Evaluation of Seismicity Using Density Analysis of 2000-2015 Earthquakes in The West Coastal Zone of Anatolia (Turkey) And Its Correlation with Geothermal Areas

Özde Bakak 1
Dokuz Eylül University, Graduate School of Natural and Applied Science, Geothermal Energy Department, Turkey
E-mail: ozde.badur@deu.edu.tr

Abstract. The purpose of the study is to evaluate the seismic activity using the density analysis methods (point density and Kernel density analysis) for 2000-2015 earthquake catalogue belonging to the study area surrounded by Çanakkale to the north, Fethiye to the south and Denizli (Buharkent) to the east, and also to apply its correlation with geothermal regions. The earthquake data, in total 6,675 earthquakes with M>3 magnitudes were obtained from DDA Catalogue of Prime Ministry Disaster & Emergency Management Authority (AFAD) official website. In this survey, data analysis and maps were prepared using ArcGIS (version 10.1) program. The analysis maps present (1) the intensity clustered earthquakes dominant in Sığacık and Gökova Gulfs, (2) regions which have high seismic risk were determined according to Buffer analysis for 2 km distance, (3) geothermal areas (21.4-153°C) in the west coastal zone of Anatolia were mapped, (4) regions the most affected by seismic activity for the last 15 years were detected from 2015 population data, and as latest (5) Seferihisar, Urla, Gülbahçe, Demircili, Bodrum, and Dağtaş provinces are identified as areas having high seismic activity for the last 15 years. Consequently, all analysis results were compared with the geothermal areas, and the review made that earthquake catalogue has not the relationship with hot regions and also these shocks triggered by active faults in this region using ArcGIS program. the author recommends that these regions should be investigated the earthquake sensitivity analysis in the near future.

1. Introduction
Anatolia is situated in a critical segment of the Alpine-Himalayan orogenic belt which occurred as resulting from the collision of Eurasian plate with Africa/Arabia and India plates and is active tectonic region. As the effect of this collision, a very large deformation zone was formed, and also Western Anatolia and the Aegean Sea have expanded approximately NNE-SSE direction [1,2,3]. Western Anatolia is characterized by N-S extension, parallel grabens and intervening horst and associated normal faults [4]. Due to enlargement of W-S and WNW-ESE trending tectonic, many grabens such as Gökova, Büyük and Küçük Menderes and Gediz [5] have important geothermal fields. Most of the faults have caused significant historical earthquakes [6,7].

The most intense earthquake clusters were located in Sığacık and Gökova Gulfs in between 2000 and 2015 (figure 1). These earthquakes and the tectonic structure of gulfs were also investigated in terms of geology and geophysics by Sözbilir et al. [8], Pamukçu et al. [9], Yolsal-Çevikbilen et al. [10], İşcan et al. [11].
2. Method

2.1. Data Sources

The earthquake catalogue (consists 6,675 earthquakes with M>3 magnitudes) was obtained from DDA catalogue in Prime Ministry Disaster & Emergency Management Authority (AFAD) official website [12]. Turkey’s terrestrial active and inactive faults were taken from Emre et al. [13], the seafloor faults from İşcan et al. [11], and location/temperature data of geothermal wells/hot springs from MTA [14].

![Figure 1](image)

**Figure 1** Locations of provinces in study area represent as green points, and the distribution of micro (3<M<5) and moderate (M>5) earthquakes by magnitudes

2.2. Data Analysis and Interpretation

All analysis and maps in this paper were prepared using ArcGIS (version 10.1) software program. Data analysis consists of Buffer, Point density, Kernel density, Inverse Distance Weighted (IDW) interpolation.

**a) Buffer analysis** creates buffer polygons around input features to a specified distance [15]. Faults/inactive faults were digitized after transferred to using program and buffer analysis was applied to 2 km distance while it hadn’t been considered necessary for seafloor faults (figure 2A). In the result of Buffer analysis, generally, active faults were showed a spreading along significance grabens in West Anatolia.

**b) Point density analysis** calculates the density point feature (earthquakes points) around each output raster cell. Conceptually, a neighbourhood is defined around each raster cell centre, and the number of points that fall within the neighbourhood is totalled and divided by the area of the neighborhood [15]. Point density analysis values are changing from 0 to 53,000, and high values changing from 11,000 to 53,000 represents Sığacık, and Gökova Gulfs (figure 2B). The distribution direction of earthquakes is found to be similar to the direction of faults in the region.
As regarding these clusters in the literature, 2005 Sığacık Gulf earthquakes along the southern segment of the Gülbağçe fault (E-W) [16], and most of the seismic activity is concentrated along the northern branch of Gökova Fault Zone controlled by E-W trending normal fault system, intense earthquake activity occurred in Gökova Gulf in August 2004 and January 2005 [17]. It is shown that the results of mentioned previous surveys are consistent with point density analysis results.

c) **Kernel density analysis** calculates the density of features in a neighbourhood around those features [15]. In the analysis, earthquake magnitude values (3>M) were written as input data in “population field” section. Kernel analysis map are grouped into three categories of high values (red colour), which seem in Sığacık and Gökova Gulfs, medium values (yellow), which seem in Samos Island, Kuşadası Gulf, between Midilli and Karaburun Peninsula, and low values (green colour). Kernel analysis map is found be almost similar point density map, even though two analyses calculate consisting difference data such as magnitude and point locations in earthquake catalogue. Its reason is that high magnitude earthquakes were located in the region be intense of earthquake points in the same way too. Areas having high Kernel density values have both an important earthquake experience and the intense seismic activity.

d) **Inverse Distance Weighted (IDW)** uses the measured/known values surrounding the prediction location to predict a value for any unsampled location, based on the assumption that things that are close to one another are more alike than those that are farther apart [15]. Geostatistical methods of data interpolation also provide the measure of the uncertainty of the prediction [16]. To more clearly demonstrate of importance and impact of earthquakes, the 2015 surface population map were prepared using Inverse Distance Weighted (IDW) method (figure 4) with obtained population data from 87 provinces. Predicted population map of 2015 shows that İzmir city centre and surrounding has the most intensity population. The population amount of Sığacık, Urla, Gülbağçe, Güzelbahçe and

![Figure 2. A) Buffer analysis (2km) for active faults categorised as Holocene and Quaternary faults, faults (or inactive), and seafloor faults [11, 13], B) point density analysis map](image-url)
Demircili village is changing from 64,000 to 140,000, Bodrum and Datça are changing from 9,600 to 240,000 (figure 4). These shocks would affect total 1,269,162 people according to 2015 data, if these earthquake series were occurred nowadays, in İzmir and its surrounding, while total 289,092 people in Bodrum-Datça and its surrounding.

**Figure 3.** Kernel density analysis map with faults and geothermal well temperature-geothermal areas (faults obtained from [11, 13], the geothermal temperatures and areas from [14, 18, 19])

### 2.3 Geothermal Areas and Well Information

Firstly, both the geographic coordinate and temperature information’s of geothermal wells and areas were added as point symbols. Temperature values are changing from 21.4 to 153°C, were labelled in figure 3. This geothermal well data could not be utilised to produce the predicted geothermal temperature distribution map using IDW/Kriging methods, because their locations do not have a homogenous distribution in the study area. Outflow geothermal water/springs and geothermal well locations were added on the Kernel analysis map (figure 3) for evaluate the relation with seismic activity.
Especially, the Büyük Menderes Graben is characterized by high temperature geothermal areas as Germencik, Aydın, Salavatlı, Yılmazköy, and Kızıldere whose temperature is approximately 84-242°C. Some of these hot sources, such as Germencik (228°C), Salavatlı (165°C), and Yılmazköy (142°C) [19] fields use to electricity production from the geothermal water until 2009. Although there located some important geothermal areas, this sources couldn’t been found close to earthquake clusters, therefore this seismic activity couldn’t be associated the geothermal process but seismicity relations with the geothermal process (injection or reinjection etc.) must be investigated as detail for a specified time period.

![Image of population map](image.png)

Figure 4 The predicted 2015 population map of study area

3. Result and Discussion

1900-2012 earthquake data (M≥4) catalogue of Aegean region was evaluated in terms of the geostatistical approach of spatial distribution by Tağıl and Alevyakalı [20], and also applied Kernel density analysis to the occurred earthquakes during specified period. In the issued survey, the prepared Kernel analysis map for M>4 magnitude presents the high density value in a wide region from İzmir city center to Çeşme, and also for M<5 magnitude this high values have been shown to concentrate in between from İzmir city center to between Seferihisar and Urla provinces. Both maps show that İzmir and its surroundings are determined as region having the density earthquake activity.

In other survey, the predicted subsurface temperature distribution map for Turkey prepared by Bașel [21] using IDW and Kriging methods which added the geothermal well and geothermal gradient data. As a result of mentioned paper, with Kriging method, İzmir and Aydın provinces have 55-85°C subsurface temperature, while Bodrum, Muğla and Datça have 33-55°C subsurface temperature for 500m depth.

As different from other studies, in this paper, in order to evaluation simply the last 15 years’ seismic activity and its general effects in region focus on the recent earthquake catalogue (2000-2015), fault structure, geothermal well temperature and population density for West Anatolia. Moreover,
geothermal well data added to the program and it has been studied the relationship with seismic activity.

4. Conclusions
In looking at the historical earthquakes recorded in West Anatolia in last 15 years, it is determined that earthquakes depths generally are determined ranges from 1 km to 100 km, and also intense clusters seem to be near Sığacık Gulf, Gökova Gulf, the region in between Midilli Island and Karaburun Peninsula, Kuşadası Gulf, and Samos Island, but Sığacık and Gökova Gulfs have the most intense within other regions according to as a result of Kernel and point density analysis. In compare with 2000-2015 earthquakes to geothermal areas, it could not found there was clear relationship between them because of seismic activity have not been dominated in geothermal areas in last 15 years.

Predicted population map of 2015 prepared using IDW method shows that İzmir city centre and its surrounding has the most intensity population within West Anatolia. As a consequently of this paper, Sığacık, Urla, Gülbahçe, Demircili, Bodrum, Dağça and Gökova provinces have been identified as the highest seismic activity for last 15 years, and the author recommends that these regions should be investigated the earthquake sensitivity as soon as possible.

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