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*Full Length Research Paper*

# The estimation capability of potential mining and quarry areas from seismic catalog using statistical analysis, an application to Turkey

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**The problem of identifying quarry-mining blasts has become an important one given the improvement of the location capability of the Kandilli Observatory and Earthquake Research Institute, National Earthquake Monitoring Center (KOERI-NEMC) seismic network, an increasing number of smaller events is currently listed in the seismic catalogue is contaminated by industrial explosions that occur in quarry, coal, gold and boron mines. We performed a time of day analysis with respect to location by investigating daytime events versus nighttime events as a function of geographic location. In this study, the temporal variation of over 22.948 events (Md ≤ 3.0) were analyzed occurring in Turkey for the period of 2000 to 2009 using KOERI-NEMC seismic catalog to identify areas where there may be explosion contamination. We present an algorithm to identify and mark mining and quarry blasts from seismic catalogs that is a well-established, a variable percentage of events could be removed by this screening. We have the location of 57 major potential quarries and mines active in the years 2000-2009 that has been detected in the study. The locations of them from 11.151 overlapping blocks, 10 x 10 km in size, have been estimated from KOERI-NEMC seismic catalog. There are a total of 22.948 events evaluated in the study, of which 3754 should statistically represent possible blasts, or 16% of the total volume of the data. In order to test of the estimated coordinates from the analysis, that was searched with the satellite images of the mining and quarry areas taken from the Google Earth program (http://earth.google.com/intl/en_uk/). In general, a good correlation between the estimated locations from this study and satellite locations may be noticed suggest that the daytime to nighttime ratio analysis can provide valuable information about the potential quarry and mining areas. That is a meaningful analysis for network operators interested in tectonic studies that, because it highlights areas where need to pay careful attention is advisable**.

**Key words:** Earthquakes, quarry-mine blasts, seismic monitoring, discrimination.

## INTRODUCTION

The location and identification of seismic events have been a challenge for seismologists for decades and still are. Discrimination between quarry-mining blasts and small earthquakes based on their seismic signals is one of the main routine aims of seismic networks. Not all recorded events are earthquakes. Based on the fact that blasting generally occurs during the day, the daytime to nighttime ratio events, we are able to identify possible quarry and mining rich areas (where the dominant percentage of daytime events occur in regions of known mine locations).Turkey is located in one of the most seismicaly active regions of the world. It lies within the Mediterranean sector of the Alpine-Himalayan orogenic system (Sengor, 1979; McKenzie, 1972). Anatolian plate, which is squeezed by the movement of Africa, Arabian

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**Abbreviations: KOERI-NEMC,** Kandilli Observatory and Earthquake Research Institute, National Earthquake Monitoring Center; **NAFZ,** North Anatolian Fault Zone; **EAFZ,** East Anatolian Fault Zone; **TTK,** Turkish hard coal enterprise; **TKI,** Turkish Coal Enterprise.

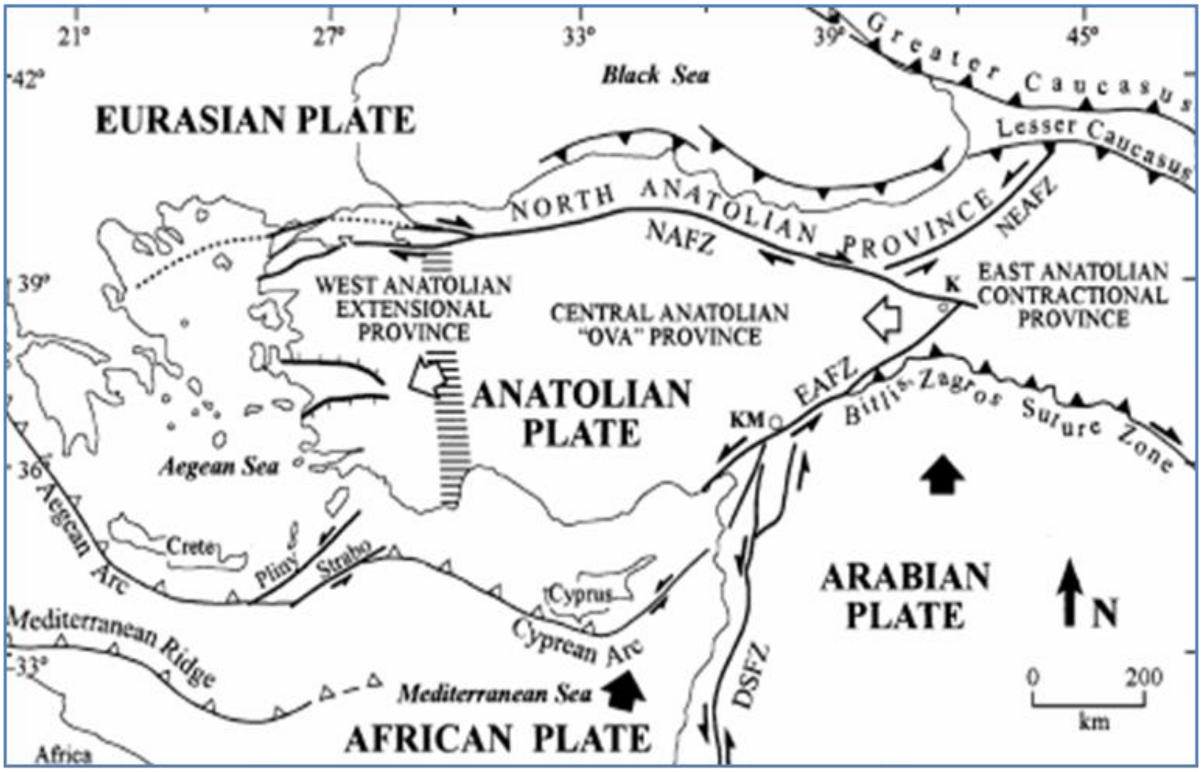


**Figure 1.** Simplified tectonic boundaries of Turkey and eastern Mediterranean area (Bozkurt and Park, 2001).

and Eurasian plates (Figure 1), has major active fault zones; North Anatolian Fault Zone (NAFZ) and East Anatolian Fault Zone (EAFZ). Northward subduction of the African plate beneath western Turkey and the Aegean region is causing extension of the continental crust in the overlying Aegean extensional province (Taymaz et al.,1991). The interplay between dynamic effects of the relative motions of adjoining plates thus controls large-scale crustal deformation and the associated earthqauke activity in Turkey and its surrounding area.Turkey has very diverse mineral deposits due to its extremely complex geology. Blasting techniques, which have been used for a long time in Turkey, are economical and powerful tool in producing raw material in mining industries. Almost half of Turkey's total primary energy prodontaminat represented by coal (43% lignite) has been officially carrying out by Turkish hard coal enterprise (TTK) and some private companies authorized by TTK (Elevli and Demirci, 2006). The TTK was established in 1983 to operate hard coal mines in Zonguldak basin. This enterprise carries out the exploration, production, and marketing of domestic hard coal (Yıldız, 2003). Tunçbilek (Kütahya), Yatağan (Muğla), Soma (Manisa), Can (Çanakkale), Beypazarı (Ankara) and Sivas are the regions that have Turkey's richest lignite reserves (Balat and Ayar, 2004). Unfortunately, all mining companies do not keep high-precision timing records of their blasting activities, at the same time they do not willing to provide information on their blasting activities for preparing a complete quarry blast-free seismicity catalog based on a regular basis by Kandilli Observatory and Earthquake Research Institute, National Earthquake Monitoring Center (KOERI-NEMC) network. Mining and quarry blasts locatable by a dense local network of KOERI-NEMC network generally have magnitudes of about $1.5 \leq Md \leq 3.0$ for Marmara region and western Anatolia. The presented algorithm that based on statistical analysis can be useful in the identification of mining and quarry areas. Some tectonic events during daytime hours, including rock-bursts triggered by the mining activity, will be removed along with the blasts. Some blasts take place in the cleaned areas where few blasts occur that is limitation of the analysis. The advantage of the analysis is that an estimate of the location and a qualitative level explosion contamination can be obtained easily by this statistical analysis when dealing with large volumes of data. Then, the identified quarry-mining rich areas should be selected to use waveforms and their spectra of digital recordings of the seismic events show signs of explosion characteristics (Hedlin et al., 1990; Musil and Plesinger, 1996).

## DATA SET AND METHOD

The earthquake catalogue of KOERI-NEMC is often biased due to incomplete detection capability of the

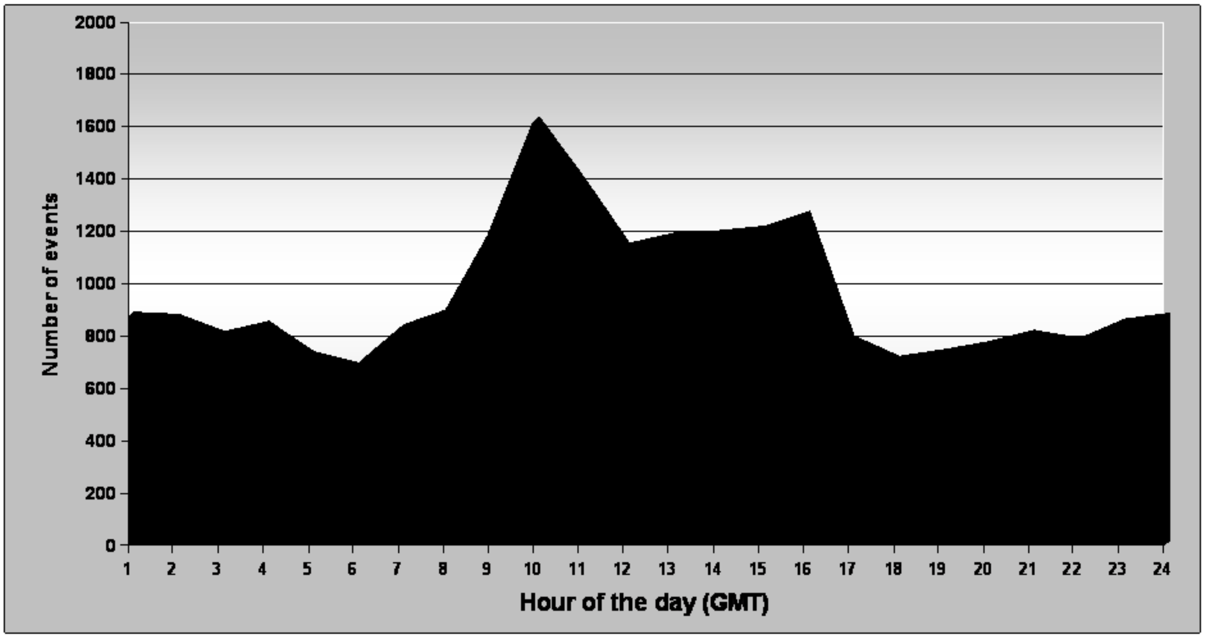


**Figure 2.** Histogram of the number of events per hour (in Greenwich Mean Time). The histogram is based on the KOERI-NEMC seismic catalog from 2000 to 2009 (Md ≤ 3.0).

seismic network for smaller magnitude earthquakes before 2000 years. Since 2000 there have been rapid improvements to the seismic data collecting, processing and archiving infrastructure at Kandilli Observatory and Earthquake Research Institute. We carried out the seismicity catalog from KOERI-NEMC network which contains approximately 22.948 earthquakes (Md ≤ 3.0) for the years 2000-2009 covering an area between 36°- 42° N latitudes, 26°- 45° E longitudes. We are particularly interested in quarry and mining blasts that are detected seismically with Md ≤ 3.0. KOERI-NEMC operates the comprehensive network of 129 seismic stations, covering the whole country, consisting of 107 broadband stations with a satellite communication, 22 short period stations. In the center, the seismological data from a total of 129 stations are manually interpreted and processed by computer for the focal parameters determination and adaptation of the software of HYPO’71 (Lee and Lahr, 1972) and the four layers regional velocity model used. A more detailed description of the seismic network and data acquisition system can also be found at www. koeri.boun.edu.tr/UDİM. Seismic monitoring is a good tool for detecting both earthquakes and man-made seismic events. The idea that using the daytime to nighttime ratio events for detection of quarry-mining blasts has been examined in different studies so far (Agnew, 1990; Wiemar and Baer, 2000; Taira and Tsumura, 2001; Gulia, 2010).

The use of a spatial grid to map, $Q_m$ and the introduction of a probability criterion to decided which parts of the data should be excluded. Seismic catalog heterogeneity as a function of time can be serious problem of identifying the daytime to nighttime ratio events. In many catalogs, the number of earthquakes per unit volume available is marginal that can lead to unsafe evaluations. From this point of view, the identification and removing of blasts are important step in analysis on seismic catalogues.

The analysis is similar to that of Wiemer and Baer (2000) that was modified in this study. We define the ratio of daytime to nighttime events ($Q_{m,}$ $\text{Quarry}_{\text{Mining}}$) can be represented as:

$$Q_m = \log T\ (2\ T_d - T_n) / (2T_n + T_d)$$

Where: $T_d$ and $T_n$ are the total number of events in the daytime and nighttime period respectively. Most quarry-mining blasts are performed during daytime hours (Agnew, 1990; Rydylek and Sacks, 1992; Taira and Tsumura, 2001). To identify likely time of these blasts, we analyze the hourly distribution of the events in the whole of Turkey (Figure 2). Since blasts generally take place during daytime hours, the overall distribution of the events in Turkey shows a clear peak that many events are performed during the hours of 06:00 to 16:00 (Greenwich Mean Time, GMT), for our data set. In this work, we selected the day time interval spans between 05:00 a.m. and 17:00p.m.Thus we separated events into12 hr day-night segments. T is the total events number, the important advantage of the presented algorithm, using a random sampling size of T that shows a largely homogeneous distribution of the events for with large volumes of data. $Q_m$ is a suitable measure for the random sample size T. The study area was divided into different cell sizes using 10, 20 and 30 km cells, that 10 km contains sufficient events for estimation of more random sampling size of T that shows a largely homogeneous distribution of the events for with large volumes of data. $Q_m$ is a suitable measure for the random sample size T. The map was divided into 10km (latitude) x 10 km (longitude) cells about 11.151, which overlapped each other by 50% in which the percentages of daytime events were calculated. We will limit our search to crustal events with a depth less than 20 km because of possible large inaccuracies in hypocentral depth estimation and Md ≤ 3.0. Hypocentral depths may give an indication; however, hypocenter accuracy, particularly for small events that can not be used as a reliable indication for discrimination analysis. The result of the analysis shows that $Q_m$ values vary from -0.5 to 5.86 in the whole of Turkey. Particularly, the negative values of $Q_m$ shows that the areas include only nighttime tectonic events. Approximately the high 61 values for the $Q_m$ ratio is ≥ 2.0 evaluated for Turkey that reports the most meaningful results for detecting of quarry-mining areas (Table 1). It is interesting that we have found information about the presence of quarries or mines for the high 61 values of $Q_m$. According to Wiemer and Baer (2000), an indicative value for the daytime/nighttime ratio is ≥1.5.

However, four locations (Tunçbilek, Gümüşpınar, Soma, Yürükkaracaören) have been obtained at two different reference coordinates due to widespread blast contamination of them. We have obtained mining and quarry areas with the satellite images in the vicinity of the coordinates obtained from $Q_m$ that is an indicative evaluation in order to test of reliability of the analysis. In this work, our discrimination while simple can be quite useful as a preliminary measure for categorizing or verifying events in the case of seismic network performance, is not homogeneous for the whole of country. In the present study, daytime events correlate with detected quarry-mining locations, and earthquakes show a mix of both daytime and nighttime activity within the whole Turkey.

## CASE STUDY: TURKEY

Supplemental information, such as satellite imagery, is imported into the database to aid in determining ground truth for the locations of the detected mining and quarry blasts. In the estimation of $Q_m$ values in the study, the map was divided into overlapping square areas. We mapped the ratio $Q_m$ using a node spacing of 10 km.

Values of $Q_m$ greater than 2.0 and up to 5.86 indicate the presence of blasts in the data set. Figure 3 shows a map of Turkey; high $Q_m$ ($Q_m$ ≥ 2.0) plotted in color coded (green to red colors) indicates potential mining and quarry rich areas. The locations of the satellite images of the mines and quarries taken from the Google Earth program. The correlation between the areas with a $Q_m$ ratio ≥ 2.0 and the detected locations of quarries and mines confirms that those areas are probably potential and active locations for blasts. Hotter colors indicate (red-yellow) the highly presence of quarries and mines active mainly during daytime hours, while cool colors (black-blue) show earthquake like events. About 22.948 events (Md≤ 3.0) were analyzed occurring in Turkey for the period of 2000 to 2009 using KOERI-NEMC seismic catalog. With regard to the errors in the epicenters of KOERI-NEMC catalog which are within 0-15 km for earthquakes since 1970's (Kalafat et al., 2007), we can say that the coordinate differences between estimated and obtained locations from satellite images generally less than 10 km, that is meaningful criterion for the reliability of our method. Particularly, Turkey's richest lignite reserves and quarries were detected with this statistical analysis includes, Tunçbilek (Kütahya), Yatağan (Muğla), Orhaneli-Orhangazi (Bursa), Gebze (Izmit), Şile-Kemerburgaz (Istanbul), Soma (Manisa), Beypazarı (Ankara), Yürükkaracaören (Eskişehir). Previous work on identifying explosion contamination has been undertaken by Horasan et al. (2009), who identified Kemerburgaz, Şile, Hereke locations of explosion contamination in the Istanbul and its vicinity that correlates with the estimated locations from our study. However, no quarry-mining blasts have been identified in the known mining quarry areas such as Can (Çanakkale), Elbistan (Kahramanmaraş), Zonguldak and Çorlu (Tekirdağ) due of poor seismic station coverage of the KOERI-NEMC network does not have the ability to locate small magnitude events that are recorded only at a few stations. The regions with the three highest $Q_m$ values that are clear regions of explosion contamination are the following:

1. The highest value of the ratio is about 5.86; this area is located in Tunçbilek township of Tavşanlı county of Kütahya Province which is an open-pit coal mine, operating by Western Lignite's Cooperation, a subsidiary of the state-owned Turkish Coal Enterprise (TKI). The iterative removal of quarry events identifies a total of 860 possible mining blasts for the cell size using 10 km in the study. It is interesting to note that all of the events occurred during working hours (05:00 to 17:00 h GMT time) suggesting that these events are dominated by mining activity in Tunçbilek open-pit coal mine (Figure 4).The reference location coordinate of the Tunçbilek area was obtained at two high $Q_m$ values due to the widespread blast contamination of the region. The seismic activity of the region has been investigated by using the earthquakes equal or greater than magnitude 3.5 that occurred with a 50 km radius of the Tunçbilek mining area for the time interval 1970-2010 due to the data set is relatively uniform for western Turkey (Figure 5). The hypocentral distribution of the earthquakes outlines no earthquakes were located in Tunçbilek mining area that is a likely sign of blasting activity. Tunçbilek mine is one of

**Table 1.** Approximately 57 locations have been detected for $Q_m$ ratio is ≥ 2.0 in this study which indicates the major potential quarry and mining areas of Turkey.

| $Q_m$ | Estimated locations (EL) | | Satellite locations (SL) | | Difference between (EL) –(SL) locations (km) | Potential active quarry - mining areas (County-Province) |
|---|---|---|---|---|---|---|
| | Lat. °N | Long. °E | Lat. °N | Long. °E | | |
| 5.86 | 39.60 | 29.40 | 39.65 | 29.44 | 6.5 | Tunçbilek (KÜTAHYA) |
| 4.89 | 37.30 | 28.20 | 37.37 | 28.16 | 8.4 | Eskihisar- Yatağan ( MUĞLA) |
| 4.35 | 39.50 | 29.50 | 39.65 | 29.44 | 17.5 | Tunçbilek (KÜTAHYA) |
| 3.96 | 39.80 | 28.90 | 39.92 | 28.84 | 14.2 | Gümüşpınar-Orhaneli (BURSA) |
| 3.91 | 41.10 | 29.30 | 41.15 | 29.38 | 8.6 | Şile (İSTANBUL) |
| 3.91 | 40.80 | 29.50 | 40.83 | 29.56 | 5.9 | Demirciler-Gebze ( İZMİT) |
| 3.74 | 41.10 | 28.90 | 41.12 | 28.96 | 5.4 | Kemerburgaz-Eyüp (İSTANBUL) |
| 3.67 | 39.10 | 27.50 | 39.10 | 27.57 | 5.8 | Eynez-Soma ( MANİSA |
| 3.42 | 40.50 | 29.30 | 40.49 | 29.28 | 1.9 | Tekke-Orhangazi (BURSA) |
| 3.28 | 38.70 | 35.80 | 38.66 | 35.81 | 4.5 | Koççağız-Talas (KAYSERİ) |
| 3.27 | 40.20 | 28.80 | 40.21 | 28.78 | 1.9 | Çatalağıl-Nilüfer (BURSA) |
| 3.27 | 39.20 | 27.60 | 39.10 | 27.57 | 11.3 | Eynez-Soma (MANİSA) |
| 3.26 | 39.90 | 33.10 | 39.88 | 33.05 | 4.7 | Kutludüğün- Mamak (ANKARA) |
| 3.18 | 38.30 | 38.10 | 38.28 | 38.08 | 2.7 | Karapınar-Akçadağ (MALATYA) |
| 3.11 | 39.70 | 30.70 | 39.70 | 30.70 | 0 | Yürükkaracaören-Kanlıpınar (ESKİŞEHİR) |
| 2.93 | 37.10 | 37.30 | 37.00 | 37.33 | 11.3 | Şahinbey-Şehitkamil (GAZİANTEP) |
| 2.89 | 41.60 | 34.90 | 41.62 | 34.84 | 5.4 | Yeniköy-Boyabat (SİNOP) |
| 2.83 | 40.80 | 39.70 | 40.85 | 39.70 | 5.5 | Barışlı-Temelli (TRABZON) |
| 2.79 | 37.10 | 38.80 | 37.09 | 38.79 | 1.3 | Şahinler-Merkez (ŞANLIURFA) |
| 2.79 | 40.00 | 33.50 | 39.97 | 33.50 | 3.3 | Keçili-Yahşi (KIRIKKALE) |
| 2.78 | 40.10 | 28.70 | 40.13 | 28.78 | 7.4 | Makşempınar Nilüfer (BURSA) |
| 2.76 | 38.10 | 32.70 | 38.09 | 32.72 | 1.9 | Karaömerler-Selçuklu (KONYA) |
| 2.76 | 40.00 | 33.10 | 40.00 | 33.18 | 6.6 | Hasanoğlan-Elmadağ (ANKARA) |
| 2.74 | 39.30 | 30.50 | 39.29 | 30.48 | 1.9 | Kırka (ESKİŞEHİR) |
| 2.72 | 39.60 | 30.10 | 39.65 | 30.09 | 5.6 | Nusretköy (KÜTAHYA) |
| 2.72 | 40.90 | 40.30 | 40.92 | 40.28 | 2.7 | Of (TRABZON) |
| 2.67 | 40.30 | 29.10 | 40.30 | 29.15 | 4.1 | Avdancık-Osmangazi (BURSA) |
| 2.64 | 40.00 | 28.90 | 39.92 | 28.84 | 10.1 | Gümüşpınar-Orhaneli (BURSA) |
| 2.64 | 39.60 | 29.70 | 39.54 | 29.68 | 6.8 | Gümüşgölcük-Tavşanlı (KÜTAHYA) |
| 2.64 | 39.90 | 33.60 | 39.97 | 33.50 | 11.3 | Keçili-Yahşi (KIRIKKALE) |
| 2.64 | 40.10 | 35.50 | 40.05 | 35.55 | 6.9 | Kurtağılı-Çekerek (YOZGAT) |
| 2.60 | 39.80 | 30.20 | 39.81 | 30.22 | 1.9 | Oklubalı-İnönü- (ESKİŞEHİR) |
| 2.58 | 40.30 | 27.80 | 40.32 | 27.82 | 2.7 | Edincik (BALIKESİR) |
| 2.55 | 39.60 | 30.70 | 39.70 | 30.70 | 11.1 | Yürükkaracaören-Kanlıpınar (ESKİŞEHİR) |
| 2.55 | 41.00 | 27.50 | 41.00 | 27.35 | 12.4 | Hacıköy (TEKİRDAĞ) |
| 2.51 | 36.90 | 34.60 | 36.91 | 34.60 | 1.1 | Yeşilova (MERSİN) |
| 2.48 | 41.00 | 36.10 | 41.03 | 36.04 | 5.9 | Emirli-Kavak (SAMSUN) |
| 2.47 | 37.40 | 28.40 | 37.46 | 28.34 | 8.3 | Kavaklıdere (MUĞLA) |
| 2.46 | 37.10 | 38.70 | 37.09 | 38.79 | 7.5 | Şahinler (ŞANLIURFA) |
| 2.43 | 40.00 | 35.60 | 40.05 | 35.55 | 6.9 | Kurtağılı-Çekerek (YOZGAT) |
| 2.42 | 37.30 | 27.90 | 37.32 | 27.97 | 6.2 | Eskihisar-Yatağan ( MUĞLA) |
| 2.40 | 39.70 | 28.90 | 39.70 | 28.90 | 0 | Karaağız-Kınık (BURSA) |
| 2.39 | 37.20 | 38.80 | 37.25 | 38.83 | 6.0 | Yusufkuyu-Öğütçü (URFA) |
| 2.37 | 40.60 | 29.30 | 40.54 | 29.26 | 7.4 | Güneyköy (YALOVA) |
| 2.35 | 38.80 | 35.90 | 38.82 | 35.78 | 10.1 | Küçükbürüngüz-Melikgazi (KAYSERİ) |
| 2.35 | 39.60 | 30.20 | 39.65 | 30.09 | 10.1 | Nusretköy (KÜTAHYA) |
| 2.35 | 40.00 | 33.20 | 40.00 | 33.18 | 1.6 | Hasanoğlan-Elmadağ (ANKARA) |

**Table 1.** Contd.

| | | | | | | |
|---|---|---|---|---|---|---|
| 2.35 | 41.30 | 35.80 | 41.35 | 35.82 | 5.7 | İnözükoşaca-Bafra ( SAMSUN) |
| 2.32 | 41.10 | 36.10 | 41.03 | 36.04 | 9.2 | Kayaköy-Kavak ( SAMSUN) |
| 2.29 | 39.70 | 35.30 | 39.79 | 35.20 | 12.9 | Sorguntatlısı-Sorgun (YOZGAT) |
| 2.29 | 37.20 | 37.50 | 37.18 | 37.43 | 6.2 | Bedirköy-Şehitkamil (GAZİANTEP) |
| 2.29 | 40.60 | 26.50 | 40.60 | 26.53 | 2.4 | Mecidiye-Keşan (EDİRNE) |
| 2.22 | 38.60 | 28.60 | 38.58 | 28.63 | 3.3 | Ahmetli-Saraçlar – Kula ( MANİSA) |
| 2.17 | 37.20 | 27.90 | 37.14 | 27.89 | 6.7 | Karacaağaç-Hüsamlar- Milas (MUĞLA) |
| 2.11 | 39.50 | 30.10 | 39.48 | 30.04 | 5.4 | Çalca -Merkez ( KÜTAHYA) |
| 2.08 | 41.50 | 27.90 | 41.47 | 27.91 | 3.4 | Kavacık-Saray (TEKİRDAĞ) |
| 2.05 | 37.10 | 38.90 | 37.09 | 38.82 | 6.7 | Abdurrahmandede (URFA) |
| 2.05 | 40.60 | 26.60 | 40.60 | 26.53 | 5.8 | Mecidiye-Keşan (EDİRNE) |
| 2.02 | 40.00 | 29.10 | 40.01 | 29.11 | 1.3 | Karaislah-Osmangazi ( BURSA) |
| 2.01 | 40.60 | 29.50 | 40.64 | 29.53 | 5.1 | İnebeyli Karamürsel (KOCAELİ) |
| 2.00 | 39.90 | 30.20 | 39.86 | 30.24 | 5.5 | Zemzemiye-Söğüt (BİLECİK) |

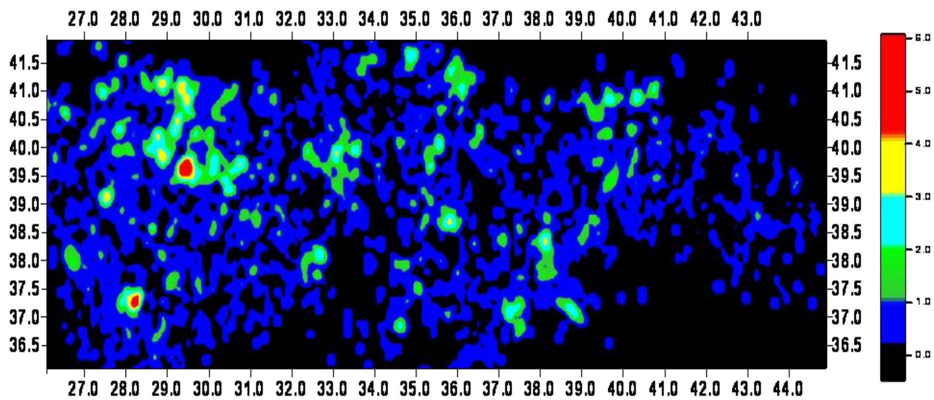


**Figure 3.** The map of potential mining and quarry rich areas of Turkey that was obtained using the statistical analysis in the study.

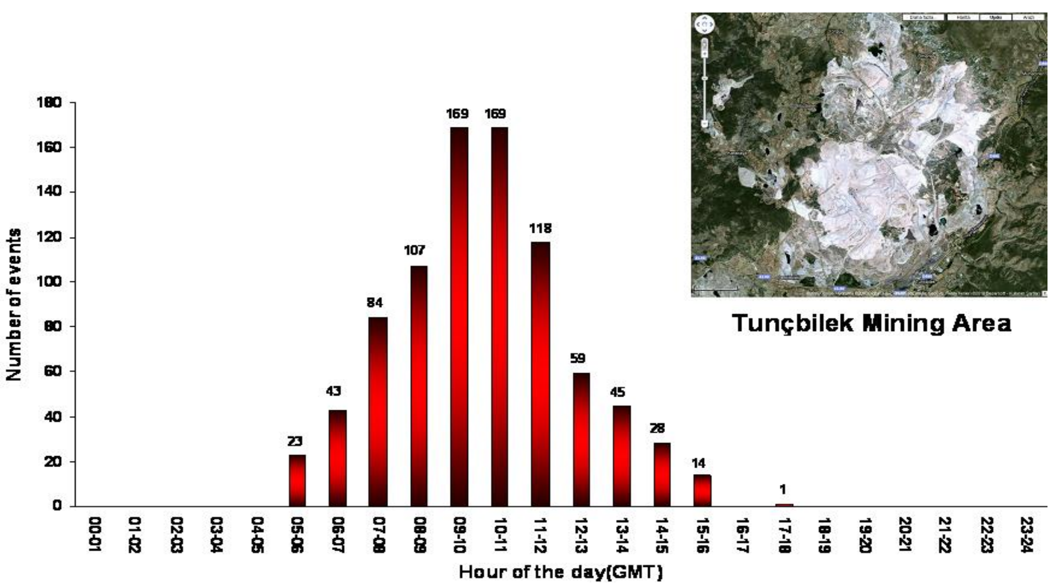


**Figure 4.** Histogram of the hourly distribution (GMT) of the events for Tunçbilek mining area.

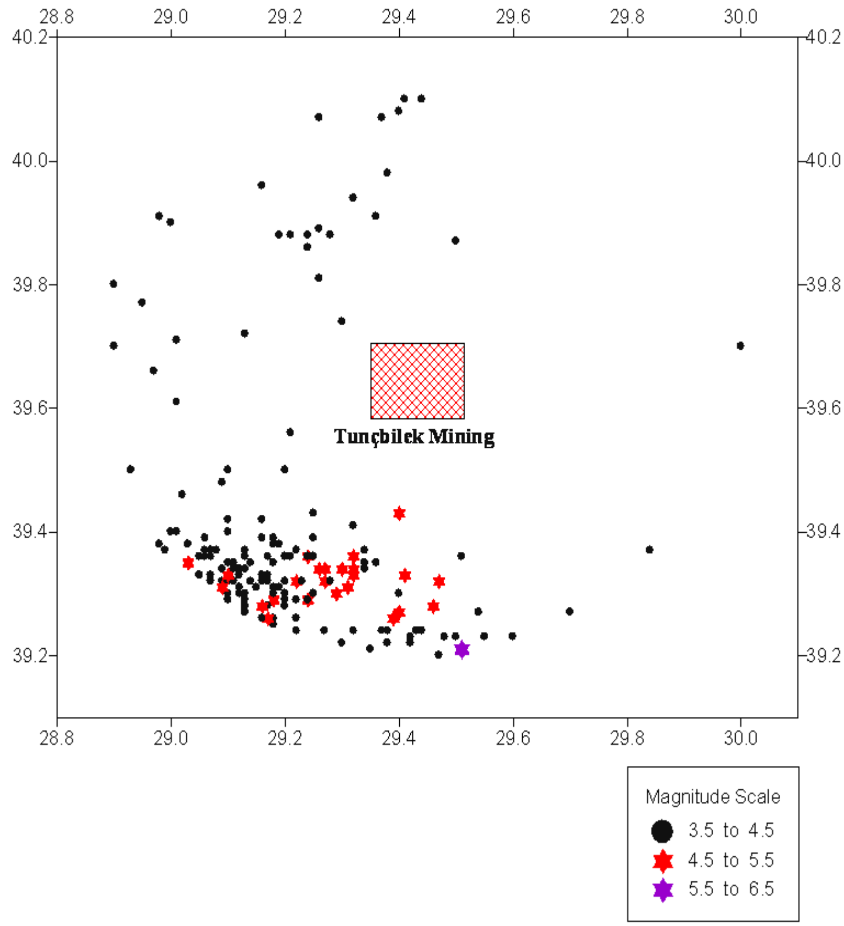


**Figure 5.** Distribution of the epicenters at the Tunçbilek mining area, during the period from 1970-2010 (Md ≥ 3.5).

the most important sources of lignite deposits in Turkey that is the clearest example of explosion contamination that shows an anomalously high daytime to nighttime ratio. Through cooperation with TKI, we have obtained basic information such as about 50 blasts are made in a month by this mine that makes the region an ideal test bed for discrimination techniques designed to separate signals from earthquakes and mining blasts.

2. The second highest ratio of the study is 4.89, which are, seen in Eskihisar township of Yatağan county of Muğla Province that is open pit coal mine belonging to TKI. The Muğla basin is one of the most well-documented coal basins of Anatolia Southwest Turkey, which was identified by Abdulselamoglu (1965), Querol et al. (1999) and Bulut et al. (2001). The Muğla basin can be separated into the two sub-basins-Yatağan and Milas (Querol et al., 1999). Coal productions with open-cast mining methods are operating in Eskihisar area using either dragline or excavator and truck methods by Government Company (Inaner and Nakoman, 2001). Figure 6 shows the variation in number of events as a function of time of day for Eskihisar coal mine that indicates events also occurring primarily during daylight hours. A total of about 466 mining blasts were identified by this analysis in the region.

The seismic activity of the Eskihisar mining area and its vicinity has been evaluated by using the earthquakes with Md ≥ 3.5 between 1970-2010 that recorded by KOERI-NEMC Network (Figure 7). We also observed that the seismic activity is high and the hypocentral distribution of the earthquakes outlines many earthquakes of magnitude 3.5 or large were located south of Eskihisar mining area since 1970's. The region is known to have active seismicity due to active faults in Aegean Extensional Province such as Yatağan-Muğla Fault, Ula-Ören Fault and Karaova-Milas Fault (Sertçelik and Başer, 2010).

3. The third highest value of the ratio is 3.96, which are seen in Gümüşpınar township of Orhaneli county of Bursa Province. The Orhaneli coal basin includes 3 coal-bearing sectors (Gümüşpınar, Sağırlar and Çivili), and lignite production is only performing from the Gümüşpınar sector by open-cast mining methods. The hour histogram (Figure 8) of the Gümüşpınar Township shows the quarry rich area trend: most of the events are recorded between

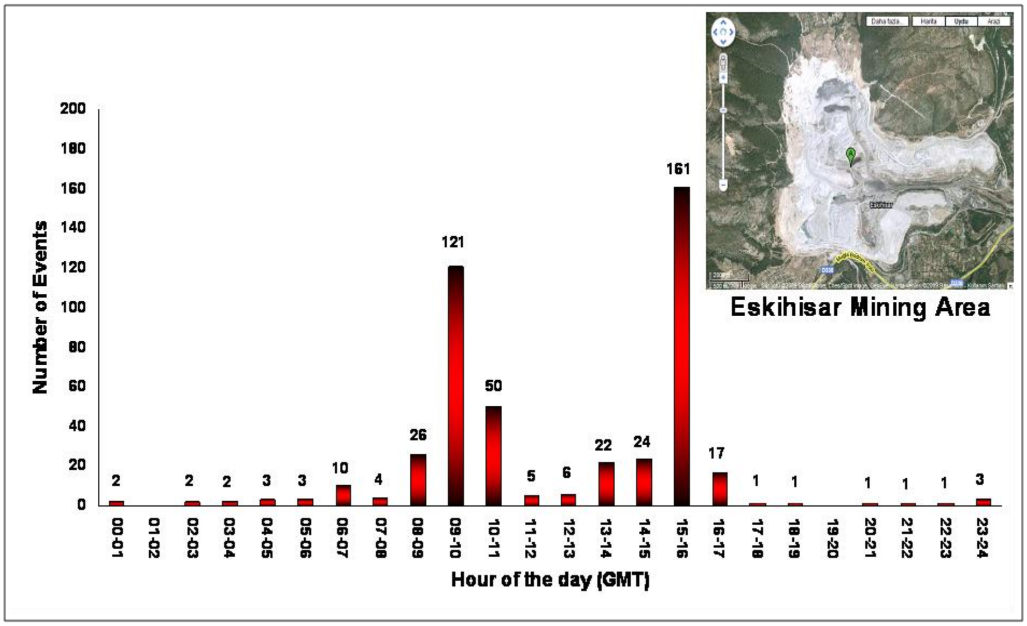


**Figure 6.** Histogram of the hourly distribution (GMT) of the events for Eskihisar mining area.

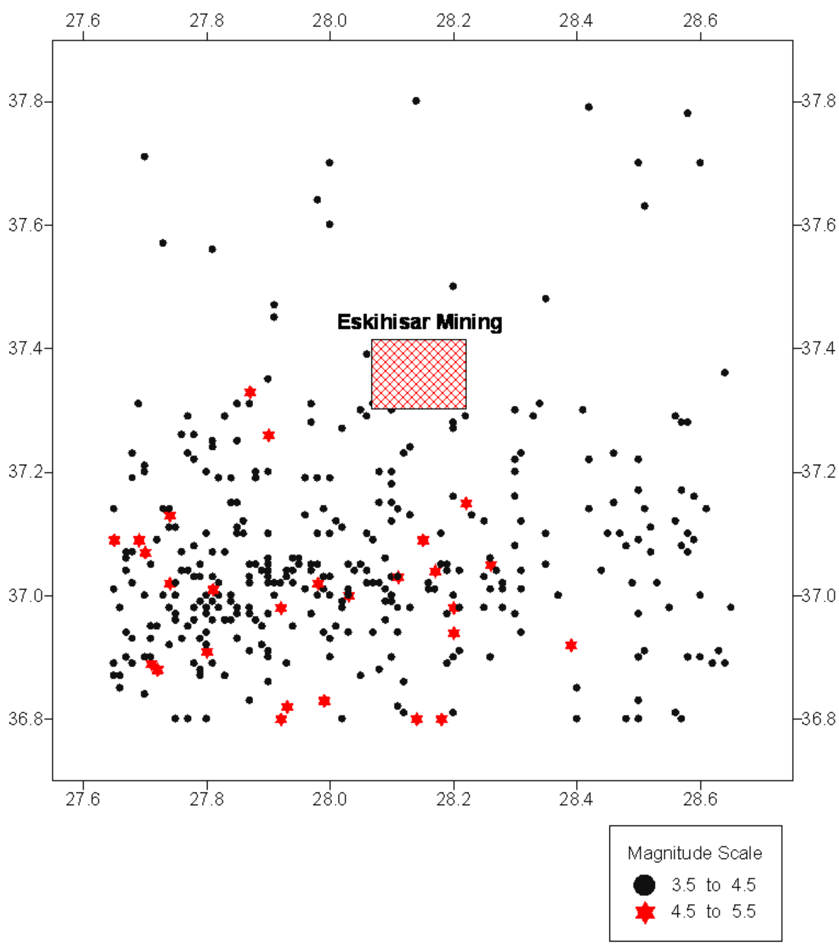


**Figure 7.** Distribution of the epicenters at the Eskihisar mining area during the period from 1970-2010 (Md ≥ 3.5).

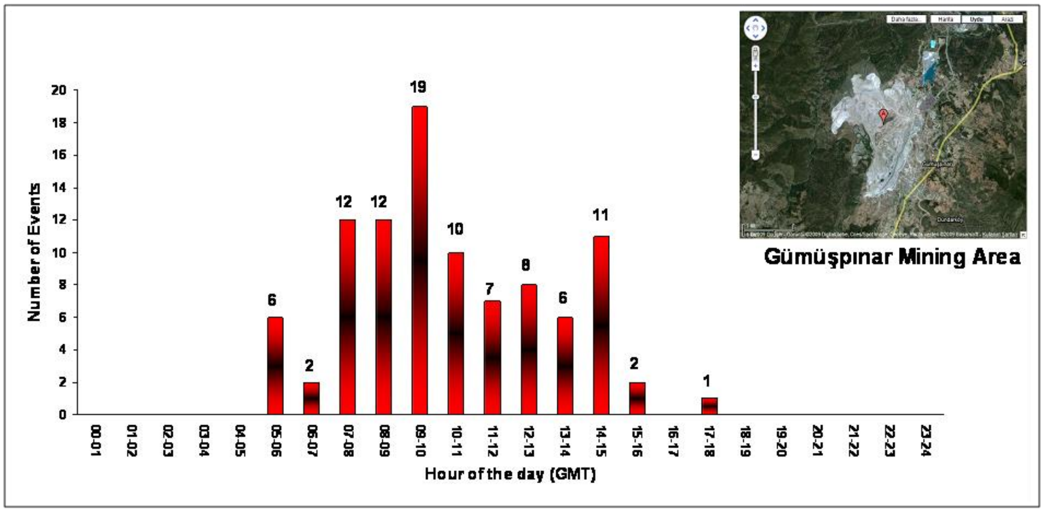


**Figure 8.** Histogram of the hourly distribution (GMT) of the events for Gümüşpınar mining area.

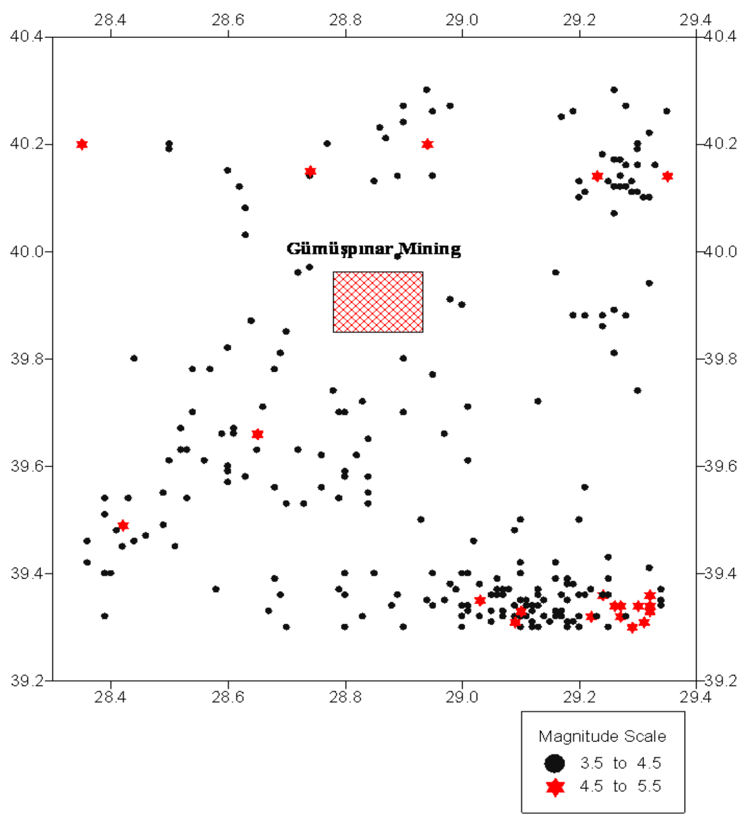


**Figure 9.** Distribution of the epicenters at the Gümüşpınar mining area during the period from 1970-2010 (Md ≥ 3.5).

05:00 and 17:00 h GMT time. A total of about 96 possible mining blasts were identified in Gümüşpınar province by the analysis. Figure 9 shows spatial distributions of earthquake epicenters with Md ≥ 3.5 in the Gümüşpınar mining area during the time period from 1970 to 2010 according to the KOERI-NEMC catalogue.

The seismic activity in the region showed that many earthquakes occurred nearby at Gümüşpınar mining area. The north of Gümüşpınar mining is known to has active seismicity due to active faults such as Bursa, Ulubat and Yenişehir faults (Barka, 1997). On the other hand, the tectonic activity at the south of the mining area is dominated by the Aegean Extensional Province in the region. Like event clusters in the Tunçbilek and Eskihisar region, the Gümüşpınar region has a significant number of events occurring during daylight hours. Particularly, the hourly distribution of the events of three mining areas (Figures 4, 6 and 8) shows a clear peak during the hours of 05:00 to 17:00 (GMT) that correspond almost entirely to mining related activity. Approximately 22.948 events analyzed in the study, of which 3921 ($Q_m \geq 2.0$) should statistically represent possible quarry and mining blasts, or 17% of the total volume of the data. $Q_m \geq 2.0$ is the meaningful criterion for our study due to values of $Q_m$ lesser than 2.0 which includes more tectonic seismicity represented by nighttime events that were not considered to be statistically significant because some daytime tectonic events are also removed.

## Conclusions

This study shows that seismic monitoring can be used for detecting and locating man-made seismic events reasonably accurately, also at sites which could otherwise pass unnoticed. We also note that Tunçbilek, Eskihisar, Gümüşköy, Orhangazi, Şile, Gebze, Kemerburgaz and Soma are areas where caution or special attention is advisable because they are heavily contaminated with daytime quarry-mining blasts. Particularly, locations of many of the probable mining blasts occur within or near Tunçbilek mining area that have large surface mines, and provisionally identified blasts occur where earthquakes of magnitude 3.5 or larger have been not recorded since 1970's. For future study, we suggest that the list of identified blasts obtained from detected quarry-mining areas in this study could be analyzed using waveform based techniques (Su et al., 1991; Musil and Plesinger, 1996; Koch and Fah, 2002; Horasan et al., 2009). The presented algorithm, based on a purely statistical criterion, can be perfect in the identification of blasts in the seismic catalogs. The results come from the time-of-day discrimination which shows that potential quarry and mining events are constrained to working hours. Our method of identifying areas of high $Q_m$ and the introduction of a probability criterion to decide 16% (3754) of the total volume of the data should be evaluated in KOERI-NEMC seismic catalog for a future study. Note that the correlation between the obtained $Q_m$ ratio is ≥ 2.0 and detected locations of quarries and mines report the reliability of the algorithm in identifying potential blasting areas. It should be mentioned that the success and reliability of the analysis is depending on the detection capacity of the small events of the network. Most of estimated potential locations from our analysis were identified within 10 km of known quarry and mining sites with satellite images. We can say that it is a good tie between our analysis of the seismic catalog data and the satellite imagery with regard to the errors in the epicenters are within 0-15 km for earthquakes in Turkey since 1970's. The catalog is cleaned up of explosions, which is compulsory for any seismicity study and probabilistic seismic hazard assessment. If explosions are not eliminated from the seismic catalogs of these regions, there is an explosion contamination problem that can result in a misinterpretation of the regional tectonics, and an erroneous assessment of the natural seismic hazard (Vazhenin et al., 1997). Consequently, areas where quarry-mining blasts occur frequently can be identified easily and with reliability by the ratio, $Q_m$ day to nighttime analysis in the study. The first objective of our study was to estimate of potential mining and quarry areas from KOERI-NEMC seismic catalogs using statistical analysis. The second objective of this study will apply to the seismic discriminating (time-frequency and amplitude ratios) to data estimated with high $Q_m$ from the study regions such as Tunçbilek, Eskihisar and Gümüşpınar with a different tectonic structures and different blasting practices because of the presence of quarry-mining blasts among the earthquakes recorded by the KOERI-NEMC seismic network, the decontamination of the catalog is essential in this approach for a reliable seismic analysis and understanding the tectonics and associated natural seismicity of Turkey.

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