Automatic calibration tool R-FSLAM

The R-FSLAM calibration module was build based on the original model FSLAM (https://github.com/EnGeoModels/fslam). Figure 1 shows the general workflow of R-FSLAM. For each parameter, the lower and upper boundaries must be specified in the R code. As they are physical parameters, these boundaries should be set considering realistic values that represent their physical characteristics. Furthermore, the module allows to visualize the Pareto curve of the specified number of nominal solutions, and the spatial results of the landslides events considering a threshold of >0.5 of the PoF to identify them. (for further details of FSLAM is recommend to read Medina et al. (2021)).

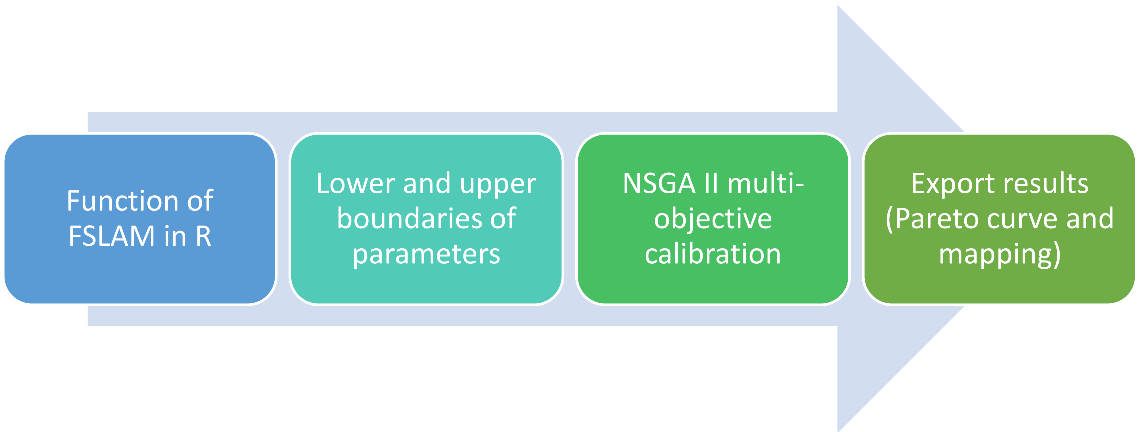

Figure 1. Workflow of the R-FSLAM calibration module.

The R-FSLAM calibration module run the model in R language and perform a multi-objective calibration (for the pre- and post-rainfall event susceptibility maps) to obtain the best parameter set based on the selected objective function (e.g. accuracy). In addition, sensitivity (True Positive Ratio – TPR) and specificity (True Negative Ratio – TNR) indices are calculated. The module can calibrate ten parameters in its preliminary version:

- Effective cohesion, which it is indicated as a multiplicative factor for the default values.
- Apparent cohesion, which it is indicated as a multiplicative factor for the default values.
- Soil depth, which it is indicated as an absolute change factor for the default values.
- Friction internal angle, which it is indicated as an additive factor for the default values.
- Effective antecedent recharge, which it is indicated as a multiplicative factor for the default values.
- Rainfall event recharge, which it is indicated as a multiplicative factor for the default values.
- Saturated hydraulic conductivity, which it is indicated as a multiplicative factor for the default values.
- Porosity, which it is indicated as an additive factor for the default values
- Curve number, which it is indicated as a multiplicative factor for the default values.

Either multiplicative or additive factor are applied to the default soil values. An example of these values is showed in the tables below.

Table 1. Soil table with initial parameter values (by default) for each soil type.

Index	Ks (m/s)	C_max (kPa)	C_min (kPa)	Phi_max (degree)	Phi_min (degree)	z (m)	Density (kg/m^3)	Porosity (m^3/m^3)	HSG
1	0.000001	0	5	20	40	1	2000	0.3	C
2	0.00001	0	3	25	45	1	2000	0.3	C
3	0.0001	0	3	35	45	1	2000	0.35	B
4	0.001	0	2	35	45	1	2000	0.4	A

Table 2. Land use table with initial parameter values (by default) for each land use type.

Index	Cr_max (kPa)	Cr_min (kPa)	A	B	C	D
			CN	CN	CN	CN
1	0	5	30	59	73	79
2	0	3	32	58	72	79
3	0	2	49	69	79	84
4	0	3	43	65	76	82
5	0	1	56	68	80	84
6	0	1	90	92	96	98
7	999	999	100	100	100	100

R-FSLAM allows to visualize Pareto curve (as showed in Figure 2) where all possible parameters set solutions (as points), that satisfies the objective function, are plotted in the Pareto front.

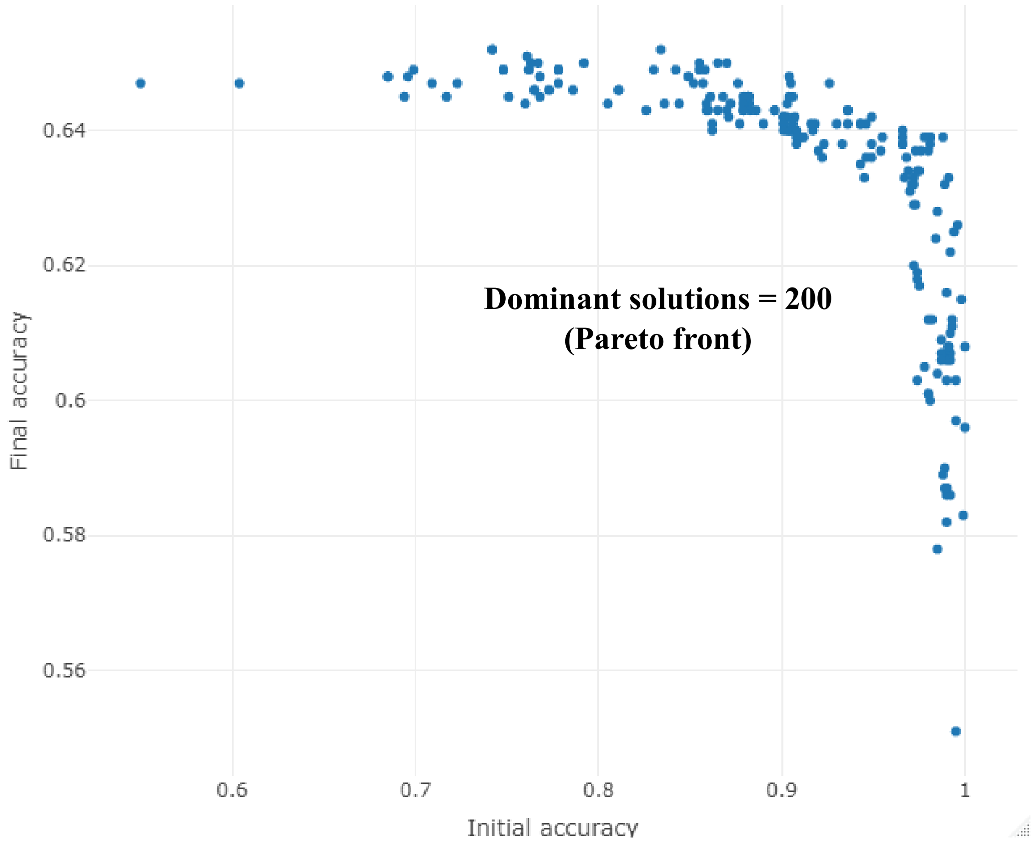

Figure 2. Pareto curve showing the most optimal solution based on the objective function (e.e accuracy, AUC) in pre-event rainfall conditions (initial) and post-event rainfall conditions (final).

The NSGA function implemented in “nsga2R” library, allows the user to specify objective function to be minimized, the number of parameters to be calibrated, the number of objective functions, number of generations, the population size of no-dominant solution represented in the Pareto curve, and the lower and upper parameter boundaries. Those arguments of the “nsga2R” function are up to be chosen by the user, whose values (specially number of generations) depends on the computational capacity. Further details of NSGA-II can be found in Ercan and Goodall (2016). In this research, the algorithm was implemented through the R library “nsga2R” (Tsou and Lee 2013).

R-FSLAM works at point level, therefore before running the calibration module, data regarding soil type, land use, effective recharge, curve number, and properties derived from digital elevation model (slope, upstream area) must be extracted for each point and put it as table (e.g. as a csv file). Those values can be obtained from FSLAM (GIS results output raster), and then extracted from the evaluated points (e.g. landslides inventory). Furthermore, each point must indicate whether it is categorized as landslide (1) or no-landslide (0). The table (format showed in Table 3) is taken as a reference table to compare with simulated results. The simulated results are estimated by an inner R-FSLAM algorithm which performs a binary classification to identify stable (0) and unstable (1) points. This discrimination is based on the chosen PoF threshold which is 0.5 by default, and the one used for this research. Points with PoF threshold < 0.5 and > 0.5 represent no-landslide and landslide conditions respectively.

Table 3. Example of reference Table to be used by applying R-FSLAM. 'x' and 'y' represent the coordinates; 'des' is the point label (0=no-landslide, 1=landslide); 'area' is the upstream catchment area of each point; 'soil' and 'lucl' represent the soil type and land use associated to a value (their respective raster classification), 'Pa' and 'Pe' are the Antecedent and Event precipitation for each poinr respectively; and 'CN' is the curve number.

x	y	des	area	slope	soil	lucl	Pa	Pe	CN
250787.4	1811238.4	1.0	208.9	0.7	1.0	3.0	5.4	296.0	79.0
250777.4	1811213.4	1.0	209.0	0.7	1.0	3.0	5.4	296.0	79.0
250897.4	1811338.4	1.0	262.7	0.6	1.0	3.0	5.4	296.4	79.0
250932.4	1811313.4	1.0	94.4	0.4	1.0	3.0	5.4	296.4	79.0
249572.4	1808523.4	1.0	201.6	0.6	1.0	3.0	5.4	292.3	79.0
249062.4	1808563.4	1.0	123.3	0.3	1.0	3.0	5.4	292.1	79.0

Additionally, the outputs susceptibility maps are plotted to visualize landslides conditions before and after the rainfall event. An example of susceptibility maps, created by using leaflet in R, are showed in Figure 3

Figure 3.

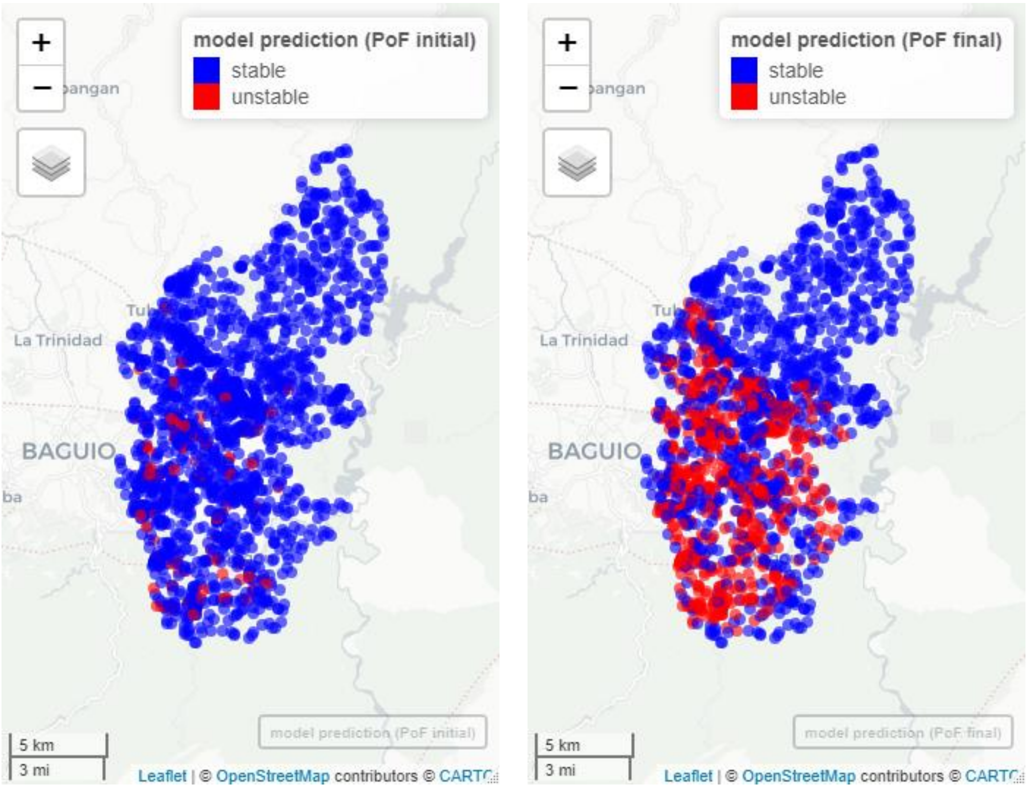

Figure 3. Susceptibility maps outputs of R-FSLAM calibration module for the total assessed points (e.g. landslide inventory). Left: Initial conditions (pre-rainfall event). Right: Final conditions (post rainfall event).

Pre-rainfall event conditions show more stable points (blue), on the other hand the post-rainfall event conditions show more unstable points (in red) which represent the landslides. Figure 3 shows a typical successful calibration due to the expected results must show more stable conditions before the rainfall event.

Moreover, R-FSLAM allows to calibrate the model in no-landslide event conditions. In this case, the expected results should show more stable conditions (blue color) in both susceptibility maps.

The preliminary version of the R-FSLAM calibration module includes three main functions:

- **'fslam_fit' function**: this function allows the user to perform NSGA-II calibration considering two objective function (accuracy) for the pre-rainfall event and post-rainfall event susceptibility maps. Maximize accuracy in both cases for the points set.
- **'fslam_fit_no_morle' function**: this function allows the user to perform NSGA-II calibration considering two objective function (accuracy) for the pre-rainfall event and post-rainfall event susceptibility maps. As it is no-landslide event conditions, no landslide should be expected and, therefore, the code internally labels all the points set as no-landslides ('des'=0) regardless they were categorized as landslide ('des'=1) before.
- **'fslam_map' function**: This function allows to visualize the susceptibility maps results for the pre-rainfall and post-rainfall event in an interactive way. This function was built using 'Mapview' library in R, which allows the user to change the background and zoom in the map.

Further details of codes can be found in the attached files.

References

Medina V, Hürlimann M, Guo Z et al (2021) Fast physically-based model for rainfall-induced landslide susceptibility assessment at regional scale. CATENA 201:105213. https://doi.org/10.1016/j.catena.2021.105213

Ercan, M. B., & Goodall, J. L. (2016). Design and implementation of a general software library for using NSGA-II with SWAT for multi-objective model calibration. Environmental Modelling & Software, 84, 112-120. https://doi.org/10.1016/j.envsoft.2016.06.017

Tsou, C.-S. V. and Lee, M. M.-C. A. (2013). Package 'nsga2r'.