Seismic hazard in the DRC and Western Rift Valley of Africa

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ABSTRACT

A probabilistic approach was used to assess the seismic hazard in Democratic Republic of Congo and surrounding areas. Seismic hazard maps were prepared using a 90-year catalogue compiled for homogeneous M_w magnitudes; the attenuation relations of Mavonga (for the Western Rift Valley of Africa), Atkinson and Boore (for eastern North America) and Jonathan (for eastern and southern Africa); and the EZ-Frisk software package. The highest levels of seismic hazard were found in the Lake Tanganyika Rift seismic zone, where peak ground accelerations (PGA) in excess of 0.32 g, 0.22 g and 0.16 g are expected to occur with 2%, 5% and 10% chance of exceedence in 50 years, respectively. The seismic hazard in the Congo basin diminishes with distance away from the Western Rift Valley until, at a distance of about 450 km, the chance of exceeding 0.05 g (the threshold value of engineering interest) is less than 10% in 50 years.

Key words: seismicity of DR Congo, probabilistic seismic hazard, peak ground acceleration, Western Rift Valley

INTRODUCTION

The Western Rift Valley of Africa (WRA) has experienced several severe earthquakes (M>6) in recent historical times, and three since 2002 (an M_s6.8 in the Lake Tanganyika region and M_w6.0 and M_w6.2 in the Lake Kivu basin). The seismic hazard in the Great Lakes region has previously been assessed by Midzi et al. [1999], Twesigomwe [1997] and Zana et al. [1992]. However, social conditions in the region are continually changing, and seismic hazard is generally not taken into account in land-use planning. Population movement and growth has led to the development of sites that are vulnerable to earthquake hazard. For these reasons, a revised assessment of hazard is urgently needed. Our study makes use of the new strong motion attenuation equation developed by Mavonga [2007b] based on digital seismic records of events from seismic stations in the Western Rift Valley of Africa, and takes local details of geology, tectonics and recent seismicity into account.

DATA

All seismic data used in this study covering the region 14°S to 6°N and 10°E to 32°E are instrumental data compiled from various sources for the period 1910 to 2008. Almost all the DRC is included in the study area, together with parts of Uganda, Tanzania, Rwanda, Burundi, Sudan and Zambia. All available catalogues and seismological bulletins were carefully searched. A catalogue was compiled in Seisan format, listing the source of the data the date, origin time, coordinates of

the earthquake, and a magnitude homogenized according to the moment magnitude scale M_w.
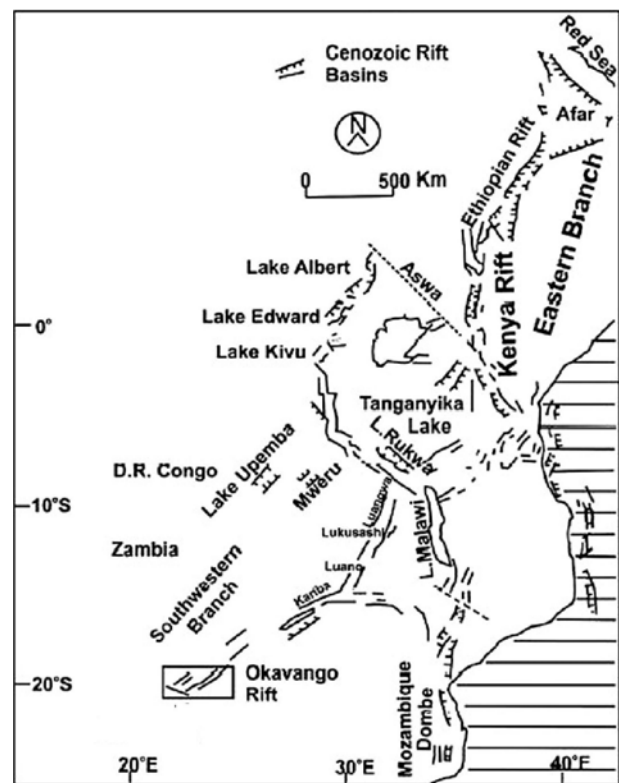

Figure 1. Schematic map of the East African Rift system showing the continental breakup in the southeast of the DRC and northern Zambia (modified from Kinabo et al., 2007)

METHOD

Unification of magnitudes

Several different magnitudes scales are used to describe the size of earthquakes (Båth, 1981) and various seismological centres may use data from different stations when determining the source parameters. Consequently, there may be a difference in the reported magnitudes. It is therefore necessary to choose a suitable magnitude scale and harmonize the various catalogues prior to any seismic study. We decided to use the moment magnitude M_w for our unified catalogue, as it is a direct indicator of the co-seismic deformation [Boore and Joyner, 1984; Joyner, 1984].

Probabilistic seismic hazard analysis

A probabilistic approach [Cornell, 1968; McGuire, 1976 and 1993] was used to map the seismic hazard in DRC and surrounding areas. The magnitude-frequency distribution of the 2249 earthquakes in the harmonized catalogue of approximately 90 years duration is shown in Figure 2.
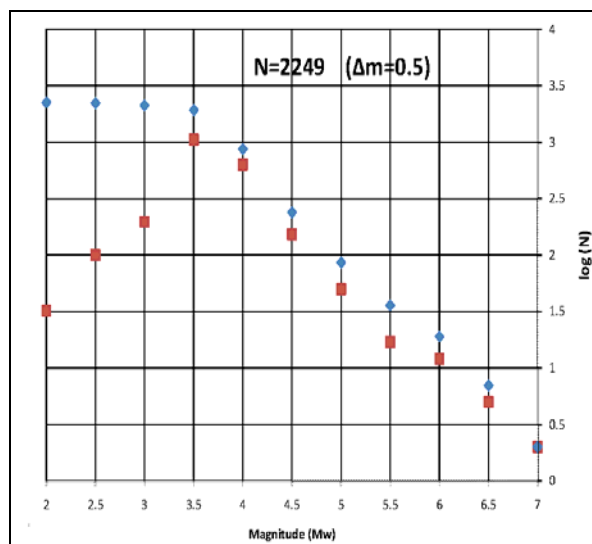

Figure 2. Frequency-magnitude distribution of M≥2 earthquakes in the 1910-2007 catalogue. Magnitude increment Δm=0.5. Squares = no. of events, Lozenges=accumulated no. of events.

A Poisson model of earthquake occurrence that assumes events are independent was adopted [Bender and Perkins, 1987]. Therefore foreshocks, aftershocks and earthquake swarms were removed from the initial catalogue of 2249 events. Furthermore, $M_w=4$ was selected as the lower magnitude bound (M_{min}) because smaller earthquakes are considered unlikely to cause damage, even to houses that are poorly designed and built. Thus any remaining events with $M_w<4$ were also excluded from the catalogue, leaving a sub-catalogue of 822 events.

Application of the probabilistic seismic hazard analysis involves three main steps:

Firstly, potential **seismic source zones** are defined i.e. zones within which all available information may be averaged. These zones are usually associated with active geological or tectonic features (e.g. faults). Based on previous studies of the tectonics and seismicity of the area, three seismic source zones were identified as the main producers of damaging earthquakes in the DRC and surrounding areas (Figure 3).
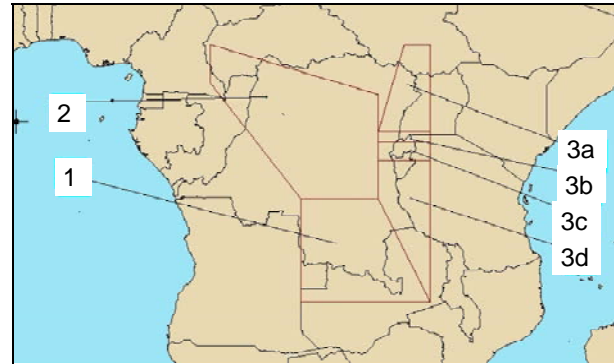

Figure 3. Seismic source zones: 1=Upemba-Moero Rift; 2=Congo Basin; 3=Western Rift Valley, which is divided into four sub-zones 3a=Ruwenzori-Lake Edouard trough; 3b=Virunga volcanic complex-Rutsuru-Masisi; 3c= Lake Kivu Basin-Ngweshe-Ruzizi and 3d=Lake Tanganyika Rift.

1. Upemba-Moero Rift

Sebagenzi and Kaputo [2002] reviewed the available gravity, heat flow and seismological data in the region, and found geophysical evidence for continental break-up in south-eastern DRC and north-western Zambia. The most prominent seismotectonic features in this region are the Upemba and Moero Rifts. The Upemba Rift may extend northward to the Kabalo area, which experienced an $M_w6.5$ earthquake on 11 September 1992. The main shock claimed 11 lives, 109 people were seriously injured, and more than 2000 families were left homeless. However, the relationship between the surface structures and deeper features needs to be determined in order to establish whether the Upemba and Moero Rifts are part of the Western Rift Valley [Sebagenzi and Kaputo, 2002].

2. Congo basin

The tectonic origin of this intracratonic basin is unknown. No surface ruptures have been documented, even though some large and damaging shocks have occurred in that area. Studies of four earthquakes with magnitudes ranging from $M_b5.4$ to $M_b5.6$ that occurred in the Congo basin during the period 1976 to 1998 demonstrated that the Congo basin is predominantly in a state of horizontal compression, which could be explained by compression of the African Plate due to ridge push forces originating from the Mid-Atlantic Ridge and the East African Rift System [Fairhead and Stuart, 1985; Dziewonski et al., 1996; Atalay, 2002].

3. Western Rift Valley of Africa (WRA)

Four seismic sub-zones were identified in the WRA based on local seismicity and geological structure.

(a) Southern Sudan, Ruwenzori area, and Lake Edouard trough. Southern Sudan is dominated by relatively strong earthquakes with poor tectonic control [Girdler and McConnell, 1994]. The Ruwenzori area experienced large earthquakes on 20 March 1966 (M_w6.8) and 5 February 1994 (M_w6.2) [National Earthquake Disaster Committee, 1994; Mavonga, 2007a].

(b) Virunga volcanic complex, Rutsuru basin and Masisi area. The Virunga volcanic complex is the largest of the Cenozoic volcanic complexes in the Kivu Province and the only one that is presently active. Earthquakes in the volcanic area generally have low magnitudes (M_w≤4).

(c) Lake Kivu basin, Ngweshe area and Ruzizi plain. The Lake Kivu basin consists of two subsiding half-grabens separated by the 700 m high Idjwi horst structure. The central part of Lake Kivu experienced a large earthquake (M_w6.2) on 24 October 2002 in the Kalehe area, which was felt strongly at Goma, Bukavu and Kigali [Mavonga, 2007a]. On 3 February 2008 an M_w6.0 earthquake occurred 20 km north of Bukavu City, claimed 9 lives, seriously injured more than 400 people, and caused about 1500 houses to collapse.

(d) Lake Tanganyika Rift. Many larger magnitude earthquakes have occurred in the Tanganyika Rift. The best known are the events which occurred on 13 December 1910 at the southern end of Lake Tanganyika (M7.3), 22 September 1960 at the northern end of Lake Tanganyika (M_s6.5) [Zana and Hamaguchi, 1978], and 5 December 2005 (M_s6.8) in the central part of Lake Tanganyika.

Next, **seismicity parameters** are determined for each seismic source zone. The seismic characteristics of the study area were modelled as a Poisson process following the standard engineering seismology assumptions. The parameters used to characterise each seismic source zone are:

(i) Mean seismic activity rate (λ), which was calculated using Seisan 8.1 (Havskov and Ottemöller, 2006). The magnitude-frequency relations for the three main source zones are shown in Figure 4.

(ii) Level of completeness of the earthquake catalogue (M_{min}).

(iii) Maximum possible earthquake magnitude (M_{max}), obtained using the iterative solution method [Kijko, 2004].

(iv) Gutenberg-Richter [1954] "b-value" (which indicates the relative number of large and small earthquakes, β=b ln10).

(v) Focal depth. Detailed seismic studies indicate that the earthquake foci generally lie at depths of 10 to 20 km in the WRA [Zana, 1977; Zana and

Hamaguchi, 1978; De Bremaecker, 1959; Wohlenberg, 1968].

(vi) Regional attenuation relationship for the strong ground motion. Five attenuation relations were considered, three of these derived using data from the African continent: Mavonga [2007b] for the Western Rift Valley, Twesigomwe [1997] for Uganda, and Jonathan [1996] for eastern and southern Africa. We also considered the relations derived by Atkinson and Boore [2006] and Somerville et al. [2001] for eastern and central North America, which have frequently been used to describe other stable continental regions [e.g. Kijko et al., 2002].
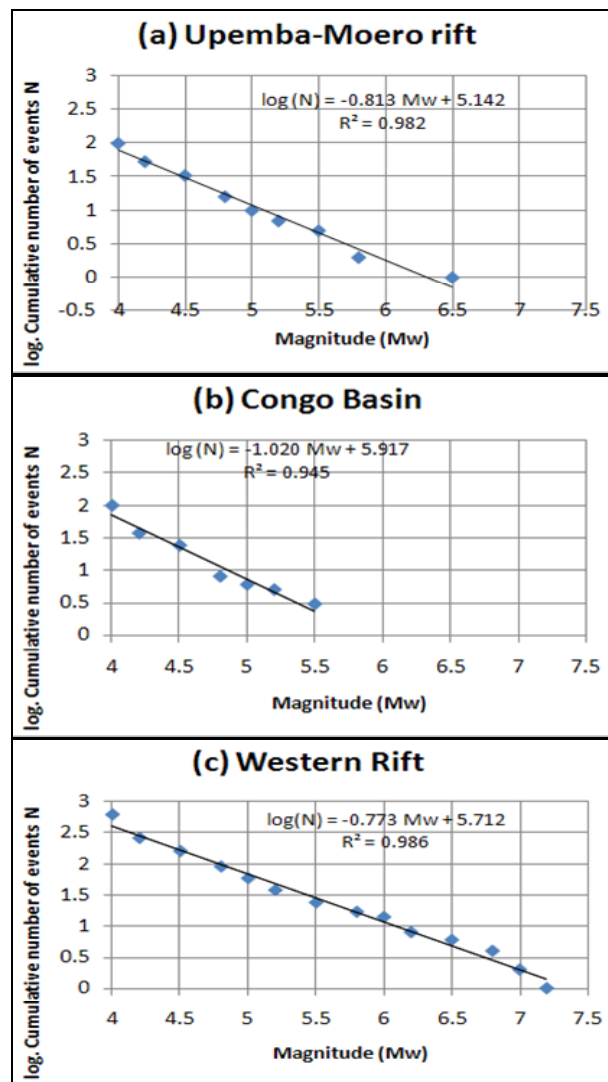

Figure 4. Cumulative magnitude-frequency plot for magnitude increment Δm= 0.25 for the three main seismic source zones used in seismic hazard analysis

Finally, **seismic hazard maps** are prepared. We used the EZ-Frisk software [Risk Engineering, Inc., 2007] to prepare seismic hazard maps for 2%, 5% and 10% chance of exceedance in 50 years for various combinations of the seismic source zones, the three attenuation equations, and two alternative focal depths.

The output is a statistical estimate of the annual chance of exceedance as a function of PGA. A 0.5 degree grid and 2%, 5% and 10% chance of exceedence in 50 years (which corresponds to return periods of 2475, 975 and 475 years, respectively) was used in the calculation. An example is shown in Figure 5.
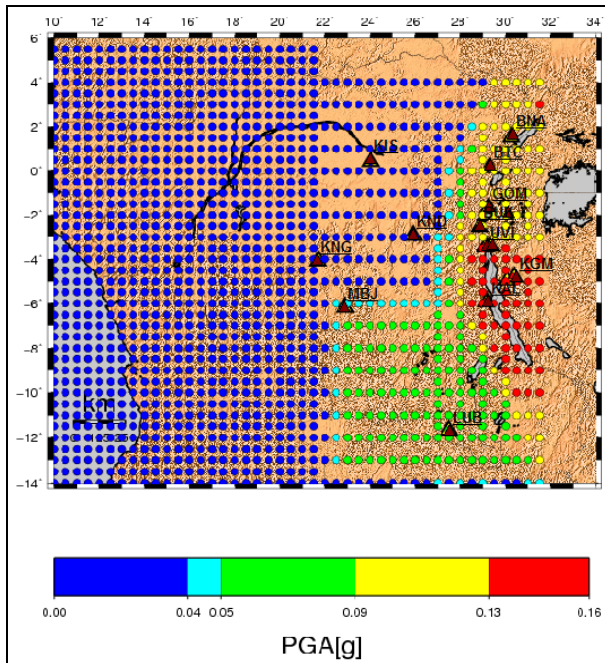

Figure 5. Distribution of mean PGA values (in units of g) in the DR Congo and surrounding areas computed for 10% chance of exceedance in 50 years. The filled circles and triangles indicate the site PGA values and main cities, respectively.

FINDINGS

The highest levels of seismic hazard were found to occur in the Lake Tanganyika Rift sub-zone, where PGAs in excess of 0.32 g, 0.22 g and 0.16 g are expected with 2%, 5% and 10% chance of exceedance in 50 years, respectively.

The regions with the next high level of hazard are the other sub-zones in the Western Rift Valley, with the exception of the Virunga volcanic complex - Rutsuru - Masisi sub-zone where the seismic hazard (due mainly to the volcanic activity) is only moderate.

The seismic hazard in the Congo basin diminishes with distance from the Western Rift Valley until, at a distance of about 450 km, the chance of exceeding a PGA of 0.05g (the threshold value of engineering interest) is less than 10% in 50 years.

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