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# Application of Fuzzy Logic in Seismic Zonation

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***Abstract*-Traditional statistical methods for seismic zonation require information from many subjects, such as regional geology and neotectonics, seismicity, stress field, damage analysis of historic earthquakes, geophysics and others. These subjects are weighted differently during statistics. In fact, the information from most of these subjects is more like fuzzy sets, ie, it is a sort of estimation rather than precise data. In this paper we propose a fuzzy logic system that uses crustal structural features (seismotectonics) and historic seismic activities (seismicity) as two fuzzy inputs for seismic zonation. Seismotectonics is a combination of features from regional and deep geology, neotectonics, stress field and geophysics whereas seismicity is defined by historic earthquakes and their damages to some specific areas. Applying this fuzzy system to the northeastern Tibetan Plateau, a well-known intraplate seismic region in the world, outlines are not only the existing well-recognised seismic zones where large earthquakes took place in history, but also some areas where there have been no strong shocks occurred for the last 2000 years. The traditional statistical methods are not able to evaluate such areas due to the lack of the historic seismicity information.**

## INTRODUCTION

There are two major areas in seismic risk assessment: earthquake prediction and seismic zonation. Although all the three factors (timing, location and strength) associated with a shock are dealt with in these two areas, earthquake prediction is focused more on the possibility of damage earthquakes that could occur in a specific region in a short term. On the other hand, seismic zonation aims mainly at where damage earthquakes will likely occur in a long term. Seismic zonation provides the fundamental information for regional development planning, civil and engineering construction designs, and seismic hazard protection and mitigation. Fuzzy logic has been widely used in earthquake predication [1][2][3] because no method for earthquake prediction has been commonly accepted by the majority of seismic researchers in the world. Thus new methods are often introduced into this area. However, since statistics-based methods have been thought working well in dealing with seismic zonation, fuzzy logic has been rarely used in this area.

Traditional statistical methods for seismic zonation are based on information from regional geology and neotectonics, seismicity, stress field, damage analysis of historic strong earthquakes, geophysics and others. These subjects are weighted differently in the combined statistics and thus different conclusions could be resulted even from the same information. In fact, the information from most of these subjects is a sort of estimation rather than precise data, eg, seismicity is classified as low or high and the seismic risk is often classified as low, moderate, high, and very high. This implies that fuzzy logic may be applicable to seismic zonation.

In this paper, we propose a fuzzy system for seismic zonation. This system uses crustal structural features (seismotectonics) and historic seismic activities (seismicity) as the two fuzzy inputs only. Seismotectonics is a combination of features from regional and crustal structure, neotectonics, stress field and geophysics whereas seismicity is defined by historic earthquakes and their damages to the studied areas. We apply this fuzzy system to the northeastern Tibetan Plateau, a well-known intraplate seismic region in the world, to test the usefulness of this system.

## STRUCTURE OF THE FUZZY SYSTEM

The general structure of this fuzzy system is illustrated in Fig. 1. The two fuzzy inputs – seismotectonics and seismicity – are valued into 0 and 10 (Table 1). Tensile and tensile-related structures are mainly associated with small earthquakes and thus are given values of 0 and 3.9. Pure compressive structures are often associated with moderate quakes so they are given values of 4.0 - 5.9. Many strong shocks occur with pure strike-slip structures so they are allocated values of 6.0 - 7.9. Large earthquakes are often generated around the intersections of compressive and strike-slip structures or of two conjugate strike-slip structures so they are given values of 8.0 - 10.

TABLE 1
DESCRIPTION OF FUZZY INPUTS

| Fuzzy input | Input 1: Seismotectonics | Input 2: Seismicity |
|---|---|---|
| 0.1 – 3.9 | Tensile structure, intersections of tensile and other (compressive or strike-slip) structures | Small |
| 4.0 – 5.9 | Compressive structure | Moderate |
| 6.0 – 7.9 | Strike-slip structure | Strong |
| 8.0 – 10.0 | Intersections of either compressive and strike-slip structures or two conjugated strike-slip structures | Large |

Seismicity is determined by the strongest earthquake occurred along a seismic structure in history. Note even if there has been no strong and/or large shock occurred in a region of intersection of compressive and strike-slip structures or of two conjugate strike-slip structures, this region always has a high seismic risk. It is because such a region always causes stress concentration that leads to the formation of strong or large earthquakes.

These two fuzzy inputs work under four fuzzy rules given in Table 2. Fuzzy operation AND (or min) is applied to the two inputs, and is also used as the implication method. All membership functions are illustrated in Fig. 1. Centroid calculation is used for defuzzification. The fuzzy output is classified into 0 to 10 as seismic risk index. The implication of the index values is given in Table 3.

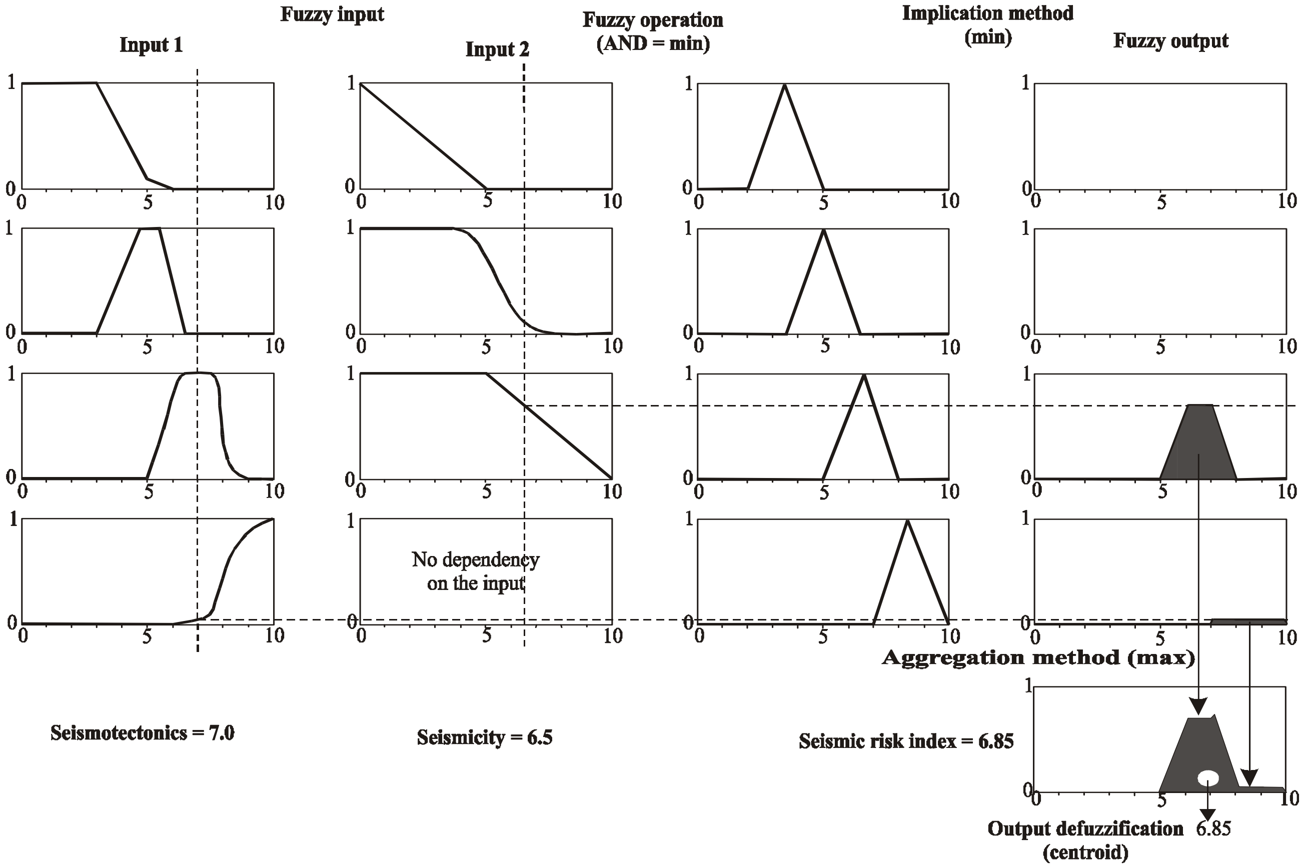


Fig. 1. General structure of the fuzzy system for seismic zonation.

TABLE 2
DESCRIPTION OF FUZZY RULES IN THE SYSTEM

| Rules | Input 1 | | Input 2 | Fuzzy operation (min) | Fuzzy output |
|---|---|---|---|---|---|
| | If seismotectonics is | | seismicity is | | seismic risk is |
| 1 | tensile | *and* | small | *then* | low. |
| 2 | compressive | *and* | moderate | *then* | moderate. |
| 3 | strike-slip | *and* | strong | *then* | high. |
| 4 | intersection of 2 & 3 or 3 & 3 | *and* | large | *then* | very high. |

TABLE 3
DEFUZZIFIED OUTPUT AND IMPLICATION IN SEISMIC ZONATION

| Defuzzified output (seismic risk index) | Implication |
|---|---|
| 0 – 3.99 | Small earthquakes (Ms < 4.75) often occur but risk of moderate shocks (Ms = 4.75 – 5.9) is low. |
| 4.00 – 5.99 | Small earthquakes occur frequently with a high risk of moderate shocks occurring sometimes. However, risk of strong shocks (Ms = 6.0 – 6.9) is low. |
| 6.00 – 7.99 | Small to moderate earthquakes occur frequently with a high risk of strong shocks occurring in a period of decades to a centenary. However, risk of large shocks (Ms ≥ 7.0) is low. |
| 8.00 – 10.0 | Small to moderate earthquakes occur frequently with a high risk of strong shocks occurring sometimes. Large shocks may occur in a period of centenaries to thousand years. |

## Application of the Fuzzy System to Seismic Zonation in the NE Tibetan Plateau

The northeastern Tibetan Plateau from north of the Qaidam Basin to the northern boundary of the Hexi Corridor (Fig. 2) is one of the well-known intraplate seismic zones in the world. At least 18 strong earthquakes (Ms ≥ 6.0) have been recorded in this region since 180 AD [4]. During the 27 years from 1927 to 1954, three major quakes, one with Ms = 8.0 and two others with Ms ≥ 7.0, struck this region and caused some casualties. Recently, two shocks occurred in 1986 (Ms = 6.4) and 1990 (Ms = 6.2) warn that this region remains in danger, particular with the rapid industrial expansion and the increase in population in the last 20 years. Therefore, seismic zonation in this region is a primary demand so as to identify and classify the region in terms of potential earthquake risk.

Exposed structures are characterised by NW-SE trending faults and compressive basins and ranges (Fig. 2). Traditionally, these NW-SE trending structures have been classified as the major seismotectonics in the NE Tibetan Plateau in China [5][6][7] because most earthquakes caused noticeable surface deformation that closely aligned with these NW-SE trending structures. Seismological evidence has shown that most earthquakes occurred at the depth of 10-25 km in this region, or in the middle crust [4][7][8]. Therefore, structures in the middle crust, rather than the exposed ones, should have significant impact in seismic zonation analysis.

By image processing and interpretation of regional gravity data [9], E–W, NW–SE, and NE–SW crustal structures have been delineated in this region (Fig. 3). In a stress field with NE–SW compression and NW–SE tension, E-trending structures are mainly sinistral strike-slip; NE-trending structures are mostly tensile; NW-trending structures are dominantly compressive. Seismic zonation associated with these crustal structures is made using the fuzzy system defined above and the results are also illustrated in Fig. 3. In additional to the well-recognised areas where large earthquakes took place in history, some areas where there have been no strong shocks occurred for the last 2000 years are also indexed as high-risk zones. The traditional statistical methods are not able to evaluate such areas due to lack of historic seismicity information, even though the assessment of these indexed areas needs to be verified in the future.

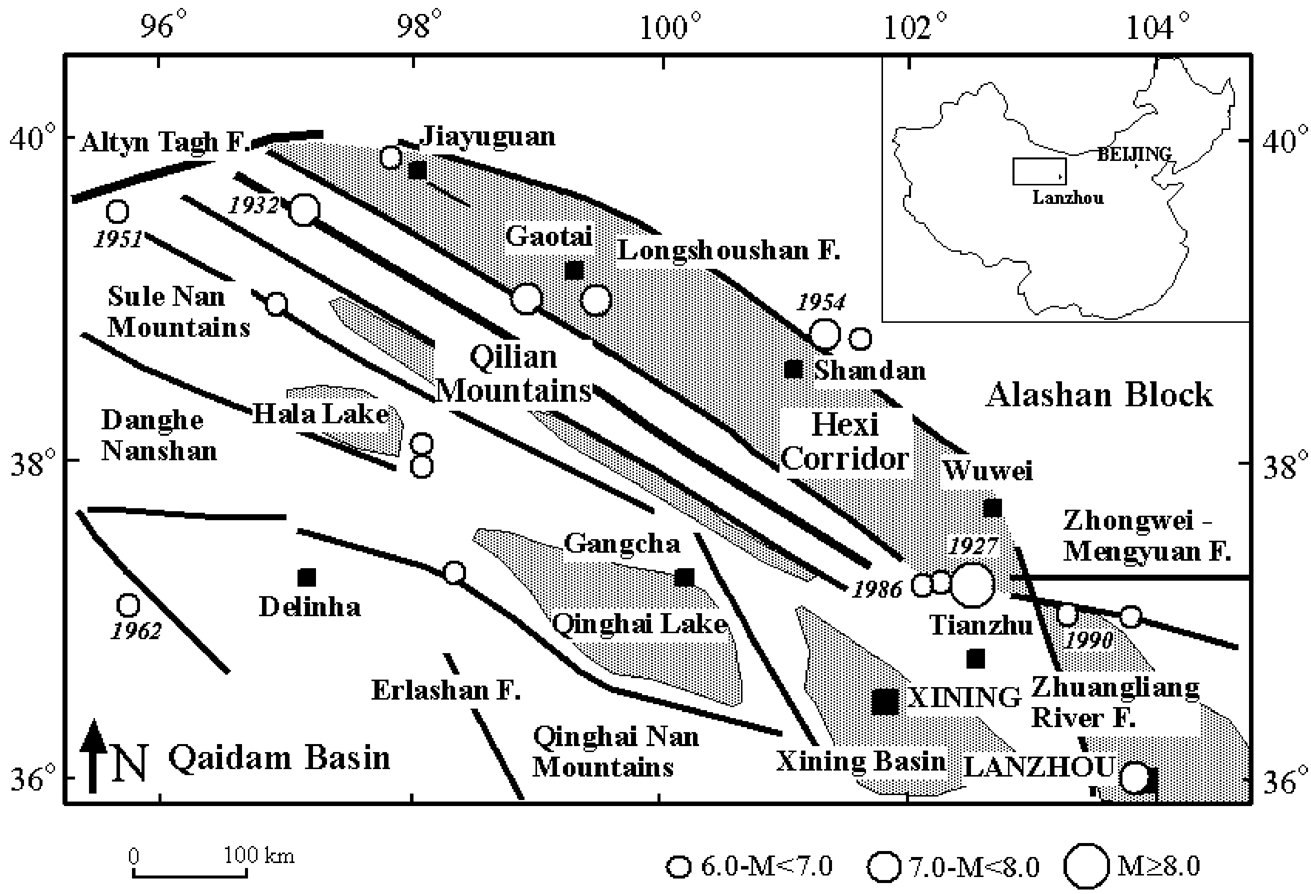


Fig. 2. Simplified structural map and seismicity (M ≥ 6.0) in the NE Tibetan Plateau.

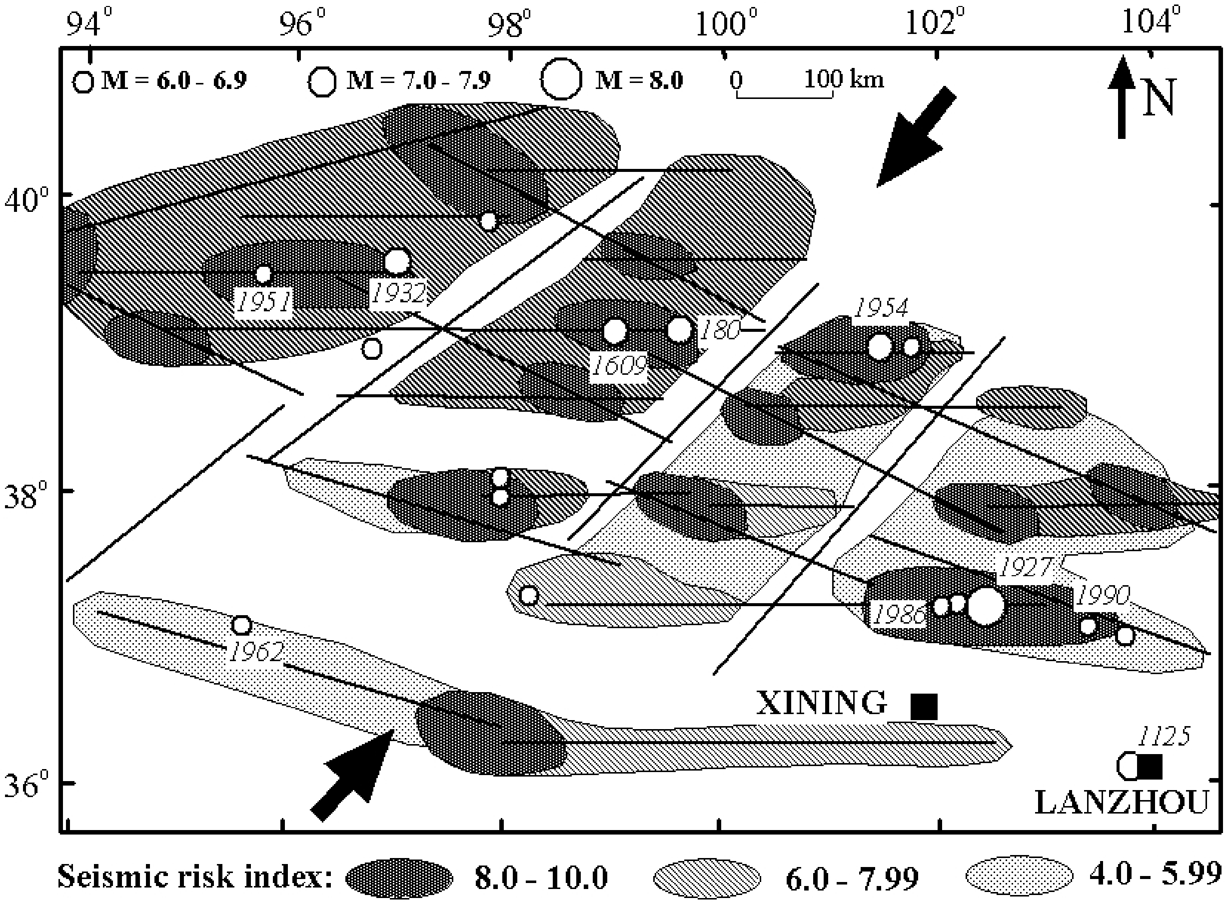


Fig. 3. Seismic zonation of the NE Tibetan Plateau using the fuzzy system.


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