Seismic hazard of Southern Ethiopia

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1. Introduction

Seismic hazard of the studied area of South Ethiopia (6,0° - 8,5°N, 37,5° - 39,5°) is conditioned by the rift character of the region. From the global point of view, the seismicity connected with rifts (both oceanic and continental) represents about 6% of the seismic energy release. Continental rifts are characteristic by a special type of seismicity, including seismic swarms and volcanic earthquakes. The presence of geothermal phenomena is another typical feature of rift regions. Core fluids (magma, CO_2, water, vapor) can decrease mechanical friction at tectonic faults and trigger seismic events. Big earthquakes in rift regions are observed less frequently than at convergent margins of lithospheric plates, however, catastrophic earthquakes are not excluded. The controlling earthquakes have long repeating periods and hence the computation of seismic hazard represents a complex problem, which is an important issue for industrial development.

East African Rift (and especially its segment in southern part of Ethiopia) is not adequately explored. Only very rough estimation of seismic hazard is available. Rapid growth of urban population, extensive house building and infrastructure development call for seismological investigation, which is a basis of more detailed estimation of seismic hazard.

2. Methodology of seismic hazard estimation

Probabilistic approach to seismic hazard estimation is recommended, as a standard used in western countries in last decade. The probabilistic seismic hazard assessment (PSHA) is suitable also for rift valley in South Etiopia. The most important input data is a catalog of historical earthquakes, seismograms of (small) recent local earthquakes, which were instrumentally measured, paleoseismological studies, seismotectonic data and the model of geological medium including seismic velocities and attenuation of seismic waves. The computation is performed in four basic steps:

1. Definition of all relevant source zones based on seismological and geological databases and on seismotectonic model. This step was not done in South Ethiopia properly. Seismological databases are extremely incomplete. This is the main reason that the list of active tectonic faults, which can generate catastrophic earthquakes, is deficient.

2. Definition of magnitude-frequency distribution (Gutenberg-Richter law - GR law) for all source zones. This task has not been accomplished in South Ethiopia yet. Only average parameters of GR-law were derived for the whole region, while the specific parameters for individual zones are needed. Very important parameter is a maximal regional magnitude. It is unknown, but it is clear that it exceeds 7.

3. Definition of ground motion prediction equation (GMPE). Site-specific GMPEs does not exist for South Etiopia. However, this holds for many other regions. The average parameters of GMPE could be adopted from global databases. The situation in rift valley is complicated by the fact that it is filled with thick sedimentary layers, which amplify amplitudes of seismic waves. The shape of the valley affects the propagation of seismic waves significantly. GMPE has to reflect these facts.

4. Computation of Probabilistic Seismic Hazard Curves (PSHC) The computation involves many scenarios, which can occur in the future. The importance of individual source zones for seismic hazard are also evaluated. The results are presented in the form of curves, which describes the probability that the earthquake exceeds the defined value of Peak Ground Acceleration (PGA).

3. Historical seismicity

In South Ethiopia reliable descriptions of historical earthquakes are sparse. Available data were compiled by Gouin, 1979. In his paper, the territory of Ethiopia is divided to five seismic zones. The region under study belongs to the zone C – "Ethiopian Main Rift, Afar, and the Southern Red Sea". Most of earthquakes in this zone are connected with volcano eruptions. Earthquakes of big magnitudes are located mainly to the North part of the rift and to the Red Sea. However, it is due to the fact that written testimonials were better preserved in northern part of Ethiopia. Certainly, it does not exclude the possibility of big earthquake in the southern part of the rift. Gouin (1979) states: "No documents never equates to no earthquakes. This statement is supported by local Galia legends about former localities presumably destroyed by seismic tremors and now covered up by lakes. The legends are heard in the rift valley from Lake Zwai to Abbaya, and on its western escarpment in Gemu-Gofa".

The oldest documented earthquakes inside the rift in South Etiopia are two events from 25.8.1906. They represent also strongest observed earthquakes in the region. Teleseismic recordings show two important shocks on 25 August 1906; the first at U.T. 11:54:48 and the second 2 hours later at U.T.13:47:36. The magnitudes were 6.6 and 6.8 and the number of reporting stations was 30 and 40, respectively. Locations of epicenters are very poor. The most probable epicenter location is N 8.0°, E 38.5°, westward from the town Adami Tullu. During the 1906 period of seismic activity, a geyser started on the island O'a (N 07.5°, E 38.6°) in the northeastern bay of Lake Langano. At its birth, in 1906, the height of the hot water column was 25-30 m. Gouin (1979). This case documents a close conjuction of earthquakes and geothermal phenomena.

On 4 October, 1928, the earthquake with magnitude 6 was observed at the scarp of the rift, westward of lake Abaya. The most probable location is (N 7.0°, E 38.0°). The reports of magnitude 6 earthquake on 6 September 1944 are disputable (because of war). The location of epicenter is unfaithful, the error reaches 200 km. The most probable location is (N 7.0°, E 38.5°). It cannot be proved that the epicenter is situated inside the rift. On 14 July 1960 in 18:39 UT the earthquake with magnitude 6.3 was located inside the rift near Chabbi volcano. It was felled up to the distance of 200 km. The average location of epicenter is N 7.1°, E 38.4°.

Historical catalog from 1960 to 1980 contains also several smaller earthquakes with magnitudes between 4 and 5:

11 July 1964 (N 08.5°, E 39.3°)
11 January 1972 (N 6.8°, E 38,4°)
13 April 1972 (N 6.0°, E 37,7°)
8 March 1973 (N 7.7°, E 37,8°)
Seismic swarm in March 1974 (N 6.2°, E 37,7°)
30 June 1974 (N 6,3°, E 37,7°)

4. Instrumental records

Since 1973, a global catalog of earthquakes provided by United States Geological Survey (USGS) is available. However, earthquakes from South Ethiopia are not reported in the catalog before 1983. The Reported events from the catalogue are in Tab.1. From 1983 until present (2013) 13 earthquakes with magnitude more or equal to 4.4 are reported. The recent earthquakes from 19 December 2010 and 19 March 2011 were felt by many people despite the fact that they were relatively small with magnitude approximately 5. The epicenters are shown in the map.

DATE_TIME	LAT	LON	DEP	MAG
2011-10-17 01:03:25.61	7.643	37.868	10.0	4.4
2011-03-19 20:08:10.36	6.659	38.521	10.0	5.0
2010-12-19 12:14:24.51	7.521	37.839	10.0	5.1
2006-07-04 05:51:58.46	7.917	39.009	10.0	4.5
2005-07-07 16:57:57.40	6.289	37.697	10.0	4.7
1999-01-05 18:27:40.44	6.018	37.513	10.0	4.7
1995-01-20 07:14:27.20	7.160	38.441	13.8	5.0
1993-02-13 02:25:49.77	8.331	39.308	12.4	5.3
1991-07-26 15:33:38.46	7.570	37.665	10.0	4.4
1989-06-08 06:24:09.61	6.837	37.878	18.6	4.9
1987-10-07 22:29:24.58	6.223	37.814	10.0	5.3
1985-08-14 20:37:44.40	8.301	38.524	33.0	4.9
1983-12-02 23:08:39.49	7.030	38.599	10.0	5.1

Tab.1 Earthquakes of magnitude M>4.3 in the region (6°N - 8.5°N), (37.5°N - 39.5°N), according to USGS catalog.

5. Conclusion

Seismic hazard assessment for the Horn of Africa by probabilistic method was published by Kebede and van Eck (1997). In this paper, eight source zones are delineated. Zone 2 comprises the southernmost rifts of Ethiopia and the main Ethiopian rift and includes also the region under study in present paper. The upper bound magnitude for this zone was estimated to 7.0 with error 0.2. Probabilistic hazard curves were constructed for seven sites in the Horn of Africa, but there is no selected site in South Ethiopia. The nearest studied site is Addis Ababa (central Ethiopia), where the PGA of 150 cm/s2 was determined for annual probability of exceedance 10^{-3}. According to historical earthquakes distribution, it can be expected that seismic hazard in South Ethiopia is even higher than in Addis Ababa. Better estimation of seismic hazard can be done only after collection of more reliable input data.

Around lakes inside the rift, intensive urban development has been taking place, which is a very worrying process, considering seismic hazard. The subsoil at most populated localities is composed by lake sediments with extremely low S-wave velocities, which can amplify the amplitude of seismic waves several times comparing to bedrock sites. As was discussed in Chap. 3, the last stronger earthquake occurred in 1906, when the population of the region was much sparser and the urban houses were infrequent. The antiseismic measures are not applied satisfactorily during house construction and the public is not prepared for a strong earthquake. For these reasons, the South Ethiopia has to be considered as a region with high seismic risk.

6. Local seismic network project in South Ethiopia

Based on recognition of the Main Ethiopian Rift area in southern Ethiopia, significant seismic hazard was recognized and construction of local seismic network (SEN – South Ethiopia Network) is recommended. In the first step, the network should consist of central seismic antenna accompanied by 5 short-period seismic station located some 25–100 km from the central seismic antenna. In the following steps, this network may be extended by other stations covering finally the area of the Main Ethiopian Rift and Ethiopian part of the Gregory Rift.

The central seismic antenna consists of 4 three-component short-period seismic sensors connected to common central data acquisition unit. The distance between individual sensors reaches up to 150m, accordingly to expected prevailing wave lengths. This setting enables reduction of seismic noise and determination of the back-azimuths and phase velocities of the incident seismic waves. Field camp of the Geological Survey of Ethiopia in Shashemene was selected as a suitable location for this central seismic antenna (fig. 2). Sensors should be placed into shallow wells to reach the hard-rock basement. The locality has coordinates 7.2119° N, 3 8.5999°E.

Fig.1 Field camp of the Geological Survey of Ethiopia in Shashemene.

Fig.2 Senkelle Swayne's Hartebeest Sanctuary rangers camp.

Other seismic sensor should be placed in the campus of the Soddo University at coordinates 6.8287° N, 37.7517°E. Near the Shashemene, with an ambition to monitor the activity within the Corbetti caldera, another station should be placed in camp of Senkele Sanctuary rangers at coordinates 7.1977° N, 38.2720°E.

Seismic activity in the vicinity of Hawasa Town would be monitored by a station located on the Hill South of the town (with re-translation antennas) at coordinates 7.014° N, 38.496°E, fig.3.

Fig.3 Re-translation antennas at Hawasa.

Fig.4 Geothermal power-plant on Aluto Volcano.

The strongest earthquake documented in 1906 occurred near Butajira, where the next station should be placed. Newly re-constructed geothermal power-plant on the Aluto Volcano is supported by local network of temporary stations belonging to private company and not available for geohazard survey. For that reason, we recommend to place in the area of the power plant also one of the stations of the South Ethiopia Network (SEN), fig.4. The power plant has coordinates 7.7870° N, 38.7935°E. Last of the proposed seismic stations should be placed in the compound of Dodola Woreda bureau (6.979° N, 39.178°E). The locality is quiet and located on the eastern edge of the Rift.

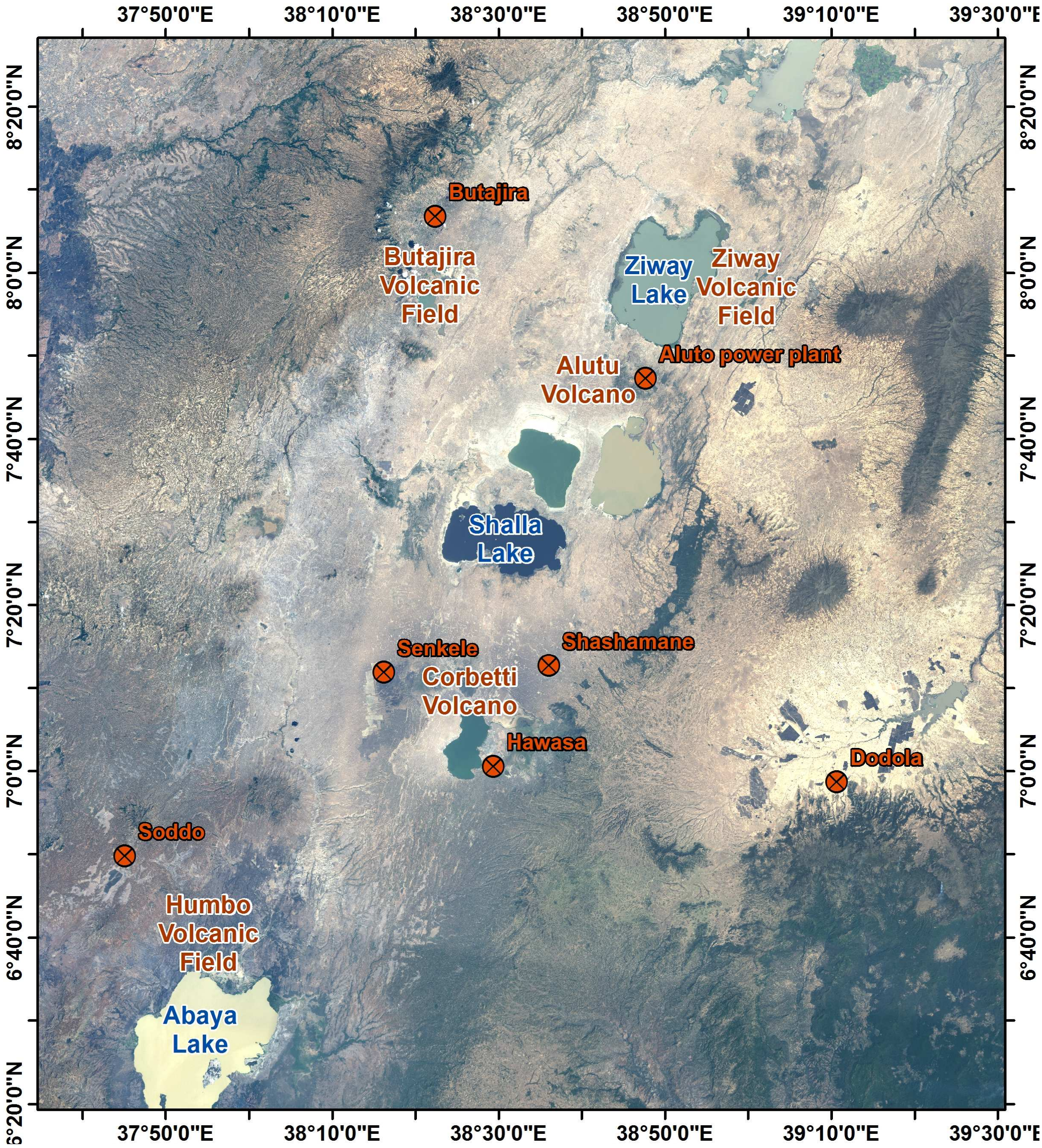

Fig.5 Map of proposed South Ethiopia Network (SEN).

Reference:

Gouin P. (1979): Earthquake history of Ethiopia and the Horn of Africa. Ottawa, Ont., IDRC, 259 p.