GLOBAL EARTHQUAKE MODEL
working together to assess risk

PSHA input model documentation for Northern Africa (NAF)

GEM Hazard Team

Version history

Table 1 summarises version history for the NAF 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 NAF input model.*

Version	2018.1	2019.1	2022.1	2023.1	Changelog
v2017.0.0					First version of the model developed by GEM.
v2017.1.0	X	X	X		Updated version of the model which is described in Poggi et al. (2020).
v2017.1.1				X	Mmin extended to M4 for crustal distributed seismicity. Source ids were revised to work with disaggregation by source.

The following text describes v2017.1.1.

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1 Summary

The Northern Africa model (NAF) was developed by GEM and is described in Poggi et al. (2020). The model extends form Morocco to Egypt along the Mediterranean coastline. The model consists of a combination of distributed seismicity and faults sources, the former calibrated on occurrence analysis of publicly available earthquake catalogue information, and the latter derived from a thorough evaluation of information from both geological literature and direct analysis of GPS velocity fields.

2 Tectonic overview

Unlike the internal parts of the continent, which are characterised by the presence of large and stable cratons of Precambrian origin, the northern margin of Africa is known to be tectonically active. The complex interaction between the Nubian and Eurasian plates, structurally varying from fold-and-thrust in the west, to a mixture of strike-slip and extensive motion to the east, is responsible for large crustal deformations, often associated with the development of moderate on- and off-shore seismicity. Several earthquakes causing non-negligible damage and fatalities are reported in a wide seismic belt of more than 5000km, extending almost continuously from Morocco to Egypt. As a matter of fact, after the East African Rift System (EARS), North Africa is recognized as the second most hazardous province of the continent.

3 Basic Datasets

3.1 Earthquake Catalogue

For the purpose of having a unique catalogue for northern Africa, GEM created a new Mw-homogenised earthquake catalogue by assembling globally and locally available sources. The GEM implementation of the North Africa Earthquake Catalogue (hereinafter GEM-NAEC) consists of 5170 events with $4 \geq M_w \geq 8.5$, covering a period from 1016 to 2013 (Figure 1).

3.2 Fault Database

In order to provide sources for fault-based PSHA, a new dataset of active faults in northern Africa was created, containing ~135 active fault traces (Figure 2). Faults were mapped on topographic data (typically 30m SRTM) based on mapping in the literature as well as interpretation of topographic, seismic and geodetic data. The faults are publicly available on GitHub in a variety of GIS formats. Slip rates were estimated for all structures even if no

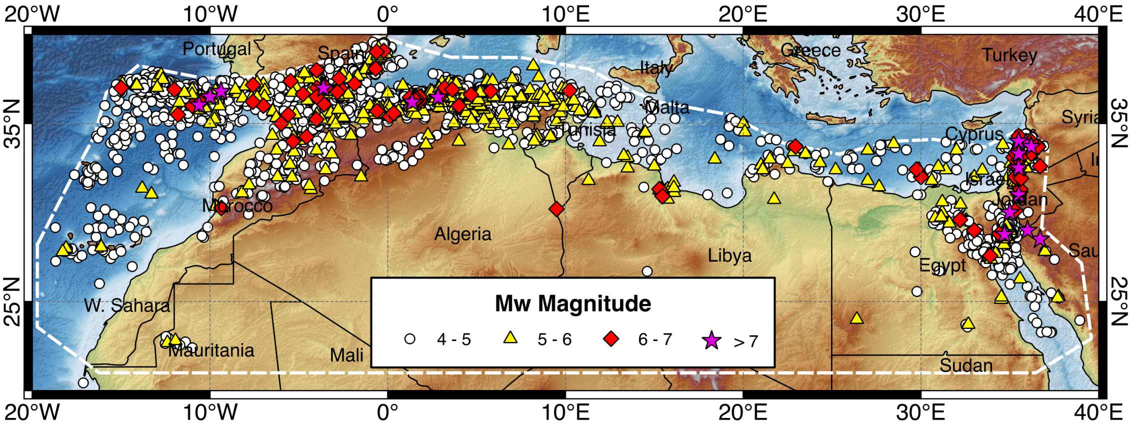


Figure 1 *– The Mw-homogenized earthquake catalogue proposed by GEM (GEM-NAEC).*

published rates were available. Slip rate estimates were made through expert judgement of the geodetic and seismic data, as well as consideration of geomorphic expression.

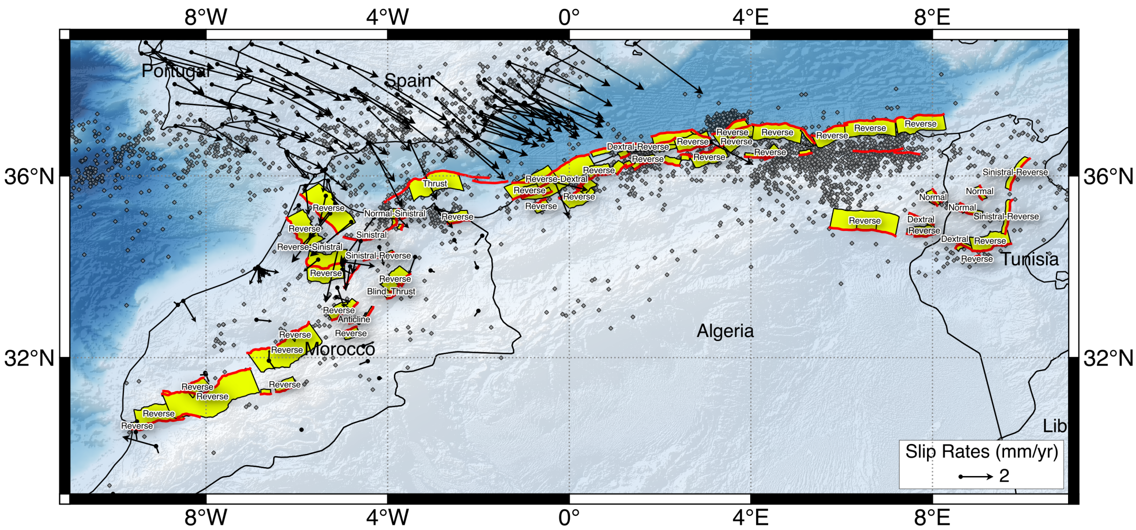


Figure 2 *– The GEM active fault database for North Africa. Measured GPS velocities are shown with black arrows.*

4 Hazard Model

4.1 Seismic Source Characterisation

Area Source Zonation The Northern Africa earthquake source model consists of a combination of distributed seismicity and finite faults. The study area was initially discretised into 54 independent source zones (Figure 3). 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. Local and regional source models from previous hazard studies were also taken into consideration as a starting point for the proposed zonation, and to assure compatibility across the borders, particularly with the SHARE (Woessner et al., 2015) and EMME (Giardini et al., 2016) models.

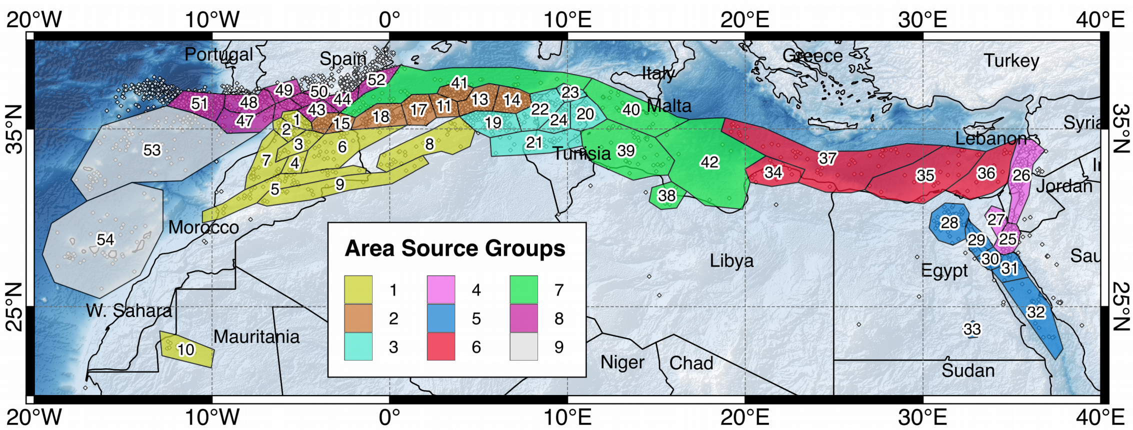


***Figure 3** – The proposed source zonation for North Africa. Different colours are used to represent the 9 main tectonic groups of the region.*

The 54 source zones were then gathered into nine 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 (Poggi et al., 2017), 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. Additionally, tectonic grouping was also used for the regional characterization of main faulting style and hypocentral depth distribution of the seismic source model.

Seismicity Analysis 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 have been calibrated for the whole catalogue and independently for each source group. Conversely, occurrence rates (a-values) have been calculated separately for each source zone by imposing the previously calibrated b-values. A different maximum magnitude (M_{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. Seismicity parameters are summarised in Table 2.

Group	Source	a-Value	b-Value	M_{max}
1	1	4.31	1.1	6.9
	2	4.08		6.9
	3	4.39		7.2
	4	4.01		5.7
	5	4.45		6.9
	6	4.08		5.8
	7	3.92		6
	8	4.09		6.3
	9	4.22		6.11
	10	4.15		5.58
2	11	4.09	0.98	7.8
	12	3.76		7.34
	13	4.47		7
	14	4.34		6.33
	15	3.89		6.3
3	16	3.72		6.86
	17	4.11		7.6
	18	4.12		7.5
4	19	3.64	0.93	6.5
	20	3.41		6.3
	21	3.83		5.83
	22	3.81		6.3
	23	3.13		7.5
	24	3.39		6.3
5	25	3.67	0.99	7.71
	26	4.06		8.15
	27	3.37		5.3
	28	4.18	1.11	7.16
	29	4.12		6.7
	30	4.35		7.1
	31	4.27		5.4
	32	3.99		6.01
	33	3.72		6.33
6	34	3.42	0.96	6.13
	35	3.61		6.73
	36	3.27		6.38
	37	3.88		6.87
7	38	4.27	1.13	7.3
	39	4.54		6.32
	40	4.25		5.3
	41	4.52		5.97
	42	4.09		6.4

8	43	4	1.07	7.2
	44	3.99		7
	45	4.23		7.3
	46	4		5.9
	47	3.95		7.2
	48	4.5		7.1
	49	3.83		6.6
	50	4.24		8.3
	51	4.75		9
	52	3.99		7.2
9	53	4.87	1.12	6.8
	54	4.74		5.75

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

Smoothed Seismicity To better represent the spatial variability of seismicity across the study area, the annual occurrence rates previously obtained for the homogeneous source zones have been redistributed within each polygon using a procedure that accounts for the irregular spatial pattern of the observed events (Figure 4). 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 gives the possibility to account for different modelling parameters (b-value, depth distribution, rupture mechanism) in separate regions.

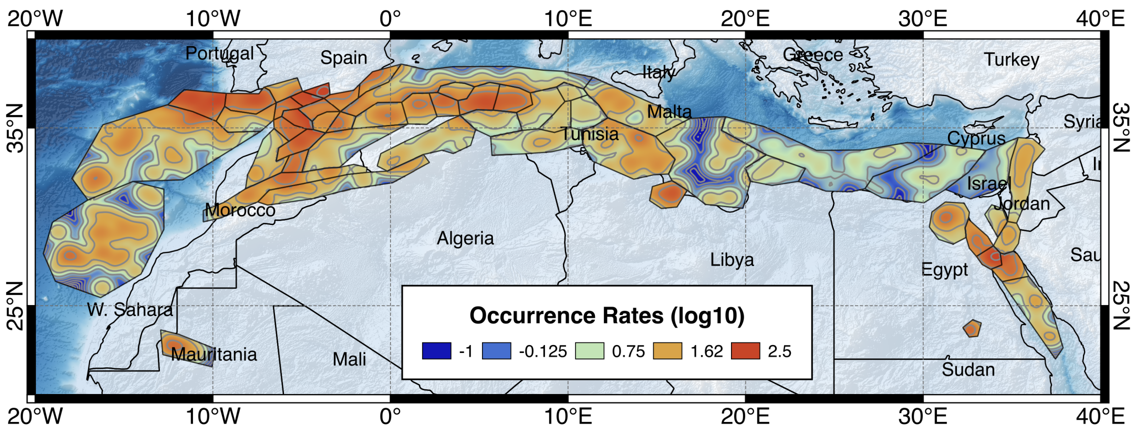


Figure 4 *– Example of spatial redistribution of the cumulative annual rates (M > 0) using a decay parameter (λ) of 100.*

4.2 Ground Motion Characterisation

A combination of different seismotectonic conditions is expected for northern Africa. While a low-attenuation stable continental crust (SCC) is to be expected in the most internal part of the continent, active shallow crust (ASC) conditions are likely at the more seismically active regions close to plate boundaries, such as the mountain chain of the Rif and Tell Atlas and regions surrounding the Red Sea. In this study, we rely on the global tectonic zonation proposed by Chen et al. (2017). Using this approach, North African source zones have been classified either as ASC (*Tectonic_Type_A*) or SCC (*Tectonic_Type_C*). An additional buffer region (*Tectonic_Type_B*) is also 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. Table **??** shows the ground motion logic tree.

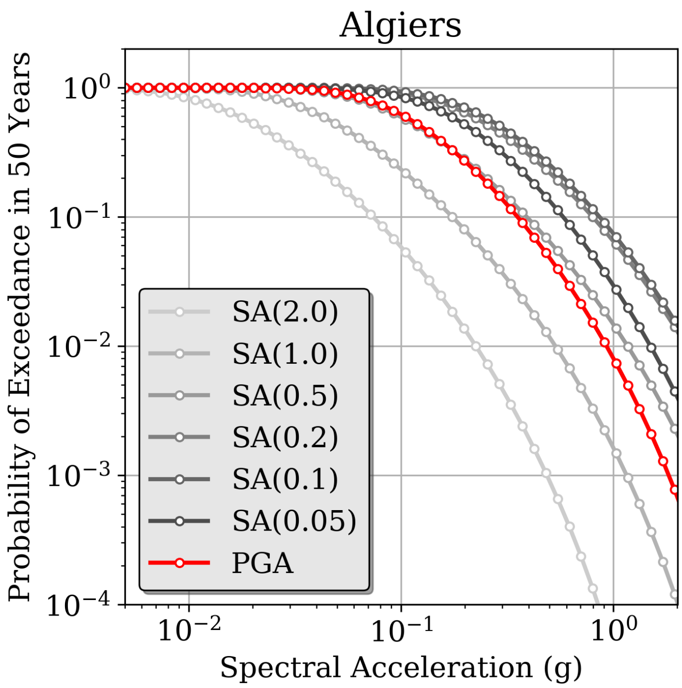
Epistemic Uncertainties Following this classification, the same combination of GMPEs selected in Poggi et al. (2017) has been used in a logic-tree approach, with two models for ASC (Chiou and Youngs 2014; Akkar et al., 2014) and two models for SCC (Atkinson and Boore, 2006; Pezeshk et al., 2011).

Tectonic_Type_B	**Weight**
AkkarEtAlRjb2014	0.25
PezeshkEtAl2011NEHRPBC	0.25
AtkinsonBoore2006Modified2011	0.25
ChiouYoungs2014	0.25
Tectonic_Type_A	**Weight**
AkkarEtAlRjb2014	0.5
ChiouYoungs2014	0.5
Tectonic_Type_C	**Weight**
PezeshkEtAl2011NEHRPBC	0.5
AtkinsonBoore2006Modified2011	0.5

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

5 Results

Hazard curves are shown for some selected sites in Figure 5.



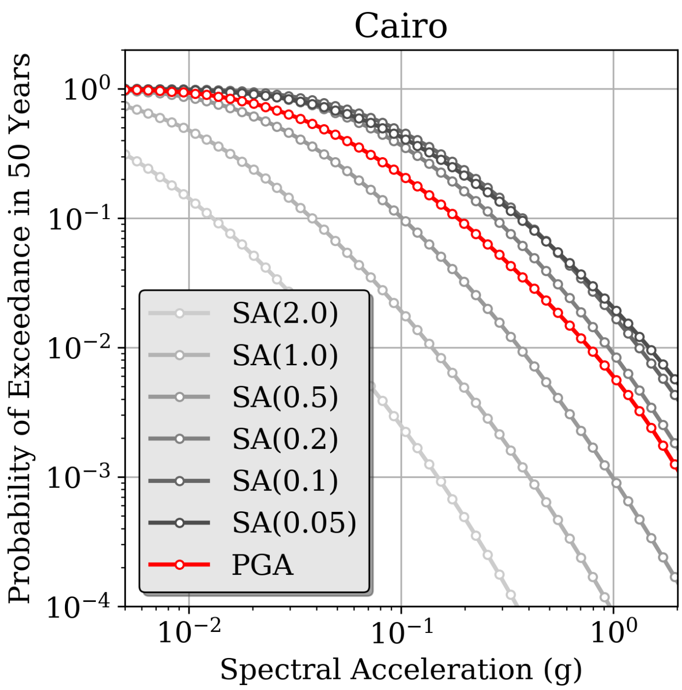


Figure 5 *– Example of hazard curves calculated at different spectral periods for two main North African capitals.*

6 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: Cairo, Algiers, Tunis, Tripoli and Rabat. 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.

7 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. doi:10.1007/s10518-017-0152-4.

Poggi, V., Garcia-Peláez, J., Styron, R. et al. (2020) A probabilistic seismic hazard model for North Africa. Bull Earthquake Eng. https://doi.org/10.1007/s10518-020-00820-4

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