PSHA input model documentation for Sub-Saharan Africa (SSA)

GEM Hazard Team

Version history

Table 1 summarises version history for the SSA input model, named according to the versioning system described here, and indicating which version was used in each of the global maps produced since 2018. Refer to the GEM Products Page for information on which model versions are available for various use cases. The changelog describes the changes between consecutive versions and are additive for all versions with the same model year.

Table 1 – *Version history for the SSA input model.*

Version	2018.1	2019.1	2022.1	2023.1	Changelog
v2016.0.0					First version of the model. This version is described in Poggi et al. (2017)
v2018.0.0	X	X	X		New version of the model using smoothed seismicity and now also covering Madagascar.
v2018.0.1				X	Mmin extended to M4 for crustal distributed seismicity.

The following text describes v2018.0.1.

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1 Summary

The Sub-Saharan Africa (SSA) Earthquake Model was developed by GEM in collaboration with AfricaArray within the USAID-supported SSAHARA project. The original model is extensively described in Poggi et al. (2017), while an extended and improved version was developed in 2018 by introducing a procedure of earthquake-driven redistribution of activity rates (smoothed seismicity approach) on the previously defined source zones. Moreover, the current model includes now Madagascar, for which an ad-hoc seismicity analysis was carried out.

2 Tectonic overview

The East African Rift System (EARS) is an example of an active continental rift system. This divergent plate boundary runs roughly north-south through eastern Africa, separating the Nubian and Somalian plates. It intersects the Afar depression in northern Ethiopia, where a triple junction connects it north-west to the Red Sea rift and north-east to the Gulf of Aden rift, which extends as far as the Indian Ocean Ridge. Towards the south, the EARS splits into two branches—the eastern and western rifts—that bracket the Tanzanian craton. The eastern rift extends along the coast of Mozambique into the Indian Ocean, and eventually joins the Southwest Indian Ocean Ridge (SWIR). The western rift continues through Lake Malawi into central Mozambique, with several splays that extend into continental Africa. The EARS was likely initiated in the region from the present-day Turkana Rift during the mid-Tertiary. The Western branch of the EARS formed subsequently around 25 Myr, simultaneously with the Eastern branch, within a spreading process that is still on going and is responsible for the largest seismicity experienced in the Africa continent.

3 Basic Datasets

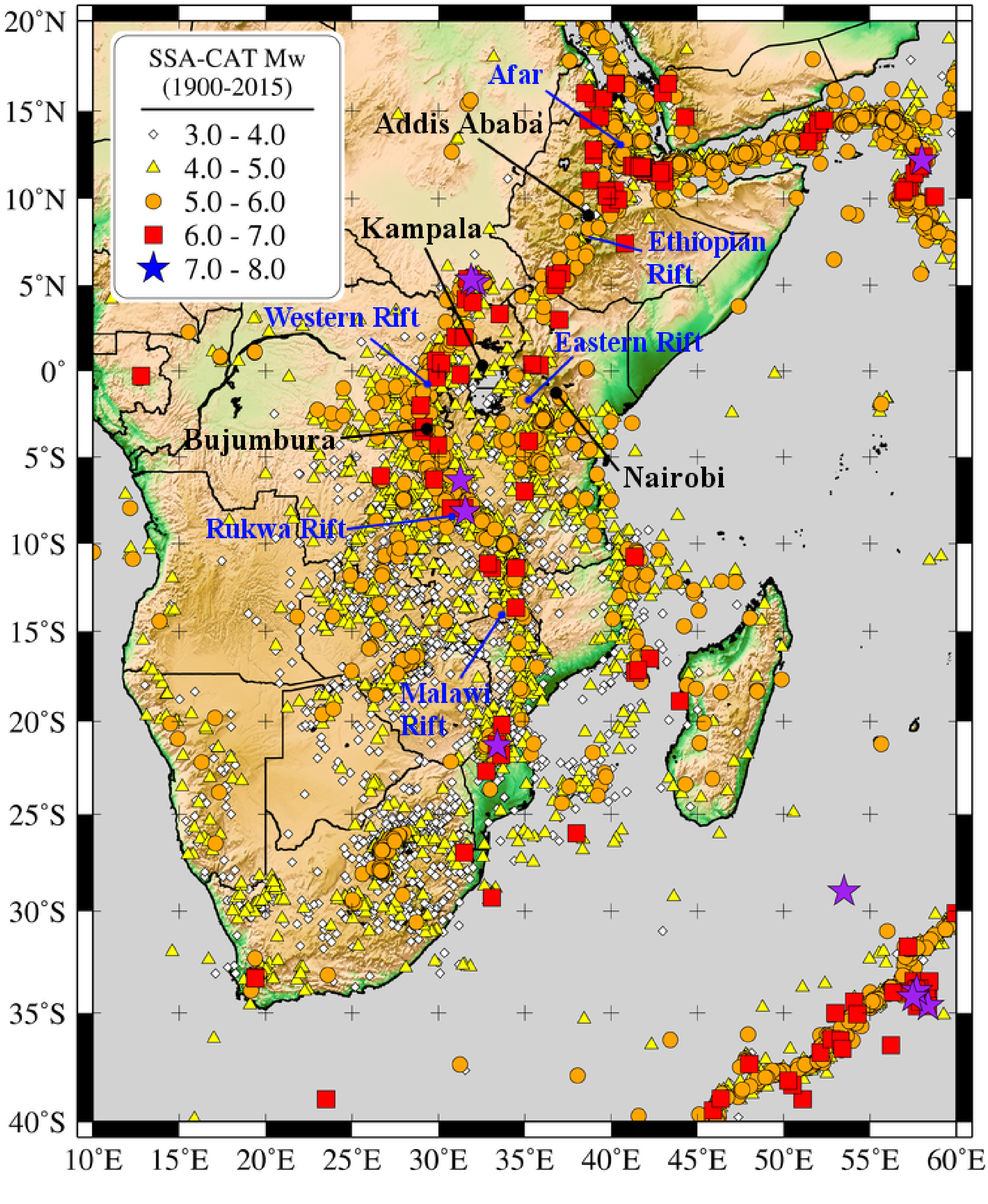
3.1 Earthquake Catalogue

An earthquake catalogue for Sub-Saharan Africa with homogenous magnitude representation (Mw) was obtained by merging available global catalogues (e.g. ISC-Reviewed, ISC-GEM, GCMT, GEM Historical Catalogue) with information from local agencies and regional projects, particularly from AfricaArray temporary deployments (e.g. The Tanzanian Broadband Seismic Experiment, The Ethiopian Plateau Catalogue, The AfricaArray Eastern Africa Seismic experiment).

The homogeneous catalogue (hereinafter SSA-GEM) was then declustered by removing fore- and aftershock sequences and seismic swarms, using the algorithm introduced by

Gardner and Knopoff (1974). The declustered SSA-GEM catalogue consists of 7,259 events out of the original 29,803 in the magnitude range $3 \geq M_w \geq 7.53$ (Figure 1).

Figure 1 *– Distribution of earthquake events (Mw > 3) from the homogenised SSA-GEM earthquake catalogue. Names of the major rift systems associated with seismicity are indicated on the map with blue labels.*



4 Hazard Model

4.1 Seismic Source Characterisation

Area Sources The study area was initially discretised into 21 independent source zones (Figure 2), following the guidelines proposed by Villanova et al. (2014) that provide a set of objective criteria to delineate regions of supposedly homogenous seismic potential. The main constraint for the development of the source model came from the analysis of the earthquake catalogue (stationarity of the completeness periods, evaluation of the mean activity rate, distribution of seismogenic depths) and from a set of geological and seismotectonic considerations, such as style, geometry, and distribution of existing faulting systems and their relation to the local stress and deformation regimes.

The source zones were gathered into six main tectonic domains, assumed to have comparable rheological and mechanical behaviour with respect to the underlying crustal geology under the regional stress regime. Source grouping is particularly useful for earthquake occurrence analysis in low seismicity regions, where the limited earthquake record might be insufficient for the proper calibration of poorly constrained seismicity parameters, such as the maximum magnitude or the slope (b-value) of the assumed frequency-magnitude occurrence model. Tectonic grouping was also used for the regional characterization of main faulting style and hypocentral depth distribution of the seismic source model.

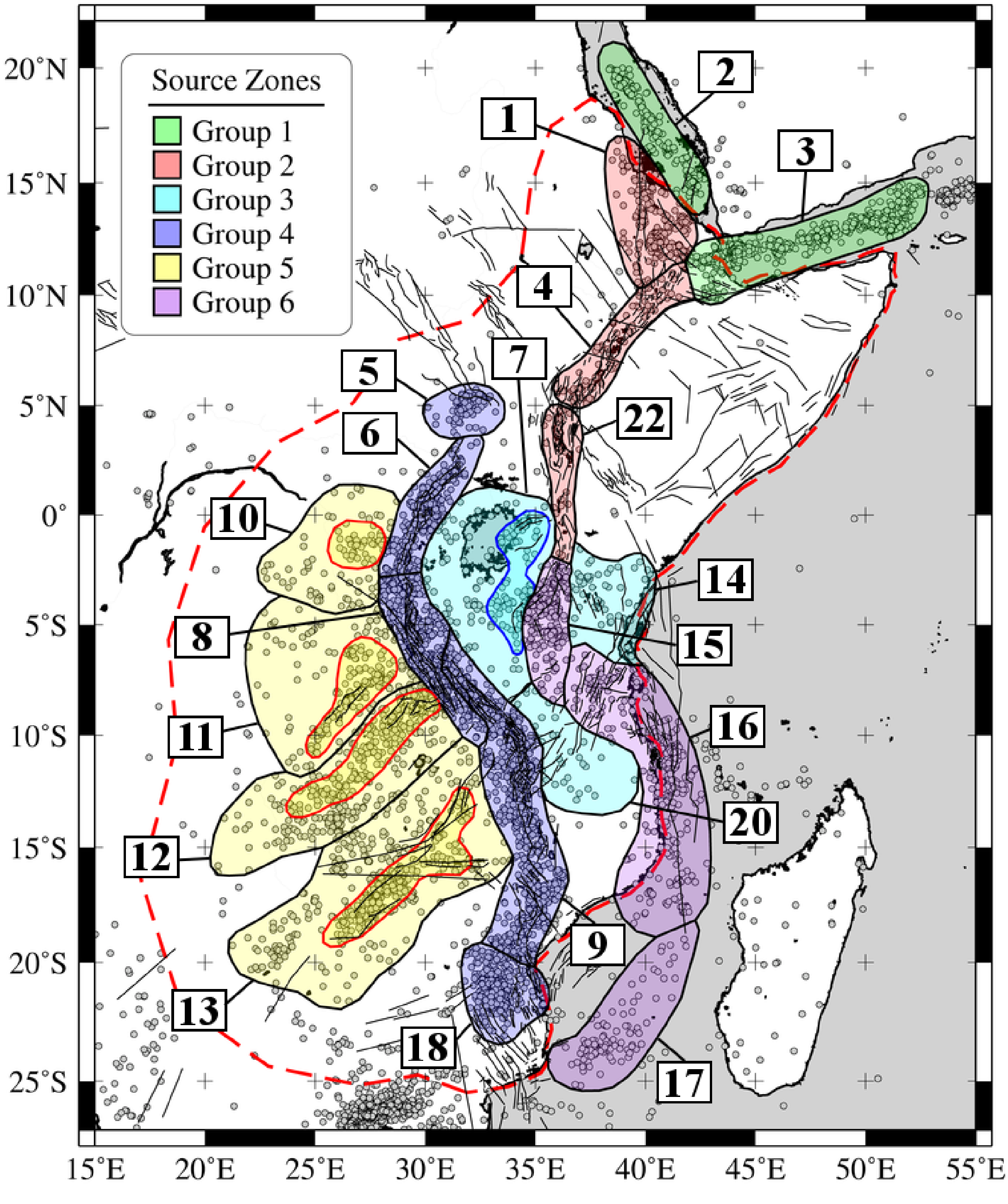
Seismicity Parameters Seismicity in each area source is assumed to follow a double truncated Gutenberg-Richter magnitude occurrence relation (or magnitude-frequency distribution, MFD). Lower truncation is arbitrarily assigned to Mw 4.5.

Gutenberg-Richter b-values were calibrated for the whole catalogue and independently for each source group. Conversely, occurrence rates (a-values) were calculated separately for each source zone by imposing the previously calibrated b-values.

A different maximum magnitude (Mw-Max) estimate is derived independently for each source group as the largest observed event plus an arbitrary - although quite conservative - increment of 0.5 magnitude units. Seismiciy parameters are summarised in Table 2.

Smoothed Seismicity In a second step, to better represent the spatial variability of seismicity across the study area, the annual occurrence rates previously obtained for the homogeneous source zones were redistributed within each polygon using a procedure that accounts for the irregular spatial pattern of the observed events. The procedure shares some similarity with the popular smoothed seismicity approach (e.g. Frankel, 1995), but is more convenient in that a unique fit of the MFD is required for each zone, while the corresponding total earthquake occurrence is a-posteriori spatially reorganised as a function of the epicentral distance to all neighbouring events. Moreover, the combined use of zones

Figure 2 *– Source zonation model used in this study. Area sources belonging to the same tectonic group are represented with the same colour. The outermost red dashed line marks the PSHA calculation area. In the background is the SSA-GEM homogenised catalogue (non-declustered, Mw > 3) and the faults from the database of Macgregor (2015).*



Group	Source	a-Value	b-Value	Mw-Max
1	2	4.83	1.02	7.2
	3	5.38		
2	1	4.48	0.95	7.5
	4	4.18		
	22	3.70		
3	7	4.00	1.02	6.9
	7.1	4.23		
	14	4.34		
	20	3.31		
4	5	4.22	1.02	7.9
	6	4.89		
	8	4.84		
	9	4.93		
	18	4.40		
5	10	3.90	0.99	6.9
	10.1	3.92		
	11	3.51		
	11.1	3.93		
	12	4.05		
	12.1	4.13		
	13	4.08		
	13.1	3.99		
6	15	5.31	1.16	7.4
	16	5.45		
	17	4.77		

Table 2 – *Seismicity parameters used in the SSA model. Mmax and b-values are consistent within source groups.*

gives the possibility to account for different modelling parameters (b-value, depth distribution, rupture mechanism) in separate regions.

4.2 Ground Motion Characterisation

Table **??** shows the ground motion logic tree, which distinguishes between two main tectonic domains: active shallow crust (ASC) for areas involving plate boundary segmentation, and and stable crust (SCC) for intra-plate areas. These correspond to *Tectonic_Type_A* and *Tectonic_Type_E*, respectively. Other tectonic regions, *Tectonic_Type_B*, *Tectonic_Type_C* and *Tectonic_Type_D*, are prescribed for transition zones of intermediate characteristics between SCC and ASC, in order to avoid abrupt variations of ground motion predicted by GMPEs calibrated for different tectonic settings.

Epistemic Uncertainties For every tectonic region, epistemic uncertainty is considered by using multiple GMPEs, each with an associated logic tree weight. Four GMPEs were selected for this study, two models for ASC (Chiou and Youngs 2014; Akkar et al., 2014) and two models for SCC (Atkinson and Boore, 2006; Pezeshk et al., 2011). All GMPEs are assigned to each source zone, with the corresponding logic-tree weight varying with the likelihood for each specific tectonic type. Assignment of weights was agreed on the basis of the direct judgement of local seismotectonic conditions by a pool of experts from the region.

Tectonic_Type_B	**Weight**
AkkarEtAlRjb2014	0.375
PezeshkEtAl2011NEHRPBC	0.125
AtkinsonBoore2006Modified2011	0.125
ChiouYoungs2014	0.375
Tectonic_Type_A	**Weight**
AkkarEtAlRjb2014	0.5
ChiouYoungs2014	0.5
Tectonic_Type_D	**Weight**
AkkarEtAlRjb2014	0.125
PezeshkEtAl2011NEHRPBC	0.375
AtkinsonBoore2006Modified2011	0.375
ChiouYoungs2014	0.125
Tectonic_Type_C	**Weight**
AkkarEtAlRjb2014	0.25
PezeshkEtAl2011NEHRPBC	0.25
AtkinsonBoore2006Modified2011	0.25
ChiouYoungs2014	0.25
Tectonic_Type_E	**Weight**
PezeshkEtAl2011NEHRPBC	0.5
AtkinsonBoore2006Modified2011	0.5

Table 3 *– GMPEs used in the SSA model.*

5 Results

Hazard curves were computed with the OQ engine for the following:

- Intensity measure types (IMTs): peak ground acceleration (PGA) and spectral acceleration (SA) at 0.2s, 0.3s, 0.6s, 1.0s, and 2s
- reference site conditions with shear wave velocity in the upper 30 meters (Vs30) of 760-800 m/s, as well as for Vs30 derived from a topography proxy (Allen and Wald, 2009)

Hazard maps were generated for each reference site condition-IMT pair for 10% and 2% probabilities of exceedance (POEs) in 50 yrs. Additionally, disaggregation by magnitude, distance, and epsilon was computed for the following cities: Kigali, Asmara, Addis Ababa, Kampala, Lusaka, Nairobi, Juba, Harare, Dar es Salaam, Moroni, Antananarivo, Mamoutzou, Lilongwe, Bujumbura and Djibouti. The results were produced as csv files and bar plots for each of the following combinations:

- hazard levels for 10% and 2% POE in 50 yrs
- PGA and SA at 0.2s, 0.3s, 0.6s, and 1.0s
- Vs30=800 m/s

All calculations used a ground motion sigma truncation of 5. Results were computed for sites with 6 km spacing

Visit the GEM Interactive Viewer to explore the Global Seismic Hazard Map values (PGA for Vs30=800 m/s, 10% poe in 50 years). For a comprehensive set of hazard and risk results, see the GEM Products Page.

6 References

Allen, T. I., and Wald, D. J., 2009, On the use of high-resolution topographic data as a proxy for seismic site conditions $Vs30$, Bulletin of the Seismological Society of America, 99, no. 2A, 935-943

Poggi, V., Durrheim, R., Mavonga Tuluka, G., Weatherill, G., Gee, R., Pagani, M., Nyblade, A., Delvaux, D., 2017. Assessing Seismic Hazard of the East African Rift: a pilot study from GEM and AfricaArray. Bulletin of Earthquake Engineering. Volume 15, Issue 11, 4499–4529, DOI: 10.1007/s10518-017-0152-4

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