastic silts lose their strength during seismic events and result in behaving like a liquid. It is responsible for severe damage to buildings, dams, and bridges during an earthquake, and most importantly it is a threat to human life. This phenomenon comes into prominence after the 1964 Niigata and Alaska earthquakes. İzmir, the interest of this study, is highly vulnerable to liquefaction because of its history of destructive

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earthquakes and proximity to active faults. In this context, this paper examines liquefaction hazards in the İzmir coastal area, particularly the İzmir lifeline road, using geotechnical data with an integration of Geographic Information System tools. A total of 82 borehole records were included and the safety factor against liquefaction was computed for each of the three levels of earthquakes (DD1, DD2, and DD3). The results are intended to provide valuable information to geotechnical engineers and decision-makers to assess the region's vulnerability to seismic risks and to increase the resilience of the region to such hazards.
Keywords: Liquefaction, Factor of safety, PGA, GIS, Lifeline Road

1. INTRODUCTION

Liquefaction is a geotechnical hazard usually occurring during earthquakes. Liquefaction may cause extensive damage to buildings, dams, and levees and sometimes, may end up with human life loss. The Niigata Earthquake is assumed as a milestone regarding the recognition of this phenomenon in the modern age. The Great Alaska earthquake which also took place in 1964, led to raised awareness among the geotechnical community. An early contribution to the field was made by Yoshimi et al. (1977), Seed (1979), and Finn et al. (1981).

İzmir has undergone moderate earthquakes ($M_W \leq 6$) in the instrumental period in or around the city. However, the most recent 2020 Samos Earthquake ($M_W > 6.5$), albeit with a distant epicenter, hit the area and resulted in substantial damages in coastal residential areas. Furthermore, the proximity of the active faults (Figure 1) defines the region as a high-risk seismic area. Therefore, the liquefiable soil profiles of the city shall be properly identified to account for future precautions. For instance, maps showing the distribution of historical liquefaction effects are very useful for further characterization and delineation of susceptibility zones (Youd,1991).

In this study, two of the major transportation arteries (Konak-Üçkuyular Coastal Highway and The Altınyol) were studied to characterize earthquake hazards originating from liquefiable soils that underlain the aforementioned highways. The study aims to give an insight concerning liquefaction hazards in this area gathering together geotechnical data and spatial information powered by the geographic information system (GIS). This information is thought to be crucial for geotechnical engineers to review the area and policymakers for enhancing the region’s resilience.

Our research comprises a collection of 82 borehole data from earlier works along the İzmir coastline. Information from laboratory tests and the drilling records were exported into GIS. Within the software, data were processed with already well-established liquefaction analysis methods. The factor of safety against liquefaction for DD-1, DD-2 and DD-3 earthquake levels corresponding to maximum accelerations of 0.85g, 0.46g and 0.175g were computed. Many data points were gathered and incorporated into the map through the use of Geographical Information System (GIS) software tools. The achieved map displays the general vulnerability of the region. This study intends to improve our knowledge of the risks of soil liquefaction in İzmir Bay. It will help to ensure the safety and sustainability of the area in the face of seismic hazards.

2. STUDY AREA

İzmir is located around a bay area of the Aegean Sea and it is the third most populated city. The geographic position of the area is 38°25′19″N and 27°07′44″E. It is a city located on the Gulf of İzmir where alluvial soils were formed by the Gediz River on the north and several other smaller rivers on the south and the west (Figure 1). The geological composition of the coastal zones consists of recent alluvial deposits and marine sediments. The coastal region is generally considered highly susceptible to liquefaction during seismic events.

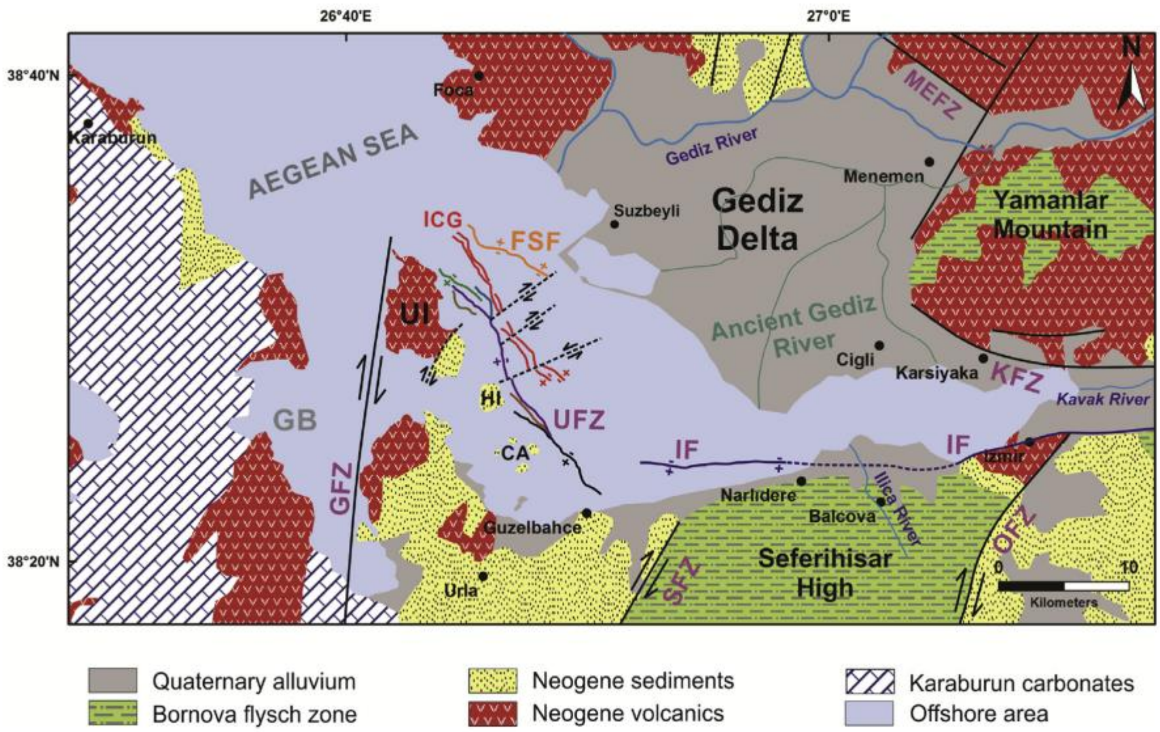

Figure 1. Simplified geological map and active faults around the Gulf of Izmir. See location on Fig. 1. UFZ: Uzunada Fault Zone, IF: Izmir Fault Zone, ICG: Izmir Central Graben, FSF: FocaSuzbeyli Fault, OFZ: Orhanli (Tuzla) Fault Zone, GFZ: Gulbahce Fault Zone, GB: Gulbahce Bay, MEFZ: Menemen Fault Zone, SFZ: Seferihisar Fault Zone, KFZ: Karsiyaka Fault Zone, UI: Uzun Island, HI: Hekim Island, CA: Cicek Archipelago. Modified from Uzel et al. (2012) and after Coskun et al. 2017)

3. METHODOLOGY

Liquefaction resistance of soils is one of the major research topics and design issues that need to be taken into consideration in routine soil dynamics and geotechnical earthquake engineering applications. Researchers from the United States and Japan developed a simplified procedure that has evolved over the years. In 1996 NCEER workshop convened by Youd, Idriss and several other participants evaluated the state-of-the-art research outcome and provided suggestions (Youd and Idriss, 2001). Although ongoing research is being made on sandy soils with cohesive and cohesionless fine content, currently this procedure which details are given elsewhere (TBDY 2018) is being used in design offices. Typically calculated factors of safety values belonging to a borehole are presented in Table 1 for DD1, DD2 and DD3 level earthquakes.

Figure 2. Location map of the study area

Table 1. Typical factor of safety values against liquefaction (@ 4_SK-11)*

Depth (m)	σ_{v0}'	N_{30}	N_{60}	$(N_1)_{60}$	r_d	$CRR_{7.5}$	CSR (1)	CSR (2)	CSR (3)	F_s (1)	F_s (2)	F_s (3)
2.5	26.1	0	0	0	0.98	0.05	0.594	0.319	0.121	0.083	0.222	0.901
4	33.0	0	0	0	0.97	0.05	0.805	0.431	0.163	0.061	0.164	0.665
5.5	40.5	0	0	0	0.96	0.05	0.946	0.507	0.192	0.052	0.140	0.566
7.5	58.2	0	0	0	0.94	0.05	0.995	0.534	0.202	0.049	0.133	0.538
9	71.0	0	0	0	0.92	0.05	0.998	0.535	0.202	0.049	0.132	0.536
10.5	82.4	5	3.75	4	0.89	0.07	0.991	0.531	0.201	0.066	0.179	0.724
12.5	97.4	8	6	6.08	0.84	0.08	0.955	0.512	0.194	0.084	0.226	0.917
14	111.8	10	7.5	7.1	0.79	0.09	0.899	0.482	0.182	0.098	0.265	1.073
15.5	126.8	15	11.25	9.98	0.74	0.11	0.839	0.450	0.170	0.135	0.362	1.469
17	141.8	15	11.25	9.45	0.69	0.11	0.783	0.420	0.159	0.138	0.372	1.507
19	161.8	28	21	16.5	0.64	0.18	0.721	0.386	0.146	0.244	0.655	2.656
20.5	176.8	21	15.75	11.85	0.60	0.13	0.683	0.366	0.139	0.190	0.511	2.071
22	191.8	24	18	13	0.58	0.14	0.653	0.350	0.132	0.215	0.579	2.347
25	220.4	13	9.75	6.6	0.54	0.08	0.611	0.327	0.124	0.138	0.371	1.503
26.5	234.7	15	9.75	7.35	0.53	0.09	0.595	0.319	0.121	0.152	0.409	1.658
28.5	252.8	31	11.25	14.6	0.51	0.16	0.579	0.310	0.117	0.270	0.726	2.943

* (1): DD1 Level earthquake; (2): DD2 Level earthquake; (3): DD3 Level earthquake
M=7.5 M=6.5 M=5.5

4. DATA ANALYSIS AND RESULTS

Approximately 82 boreholes from various projects along İzmir's coastline were included in the study's scope. Borehole values are incorporated into GIS and all relevant calculations have been processed with Python in GIS. All points were transferred onto the map within the program according to their coordinates and depths. Safety against liquefaction (F_s) calculations was performed and attained values $F_s(1)$, $F_s(2)$ and $F_s(3)$ at 10-meter depth, which corresponds to DD1, DD2, and DD3 earthquake levels, are presented in Figure 3 and Figure 4.

To find out the liquefaction potentials where the borehole data does not exist, a special geoprocessing tool has been used which is the Empirical Bayesian Kriging (3D) method. Empirical Bayesian Kriging (EBK) 3D is a geostatistical interpolation technique designed for predicting 3D spatial phenomena. Unlike conventional methods, EBK 3D provides a robust approach by modeling the variogram parameters while accounting for uncertainty.

5. CONCLUSIONS

Geotechnical problems come from liquefaction-related issues because of their damage to many structures considering liquefaction-induced ground deformations. Due to its proximity to faults and history of moderate earthquakes, the Izmir coastline which is regarded to be liquefiable was chosen for this investigation.

In this study an attempt to gave an insight regarding the soil susceptibility map for the coastline of İzmir. Using GIS, several borehole data have been mapped and all individual values marked their geographical information. Liquefaction safety factor calculations at 10-meter depths carried out at DD1, DD2 and DD3 earthquake levels (corresponds to M_W=7.5,

M_W=6.5 and M_W=5.5). The Kriging method is used to create a continuous hazard map. Figures 3 and 4 demonstrate the obvious that, for a DD1 earthquake level, the safety factor is approximately 0.1-0.2 on average in the Konak-Balçova and Alsancak region which is very high in terms of liquefaction potential and roughly 0.4 in the Bayraklı region. For the DD2 earthquake level, these average values varied across all regions from 0.4 to 0.6. In general, the Konak Balçova and Alsancak regions have achieved up to 1.5 for the DD3 earthquake threshold. While there are areas in the Bayraklı region with safety factors as high as 2, the overall picture indicates that the average value is around 0.8. The estimated liquefaction values in this major artery indicate that excessive settlement, sliding towards the sea, and loss of bearing capacity are inevitable. It is strongly recommended that local administrators take this into consideration.

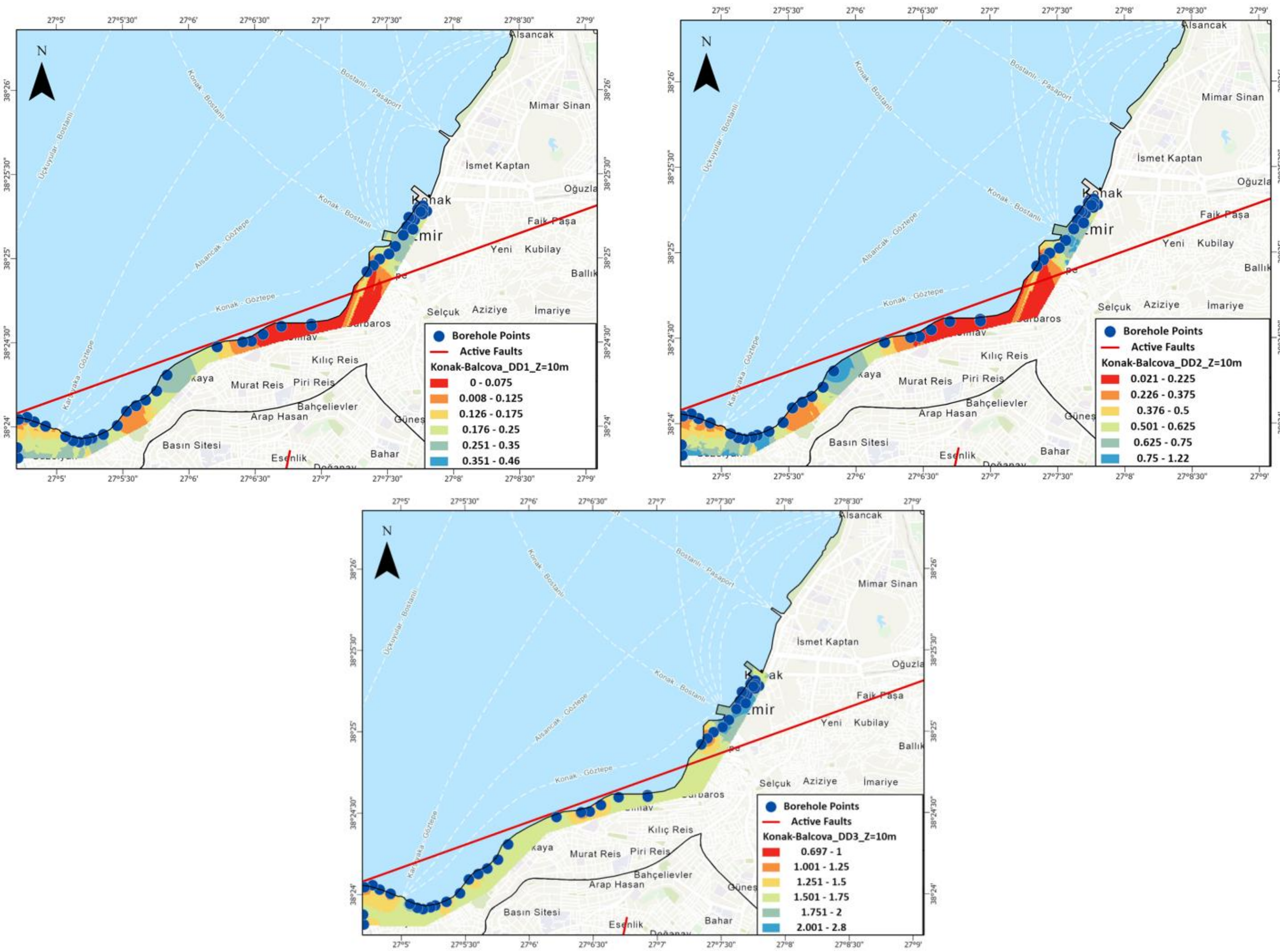

Figure 3. The factor of Safety Against Liquefaction (F_S) Distribution with Kriging Method Konak-Balçova District for DD1/DD2/DD3 Earthquake Levels

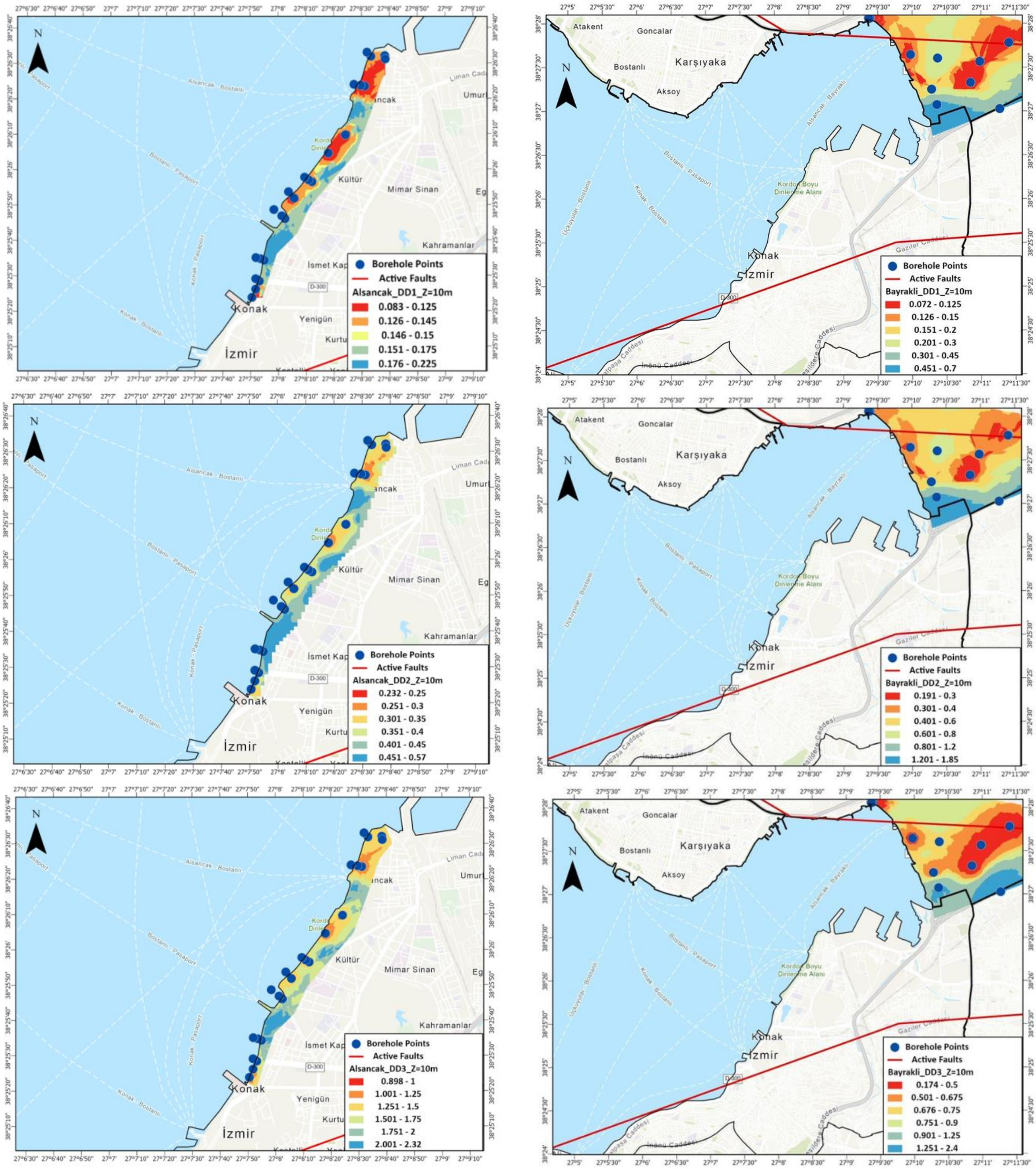

Figure 4. The factor of Safety Against Liquefaction (F_S) Distribution with Kriging Method Alsancak and Bayraklı District for DD1/DD2/DD3 Earthquake Levels

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