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Interpolation with Uncertain Spatial Covariances: Modeling to Probability Estimations of Earthquake Occurrences Using Kriging Method in the East Anatolian Fault Zone (Eastern Turkey)

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Abstract

In this study, Kriging method used to probability estimations of earthquake occurrences for different seismogenic sources zones in the East Anatolian Fault Zone (EAFZ), Turkey. We used the instrumental and historical catalog for M_s magnitude. Kriging method depends on mathematical and statistical models. Kriging is an interpolator that can be exact or smoothed depending on the measurement error model. It is very flexible and allows to investigate graphs of spatial auto- and cross-correlation. Kriging uses statistical models that allow a variety of output surfaces including predictions, prediction standard errors, probability, and quantile. The flexibility of kriging can require a lot of decision-making. Kriging assumes the data come from a stationary stochastic process, and some methods assume normally-distributed data. We have used $Z(s) = \mu(s) + \varepsilon(s)$ basis formula for all the different types of Kriging method. We determined two different approaches for probability estimates. Also, this method applied two significant declustering method for all earthquake dataset. Firstly, we selected Gaussian Kernel function, Gaussian Kernel approximation type, and Gaussian model type for covariance variable with 0,5 quantile and applied polygonal declustering method. Secondly, we selected Exponential Kernel function, Multiplicative Skewing approximation type for empirical base distribution, and Exponential model type for covariance variable 0,5 quantile and applied cell declustering method. As a result, interpolation with uncertain spatial covariances calculated probability estimates of earthquake occurrences for different source zones in EAFZ. Each zone determined high and low probability estimates from in the past earthquakes with Kriging method. This study can give a lead significant science humans for statistical estimates of earthquake occurrences of different regions in Turkey.

Key words: Kriging method, Gaussian Kernel approximation, Exponential Kernel function, Multiplicative Skewing, East Anatolian Fault Zone

1. Introduction

The East Anatolian Fault Zone (EAFZ) was the left lateral strike-slip fault and one of the major active tectonic structures of the Eastern Mediterranean. The EAFZ composed the southeastern boundary of the westward run away Anatolian Block, and established the relative motion between the Anatolian Block and the Arabian Block (Barka and Kadinsky-Cade, 1988). The EAFZ has about 550 km in length and it contained from Karlıova in the Northeast to the Mediterranean Sea

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in the Southwest. The north-east extension of the EAFZ completed in the Karlıova junction, where it cutt off with the North Anatolian Fault Zone (NAFZ). Though there was settlement concerning the primary trace of the fault zone among Karlıova in the northeast and Türkoğlu in the southwest, the junction site with the Dead Sea Fault Zone (DSFZ) was under discussion.

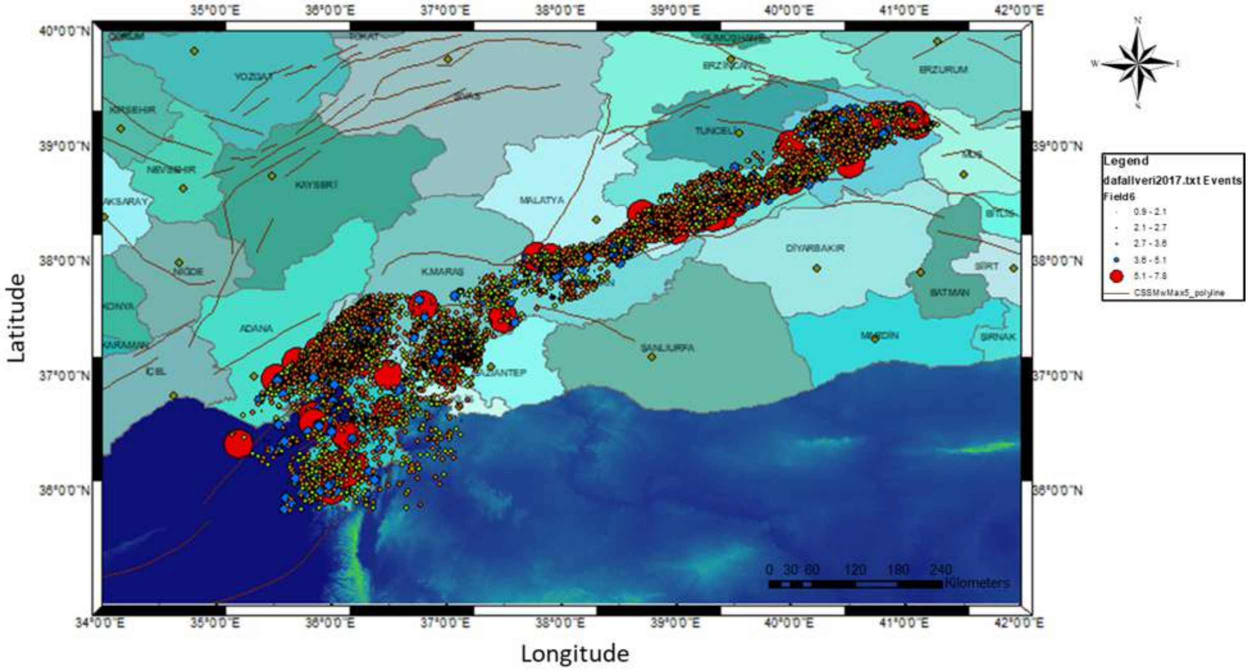

Figure 1. The East Anatolian Fault Zone plotted map of the tectonic structure and epicantr distributions (database included the instrumental and historical period).

The aim of this study, we used the application and the importance of the geostatistical analytical technique (kriging method) to probability estimations of earthquake occurrences for 5 different seismogenic sources zones in the East Anatolian Fault Zone (EAFZ), Turkey (Table 1). We used historical and instrumental period so, it included all earthquake database for M_s magnitude. Kriging method forms from mathematical and statistical models. Also, Kriging was an interpolator that can be complete or smoothed counting on the measurement error model (Barton et. al. 1999). Kriging used statistical models that let a diversity of output surfaces including predictions, prediction standard errors, probability, and quantile Kriging accepted the data get from a constant stochastic process, and some methods accept normally-distributed data. In this study, we used $Z(s)=\mu(s)+\varepsilon(s)$ basis formula for all the different types of Kriging method. We determined two different approaches for probability estimates. Also, this method applied two significant declustering method for all earthquake dataset. Firstly, we selected Gaussian Kernel function, Gaussian Kernel approximation type, and Gaussian model type for covariance variable with 0,5 quantile and applied polygonal declustering method. Secondly, we selected Exponential Kernel function, Multiplicative Skewing approximation type for empirical base distribution, and Exponential model type for covariance variable 0,5 quantile and applied cell declustering method.

2. Theory

2.1. Kriging Method

The kriging method of interpolation was one of from geostatistical technique. İt considered both the distance and the degree of variation among known data points when predicting values in undetermine areas. In kriging, the first step determined the data with identify the spatial structure. Also, it often represented by the empirical semivariogram (Isaaks and Srivastava, 1989). The BLUE of unknown realization *Un'* denoted as U~, is constructed linearly in terms of *(n* - 1) known realizations Joumel and Huijbregts (1989). This process of evaluating BLUE is the original meaning of kriging. Eq. (1) may also be presented in the estimator form involving corresponding stochastic variates:

$$U_n^e = \sum_{i=1}^{n-1} \lambda_{in} U_i \tag{1}$$

The kriging weights (Eq.2) are determined based on the unbiased condition:

$$E(U_n^e - U_n) = E\left(\sum_{i=1}^{n-1} \lambda_{in} U_i - U_n\right) = \sum_{i=1}^{n-1} \lambda_{in}\mu - \mu = 0 \tag{2}$$

and on the minimum estimation variance (Eq.3):

$$\begin{aligned} E[(U_n^e - U_n)^2] &= E\left[\left(\sum_{i=1}^{n-1} \lambda_{in} U_i - U_n\right)^2\right] \\ &= \sum_{i=1}^{n-1} \sum_{j=1}^{n-1} \lambda_{in}\lambda_{jn} R_{ij} - 2\sum_{i=1}^{n-1} \lambda_{in} R_{in} + R_{nn} \end{aligned} \tag{3}$$

where = denotes "by definition;" and *[K]* =kriging matrix. When the stochastic process has zero mean (Eq.4):

$$\begin{aligned} \begin{Bmatrix} \lambda_{1n} \\ \lambda_{2n} \\ \vdots \\ \lambda_{(n-1)n} \\ \gamma_n/2 \end{Bmatrix} &= [\mathbf{K}]^{-1} \begin{Bmatrix} R_{1n} \\ R_{2n} \\ \vdots \\ R_{(n-1)n} \\ 1 \end{Bmatrix} \\ &= \begin{bmatrix} R_{11} & R_{12} & \cdots & R_{1(n-1)} & 1 \\ R_{12} & R_{22} & \cdots & R_{2(n-1)} & 1 \\ \vdots & \vdots & \ddots & \vdots & \vdots \\ R_{1(n-1)} & R_{2(n-1)} & \cdots & R_{(n-1)(n-1)} & 1 \\ 1 & 1 & \cdots & 1 & 0 \end{bmatrix}^{-1} \begin{Bmatrix} R_{1n} \\ R_{2n} \\ \vdots \\ R_{(n-1)n} \\ 1 \end{Bmatrix} \end{aligned} \tag{4}$$

Minimum estimation variance known as the kriging variance, for the nonzero mean stochastic process (Eq.5):

$$\sigma_k^2 = \min\{E[(U_n^e - U_n)^2]\} = R_{nn} - \sum_{i=1}^{n-1} \lambda_{in} R_{in} - \frac{1}{2}\gamma_n \tag{5}$$

and for the zero mean stochastic process (Eq.6):

$$\sigma_k^2 = \min\{E[U_n^e - U_n)^2]\} = R_{nn} - \sum_{i=1}^{n-1} \lambda_{in} R_{in} \tag{6}$$

Table 1. 5 different seismogenic sour zones were in the EAFZ.

Region	Tectonics
1	Bingöl–Karlıova
2	Between Pütürge–Palu
3	Tut and Sürgü Faults
4	Karatas–Osmaniye Faults
5	Kırıkhan–Islahiye

3. Results and Discussions

We determined probabilitiy maps to interpolation with uncertain spatial covariances calculated probability estimates of earthquake occurrences of different seismogenic zones (Bingöl-Karlıova, between Pütürge-Palu, Tut and Sürgü faults, Karatas-Osmaniye faults, Kırıkhan-Islahiye faults) in EAFZ. Two different approach used to probability estimates of all seismogenic zones. Addition, two significant declustering method applied for all earthquake dataset. Firstly, Gaussian Kernel function, Gaussian Kernel approximation type selected. Then, Gaussian model type for covariance variable with 0,5 quantile determined and polygonal declustering method selected for method. As a result of this, we estimated probability values for different magnitude values at historical and instrumental periods. We plotted probability map for selected method in the 5 zones. We estimated high probabilities with this method. Secondly, Exponential Kernel function, Multiplicative Skewing approximation type for empirical base distribution selected. Also, Exponential model type for covariance variable 0,5 quantile determined and applied cell declustering method. We estimated high probability values in 5 different zones with this method. Consequently, when two method compared, second method probability results estimated higher than first method probability results. Maybe, this study, science humans will be reference seismic risk and hazard researches.

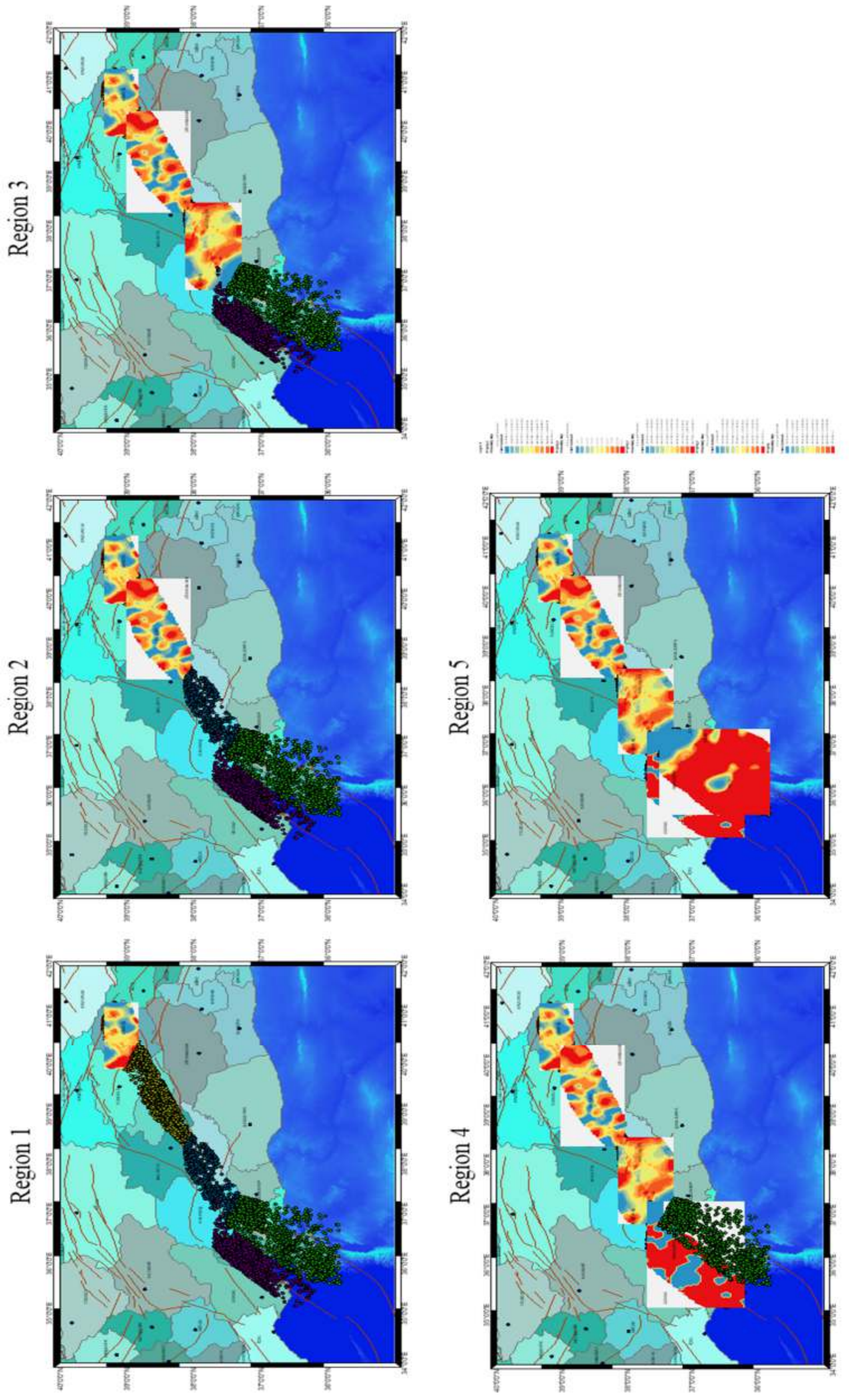

Figure 2. Second method results plotted to probability maps for separately 5 different seismogenic zones in EAFZ.

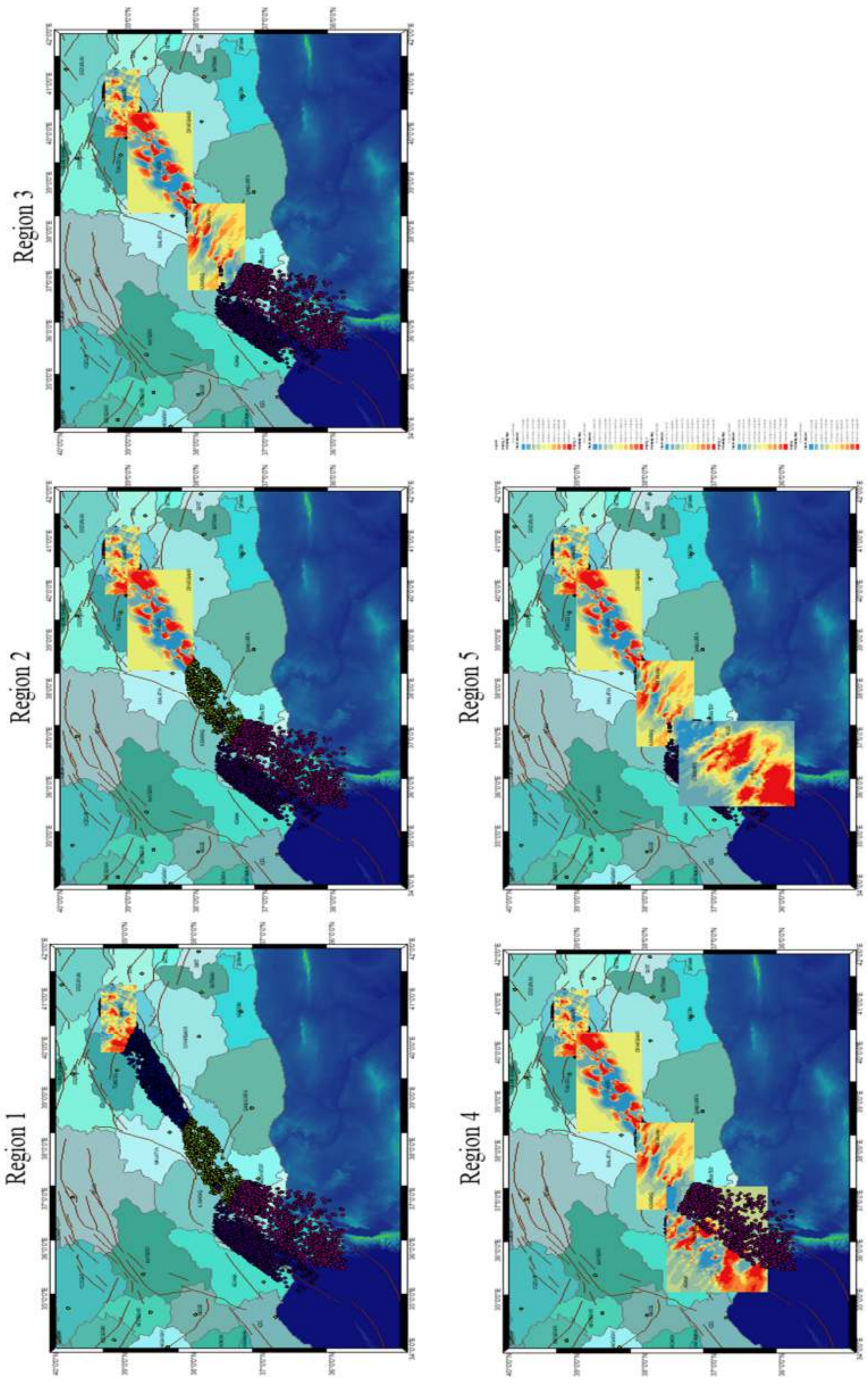

Figure 3. First method results plotted to probability maps for separately 5 different seismogenic zones in EAFZ.

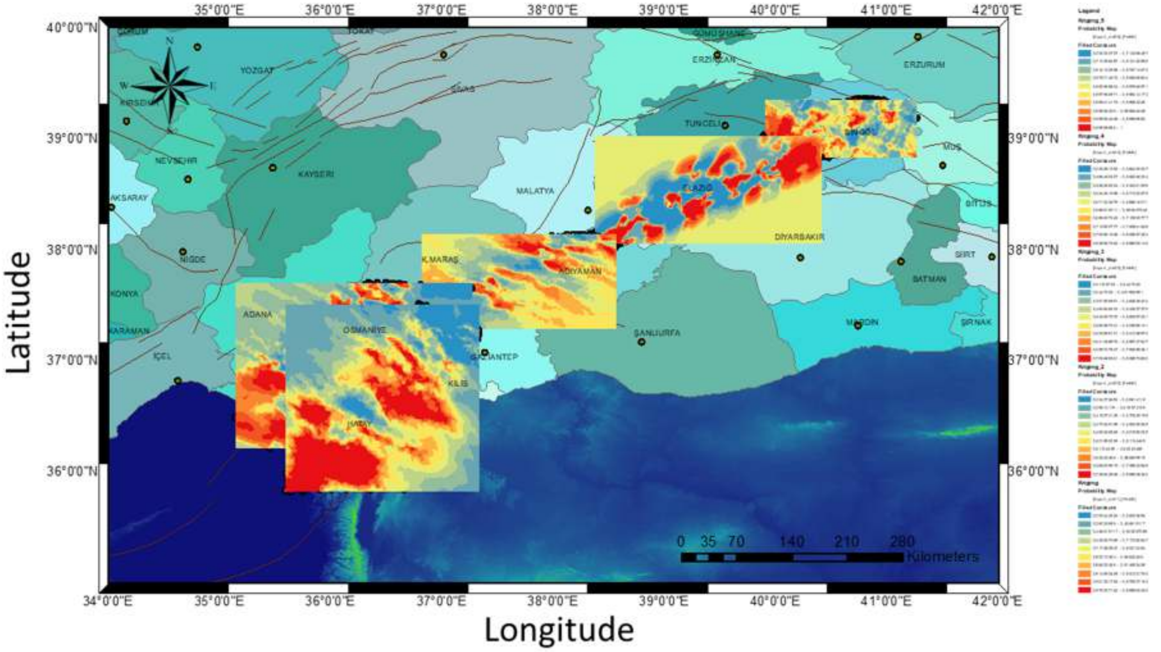

Figure 4. Frist method probability map plotted for all seismogenic zones.

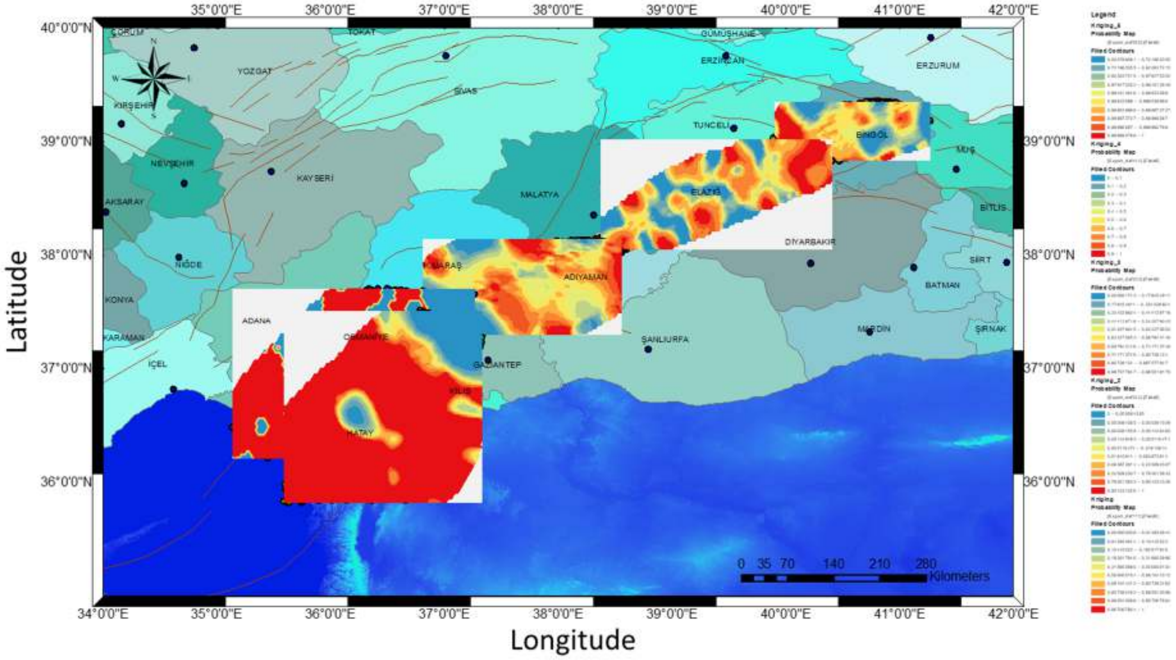

Figure 5. Second method probability map plotted for all seismogenic zones.

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