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A COMPARISON STUDY ON THE INFRASTRUCTURE OF NATIONAL SEISMIC NETWORKS

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Abstract

Distribution of national seismic networks is generally designed by seismologist's experience. They are typically not optimized for various applications in engineering seismology such as earthquake early warning systems (EEWS). On the other hand, optimum performance can be achieved by investigating current station distribution, active faults and population of regions with the focus on EEWS. In this study, I investigated Turkey's seismic station infrastructure and compared the station distribution with three region/country EEWS; California, Japan, and Switzerland. Region's area and population together with area and population per station statistics are calculated. I explored the distribution of interstation distances within Turkey. I assigned an average interstation distance value, which is computed from the average distance to the three closest stations. From these values, I created contour maps of interstation distances using a linear interpolation between stations. The current distribution of stations in the Turkey's network was not designed for EEWS purposes. The capabilities of an EEWS are primarily determined by station distribution. The distribution of station is currently not adequate for EEWS in Turkey. However, budget-limited reality, I proposed three strategies to improve seismic station density in this study.

Keywords: National seismic networks of Turkey; Interstation distance; Earthquake early warning

1. Introduction

Seismic networks are one of the vital components of instrumental seismology. In the last two decades, the technical improvements of seismic instruments allow scientist to process earthquakes in real-time. Earthquake early warning systems (EEWS) uses those sophisticated hardware and high-quality sensors together with the development of telecommunication technologies and warn people living in earthquake prone-regions [1, 2, 3, 4]. Number of stations and distribution of the seismic network are the two parameters that determines the quality of earthquake source information and the speed of the earthquake solution in real time. However, most of the advanced seismic networks are not specifically designed for EEWS [1].

The current distribution of stations in the Disaster and Emergency Management Presidency (AFAD), Turkey network was also not designed for EEWS purposes. As Japan built Kyoshin network (K-NET) after Kobe earthquake, AFAD-Turkey extended seismic networks after 1999 Izmit earthquake. Most of the time, seismic stations are located close to active faults where seismic activity is high. The other two reasons are based on geographical convenience and the experience of seismologist. At this moment, AFAD has more than 800 stations in Turkey (Table 1). However, 772 stations provide real time data streaming to their dedicated network. Table 1 disaggregates the station depending on the type of network.

Table 1 - AFAD network and stations in Turkey

Network	Type	Number
Strong Ground Motion Network	CMG-5TD	320
	GMSplus	218
	Total	538
Weak Motion Network		234
	Total	772

In this study, AFAD's seismic station infrastructure is investigated and the station distribution of four region/country EEWS; California, Japan, Turkey and Switzerland are compared. Region's area and population together with area and population per station statistics are calculated. The distribution of interstation distances, blind zones in terms of EEWS are explored within Turkey.

2. Statistical Comparision of Seismic Network

First of all, I compared the number of station of the four region/country EEWS; California, Japan, Switzerland and Turkey (Table 2). Region's area and population together with area and population per station statistics are calculated. The number of stations (1089) used in Japan JMA EEWS is ~1.5 times higher than the number of stations (772) that contribute to AFAD Turkey. Statistics of area and population per stations statistics are shown in Table 2. JMA EEWS covers 347 km^2 area per station where AFAD covers 1015 km^2 area per station.

Comparing the median interstation distances of stations in AFAD network with that of the other networks, I found striking differences (Figure 1). Firstly, histograms of the distributions show the JMA EEWS has a near-normal distribution with a mean of 17.7 km whereas the others have a non-normal distribution. AFAD network may also be considered as normally distributed with a large standard deviation but there are many stations between 5 -15 km interstation distances. Median of interstation distances are less than 18 km except Turkey. California and Switzerland networks are skewed at the small-distance end by very dense network configuration.

Assuming the ideal interstation spacing is between 10 and 20 km, only 21.9% (169) stations in Turkey would be well situated whereas the percentage is 27.9% (105) stations in the California and triple with 58.2% (634 stations) in Japan (Table 3). JMA EEWS has the most well suited stations within network whereas AFAD has the worst.

Table 2 - Comparison of the number of stations used in the different region/country EEWSs

Region / Country	**Number of Stations currently contributing to EEWS**	**Area (km^2)**	**Area / # of Station**	**Population**	**Population / # of Station**
California, CISN EEWS	377	410 000	1 088	33 871 648	89 845
Japan JMA EEWS	1089	377 944	347	127 333 002	116 927
Switzerland SED	92	41 285	449	7 452 075	81 001
Turkey, FAD	772	783 562	1015	76 667 864	99 310

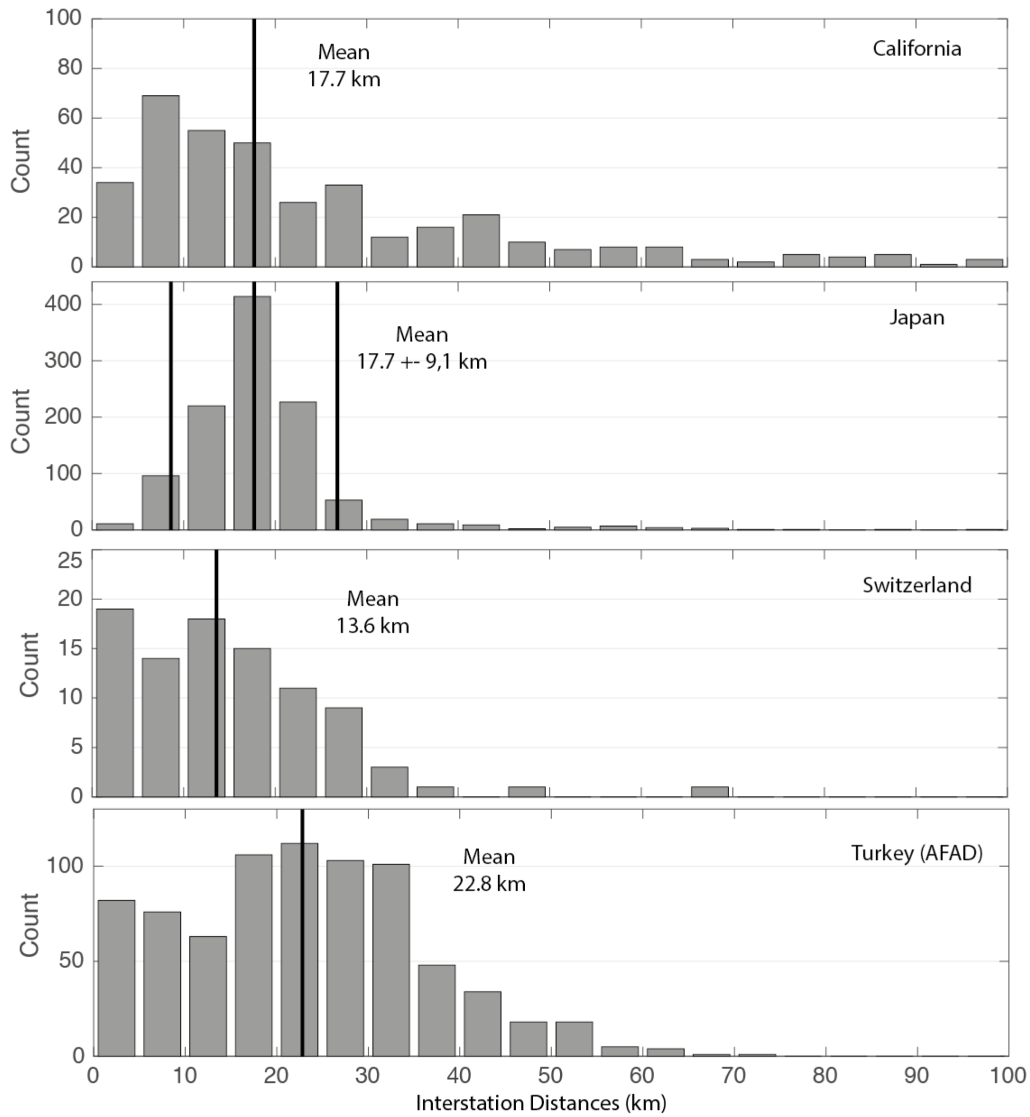

Fig. 1 - Histogram of interstation distance determined for each stations calculated by averaging the distance to the three closest stations. Results from a) the CISN/ShakeAlert/EEW Network, California, b) JMA/NIED Network, Japan, c) Switzerland, d) AFAD Network, Turkey.

Table 3 - Comparison of number of well situated stations for EEWS in four region

Region	Over-dense	Well situated	Under-dense
California	123 (32.6%)	105 (27.9%)	149 (39.5%)
Japan	107 (9.8%)	634 (58.2%)	348 (32.0%)
Switzerland	33 (35.9%)	33 (35.9%)	26 (28.3%)
Turkey – AFAD	158 (20.5%)	169 (21.9%)	445 (57.6%)

I explored the distribution of interstation distances within Turkey. At each of the AFAD stations, I assign an average interstation distance value, which is computed from the average distance to the three closest stations. From these values, I create a contour map of interstation distances using a linear interpolation between stations (Fig 2). I found that more than 50% of Turkey has an average of 30 km or more (Fig 2, primarily yellow regions) whereas highly populated areas, such as Istanbul, Kocaeli, have less than 30 km spacing (red colors).

An EEWS should be devised to be the most robust at issuing alerts in regions identified as having high shaking potential from earthquakes in combination with a large population base from the standpoint of probabilistic seismic hazard. For Turkey, I can examine this using a two-step process. The first is to assess which regions have both a high shaking potential (Figure 3a) and a large population density (Figure 3b). The seismic networks have been designed to have higher station densities in the regions of higher population.

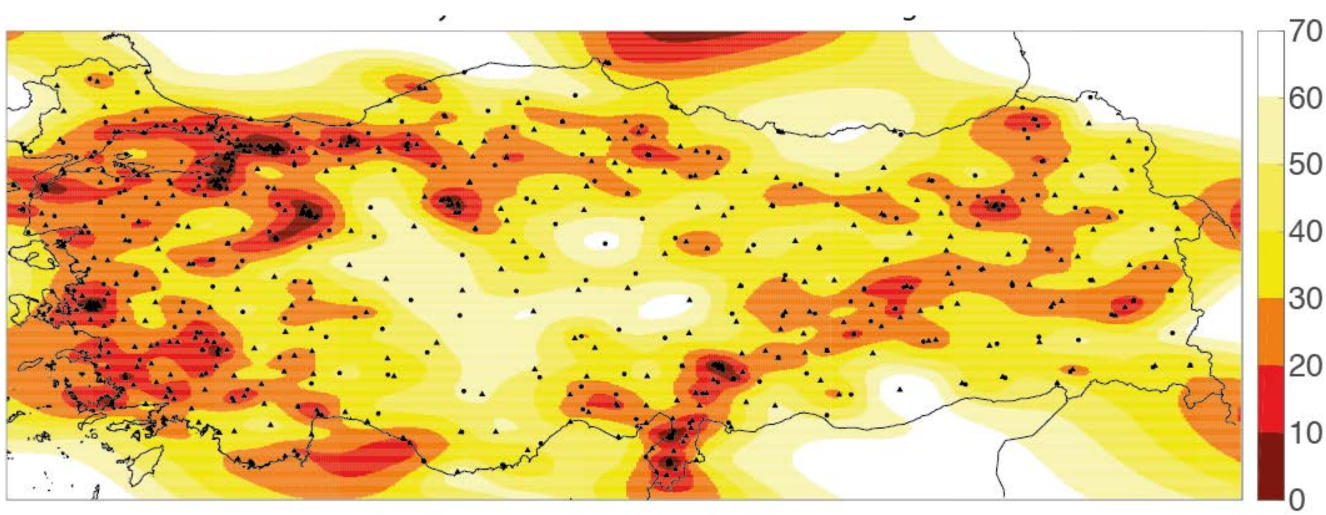

Fig. 2 - Seismic-station interstation density map in which yellow colors indicate lower densities. For a given station location, the interstation density is determined by averaging the distance to the nearest three stations.

Qualitatively, regions that have both large populations and high likelihood of experiencing strong shaking include: the southern part of Trakya, the extended parts of North Anatolian Fault Zone (NAFZ), the southern part of Turkey around Hatay, and lastly Aegean region around Izmir. In the second step, I evaluated if the interstation distances in these identified regions are at or below the 20 km. For the central NAFZ, between Kocaeli Erzincan, I find there are an inadequate number of stations. In this critical part of Turkey, the interstation distance varies from 30 to 50 km but mostly over 70 km. These values are well outside the desired interstation distance of 20 km or less. Currently, the number of stations covering this portion of the NAFZ is 10. Putting 20 more stations on the two sides of the fault would increase the EEWS accuracy and warning time tremendously for populated cities on NAFZ, as well as increasing warning times for big earthquakes that rupture toward Istanbul or Erzincan.

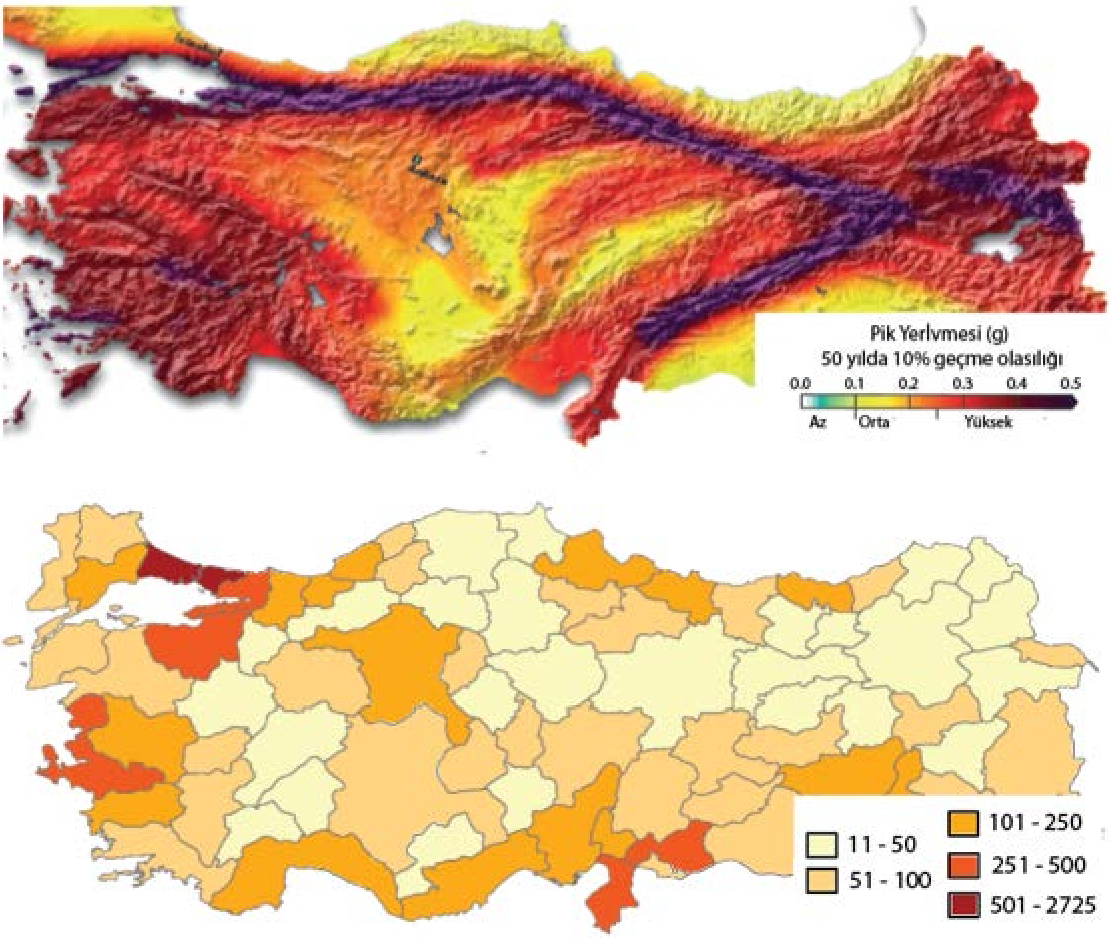

Fig. 3 - Probabilistic seismic-hazard map (adopted from [5]) and population density of Turkey (adopted from [6])

Using the same methodology to generate interstation density map of California and Japan, California has very large regions without adequate stations whereas Japan's average station density is between 10 and 30 km across the whole country (Fig 4).

I next compared the AFAD's existing station density map with the spatial distribution of 685 large Turkey earthquakes (M > 5 with less than 40 km depth) that occurred in the years 1900-2014 (Fig. 5). Although there was some correlation between regions of high seismicity and dense station coverage (e.g., in the Marmara and Kutahya regions), I found many regions with minimal correlation, suggesting the station density is likely inadequate for successful EEWS. One region that needs immediate denser station coverage is the North and East Anatolian Fault. To improve EEWS in this region would require a denser station network. Another problematic region is region between Kocaeli and Duzce, where there are less than 5 stations within a similar area covering the Marmara Sea. The paucity of stations in this region can result in large uncertainties in estimates of the location and magnitude of earthquakes, which, in turn, increase uncertainties in EEWS predictions.

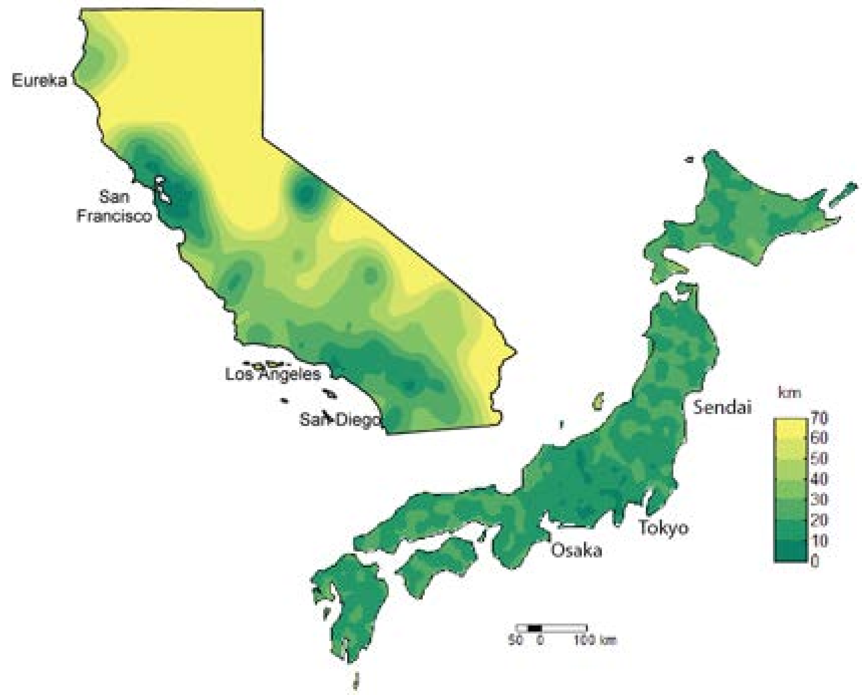

Fig. 4 - Interstation density map of California and Japan (adopted from [1]).

3. Evaluating Blind Zone

One of the challenges with EEWS is minimizing the blind zone, that is, the region around the epicenter where no warning is possible because the strong shaking has already occurred by the time the alert is generated. Some factors that influence the radius of the blind-zone area are simply out of our control. For example, we cannot dictate exactly where earthquakes occur and how deep an earthquake hypocenter is. The blind zone as defined in here is the radius from the epicenter to the distance traveled by the seismic S wave at the time the alert is issued. It is a minimum value, as for any practical use, the blind zone will be larger depending on the time required for a specific action to be taken once the alert is received. The blind-zone radius depends on how close the seismic stations are to the earthquake epicenter, and the total system latency after the fourth station has detected a P wave.

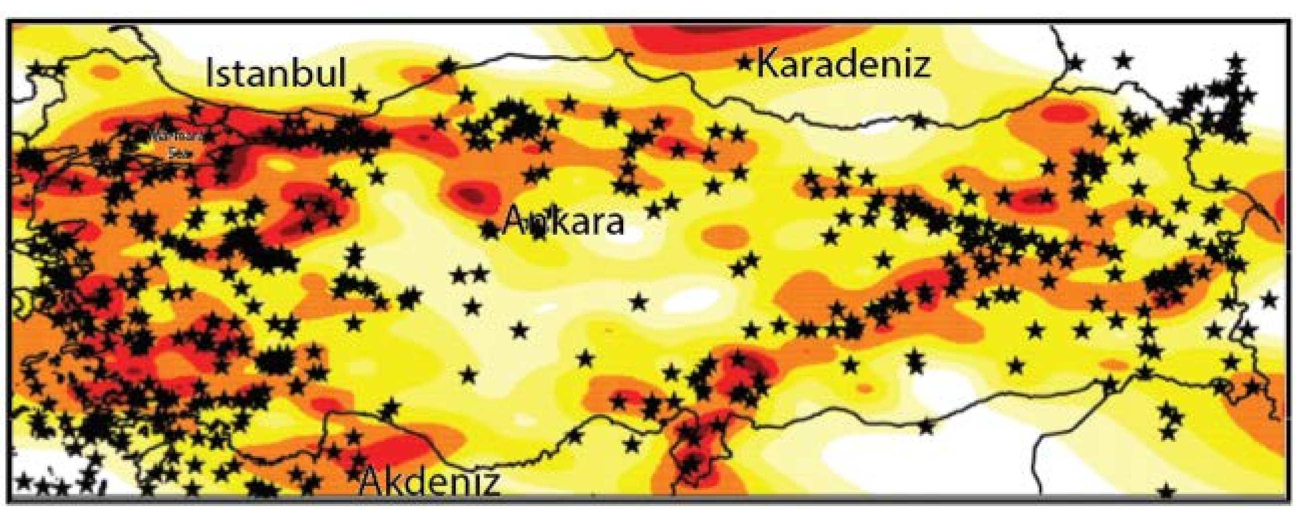

Fig. 5 - Epicenters of 685 M >5 earthquakes from 1900 to 2014 juxtaposed on the interstation-distance contour map of Fig. 2.

Fig. 6 is the map of blind zone of Turkey. Red and dark-red colors correspond to regions with small blind zones and yellow and orange colors correspond to regions with large blind zones. Blind zones are calculated the same methodology that is done by Kuyuk and Allen (2013). Currently all most all of Turkey has a blind zone larger than 30 km. Increase in number of stations reduces the blind zone radius but still it is inadequate. Immediate solution would be to employ more stations on the North and South Anatolian Fault.

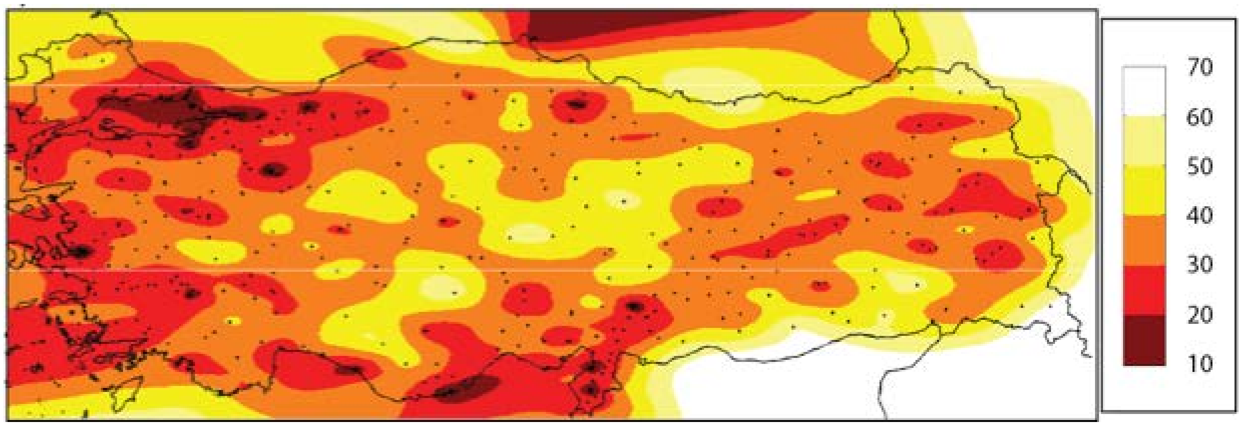

Fig. 6 - Map of blind-zone radius for Turkey. Red and dark-red colors correspond to regions with small blind zones and yellow and orange colors correspond to regions with large blind zones.

4. Recommendations and Conclusion

I proposed three strategies to improve seismic station density in this study;

1. Because of the interdependence between interstation distance and warning time, I propose that, in general, networks need to have smaller interstation distances surrounding known active faults such as NAFZ, particularly within large metropolitan areas. This will rise the warning time for densely populated cities. However, the dense station coverage should also be extended along the hazardous faults adjacent to the metropolitan regions in order to improve warning times for earthquakes that occur adjacent to the cities. Several regions in Turkey have inadequate station coverage to support successful EEWS. Two areas stand out where there is both high risk of earthquake rupture and very low station density: along the North and South Anatolian Fault and Aegean region.

2. Improved, that is, denser, interstation distance could be achieved in a number of ways:

(a) Upgrading infrastructure at selected existing stations, such as employing new loggers and faster telecommunication devices. There are currently hundreds of station sites in Turkey, but only 772 with equipment suitable for an EEWS. The advantage of upgrading these sites is that the operating costs are already covered; the only cost needed is to upgrade hardware.

(b) Integrating other seismic stations from local seismic networks into the warning system would help improve the coverage for Turkey.

(c) Relocating some existing stations. There are more than 158 stations in Turkey with interstation distances less than 10 km, relocation of some could make a big difference to warning times in other regions.

(d) Employing new stations to fill the gaps between existing stations and known seismic zones.

3. The current distribution of stations in the AFAD network was not designed for EEWS purposes. The capabilities of an EEWS are primarily determined by station distribution. The approach taken to building the

networks for the Japanese EEWS was to have an even station distribution of 18.7 km across the country. In Turkey, the distribution of station is currently not adequate for EEWS. However, in our budget limited reality, optimum performance is also not achieved by even station distribution. Stations should be

(a) densest (~10 km) in the urban areas that are abov

(b) fairly dense (~20 km) along hazardous faults

(c) least dense in other regions. Based on the current distribution of stations and hazards in Turkey[6]

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