

# Effect of Epicenter Data Inconsistency in Determining Bandwidth and its Subsequent Use in Hazard Analysis for Chennai Using Kernel Smoothing Approach

*C. K. Ramanna, Department of Civil Engineering, Indian Institute of Technology Madras, Chennai, Tamil Nadu, India*

*G. R. Dodagoudar, Department of Civil Engineering, Indian Institute of Technology Madras, Chennai, Tamil Nadu, India*

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## ABSTRACT

*The most important parameter in the kernel density estimator is the bandwidth or spread or window width. The bandwidth of the kernel density estimator, which follows the power law, is determined using the nearest neighborhood technique for the earthquake catalog which is divided into bins. For reliable hazard estimates, the magnitude bins used in developing the power law and estimating the spatial activity rate density function should be the same. It is important that consistency be maintained between the earthquake epicenters used in determining the bandwidth and the epicenters to which the bandwidth is applied subsequently. In this paper, the effect of epicenter data inconsistency on hazard estimates for various return periods for Chennai is evaluated. Two methods of binning are used, one in which the epicenters used in deriving the bandwidth is in line with the epicenters used in arriving at the spatial activity rate and the other where the epicenters used in deriving the bandwidth are just grouped by dividing the catalogue into equal bins. Seismic hazard estimations are compared using these two approaches of forming the magnitude bins for Chennai, Tamil Nadu, India. The peak ground acceleration (PGA) values obtained from Binning Methods 1 and 2 for 475 years return period are 0.0955g and 0.0802g respectively. The difference in PGA and peak spectral acceleration (PSA) from the two binning methods ranges from 20 to 10% with respect to Binning Method 1 for the return periods of 72 to 2475 years.*

*Keywords:* Bandwidth, Binning Methods, Hazard Estimates, Kernel Density Estimator; PGA, PSA

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## INTRODUCTION

Seismic hazard analysis (SHA) plays an important role in the earthquake resistant design of structures by providing a rational value of input hazard parameters such as peak ground acceleration (PGA) or the response spectrum amplitudes at different natural periods. Zonefree technique to seismic hazard analysis is gaining popularity in regions of distributed seismicity. One such zonefree technique most often used (Secanell *et al.*, 2008; Lai *et al.*, 2009; Menon *et al.*, 2010; Ramanna & Dodagoudar, 2012) and also widely studied (Molina *et al.*, 2001; Beauval *et al.*, 2006) is the kernel density estimator to seismic hazard analysis. The kernel estimator has been mainly used to replace the seismicity determined by the Gutenberg-Richter (G-R) recurrence law with a spatially varying seismic activity rate density function. A simple illustration of the kernel density estimator is shown in Figure 1. In this technique, the probability density function (PDF) is determined as the normalized sum of individual function called kernels placed on the data or sample points. The most important parameter in a kernel density estimator is the bandwidth or the spread of the kernels over the epicenters. Figure 2 and Figure 3 illustrate the effect of bandwidth on the final PDF derived. The bandwidth used for each epicenter plays a vital role in arriving at the hazard estimate for a given site and hence it needs to be determined carefully. There are several methods of determining the optimal bandwidth for a data set as summarized by Mugdadi (2004). However, Woo (1996) suggests the use of nearest neighborhood technique for arriving at the bandwidth for a set of epicenters.

Most of the previous studies do not mention the magnitude bins used in deriving the bandwidth parameter. The commonly used program to carry out the seismic hazard estimate using the kernel density estimator is the KERFRAC developed by Woo (1996). However in the program KERFRACAT the spatial activity rate is determined in steps of 0.1 magnitude increment starting from  $(M_{\min} \pm 0.49)$  to  $(M_{\max} \pm 0.49)$ . This study aims at highlighting the effects of

not maintaining the consistency in the data used in deriving the bandwidth and the data to which this bandwidth is applied in arriving at the spatial activity rate density function. The effects are shown for every magnitude at the spatial activity rate density function in the form of integrated squared error score and also at the final hazard estimates in the form of PGA and spectral ordinates.

## Seismic Hazard Analysis Using Kernel Density Estimator

It is now a well-known fact that the distribution of epicenters follow a fractal dimension and the earthquake process itself follows a power law. Hence the bandwidth to be used for earthquakes is said to follow the power law and is of the form:

$$H = ce^{dM} \quad (1)$$

where  $H$  is the bandwidth, and  $c$  and  $d$  are the bandwidth parameters and  $M$  is the earthquake magnitude. The bandwidth parameters are determined by the nearest neighborhood technique by dividing the earthquake catalog into several magnitude bins. According to this technique, the bandwidth for each data set is determined as the average nearest distance within the data set.

The kernel density estimation (KDE) consists of determining the density function  $f(x)$  by placing standard form of distributions such as Uniform, Triangular, Normal or Epanechnikov density curves on the sample or data points known as kernels. The  $f(x)$  is then determined as the normalized sum total of these kernels (See Figure 1). A univariate PDF determined by KDE is of the form:

$$f(x) = \frac{1}{nh} \sum_{i=1}^n K\left(\frac{x - x_i}{h}\right) \quad (2)$$

where  $n$  is the number of sample data  $x_i$ ,  $h$  is the smoothing parameter also known as the bandwidth,  $x$  is the estimation or evaluation point where density is determined and  $K(\cdot)$  is

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