FingerPro unmixing model

FingerPro, developed by the **EESA research group** (Erosion and Evaluation of Soil and Water), builds on more than 16 yr of methodological advances in sediment mixing models at the Spanish National Research Council **(CSIC)**, Experimental Station of Aula Dei (EEAD), Zaragoza, Spain.

Tips (Methodological Principles)

- ✓ In fingerPro, a fundamental idea is that **each mixture must be analysed independently**. The tracer selection explicitly depends on the combined information from both the sources and the mixture. Therefore, tracer selection methods must be performed separately for each mixture. The optimum tracers for one mixture are not necessarily suitable for other mixtures and this reflects the adaptation of the model to the specific characteristics of each dataset.
- ✓ Comparisons between mixtures are not affected by the use of different optimum tracers. Even at the same location, variations in sampling time (e.g. seasonal variability or hydrological conditions) may lead to differences in tracer signals and therefore require different tracer selections.
- ✓ Another important aspect of fingerPro is that **the user plays an active role in the decision-making process**. At different stages of tracer selection, decisions must be made based on the interpretation of the dataset and the results. These decisions directly determine the subsequent steps in identifying the most suitable optimum tracers.

fingerPro: Unmixing Model Framework

Quantifies the provenance of sediments by applying a mixing model algorithm to end sediment mixtures based on a comprehensive characterization of the sediment sources. The 'fingerPro' model builds upon the foundational concept of using mass balance linear equations for sediment source quantification by incorporating several distinct technical advancements. It employs an optimization approach to normalize discrepancies in tracer ranges and minimize the objective function. Latin hypercube sampling is used to explore all possible combinations of source contributions (0-100%), mitigating the risk of local minima. Uncertainty in source estimates is quantified through a Monte Carlo routine, and the model includes additional metrics, such as the normalized error of the virtual mixture, to detect mathematical inconsistencies, non-physical solutions, and biases. A new linear variability propagation (LVP) method is also included to address and quantify potential bias in model outcomes, particularly when dealing with dominant or non-contributing sources and high source variability, offering a significant advancement for field studies where direct comparison with theoretical apportionments is not feasible. In addition to the unmixing model, a complete framework for tracer selection is included. Several methods are implemented to evaluate tracer behaviour by considering both source and mixture information. These include the Consistent Tracer Selection (CTS) method to explore all tracer combinations and select the optimal ones improving the robustness and interpretability of the model results. A Conservative Balance (CB) method is also incorporated to enable the use of isotopic tracers. The package also provides several graphical tools to support data exploration and interpretation, including box plots, correlation plots, Linear Discriminant Analysis (LDA) and Principal Component Analysis (PCA).

Version:	2.1
Depends:	R (≥ 3.5)
Imports:	Rcpp (≥ 0.11.3), klaR (≥ 0.6-12), ggplot2 (≥ 2.2.1), GGally (≥ 1.3.2), plyr (≥ 1.8.4), MASS (≥ 7.3-45), reshape (≥ 0.8.7), grid (≥ 3.1.1), gridExtra (≥ 2.3), scales (≥ 0.5.0), car (≥ 3.0.0), RcppProgress (≥ 0.4), Ternary (≥ 1.2.2), dplyr (≥ 1.0.7), crayon (≥ 1.4.2), plotly (≥ 4.10.3)
LinkingTo:	Rcpp, RcppGSL, RcppProgress
Suggests:	knitr, rmarkdown
Published:	2026-04-15
DOI:	10.32614/CRAN.package.fingerPro
Author:	Borja Latorre (Core Team) [aut, cre], Leticia Gaspar (Core Team) [aut], Ivan Lizaga [aut], Leticia Palazon [aut], Vince Q Vu [ctb], Ana Navas (Core Team) [aut, fnd, ths]
Maintainer:	Borja Latorre (Core Team) <borja.latorre at csic.es>
License:	GPL-2
URL:	https://github.com/eead-csic-eesa/fingerPro
NeedsCompilation:	yes
Citation:	fingerPro citation info
Materials:	README, NEWS
CRAN checks:	fingerPro results

Documentation:

Reference manual:	fingerPro.html , fingerPro.pdf
Vignettes:	About FingerPro (source, R code) Getting Started (source, R code) Workflow Example (source, R code)

Downloads:

Package source:	fingerPro_2.1.tar.gz
Windows binaries:	r-devel: fingerPro_2.1.zip, r-release: fingerPro_2.1.zip, r-oldrel: fingerPro_2.1.zip
macOS binaries:	r-release (arm64): fingerPro_2.1.tgz, r-oldrel (arm64): fingerPro_2.1.tgz, r-release (x86_64): fingerPro_2.1.tgz, r-oldrel (x86_64): fingerPro_2.1.tgz
Old sources:	fingerPro archive

Linking: Please use the canonical form https://CRAN.R-project.org/package=fingerPro to link to this page.

Citation

To cite FingerPro in your research and publications use:

Latorre, B., Gaspar, L., Lizaga, I., Palazon, L., Vu, V.Q., Navas, A. 2026. FingerPro: Unmixing Model Framework (R package). Comprehensive R Archive Network (CRAN). https://doi.org/10.32614/CRAN.package.fingerPro

Legal Deposits

- FingerPro R. An R package for sediment source fingerprinting (computer program). Authors: Iván Lizaga, Borja Latorre, Leticia Gaspar, Ana María Navas. (EEAD-CSIC). Notarial Act No. 3758 (José Periel Martín), 18/10/2019. Representative of CSIC: Javier Echave Oria.
- FingerPro. Model for environmental mixture analysis (computer program). Authors: Leticia Palazón, Borja Latorre, Ana María Navas. (EEAD-CSIC). Notarial Act No. 4021 (Pedro Antonio Mateos Salgado), 21/07/2017. Representative of CSIC: Javier Echave Oria.

Github repository

- FingerPro: Unmixing Model Framework. GitHub repository. https://github.com/eead-csic-eesa/fingerPro

fingerpro@eead.csic.es

References

Unmixing model

- Latorre, B., Lizaga, I., Gaspar, L., Navas, A. 2025. Evaluating the Impact of High Source Variability and Extreme Contributing Sources on Sediment Fingerprinting Models. *Water Resources Management* 39, 4589–4603. https://doi.org/10.1007/s11269-025-04169-8
- Lizaga, I., Latorre, B., Gaspar, L., Navas, A. 2020. FingerPro: an R package for tracking the provenance of sediment. *Water Resources Management* 34, 3879–3894. https://doi.org/10.1007/s11269-020-02650-0
- Palazón, L., Latorre, B., Gaspar, L., Blake, W.H., Smith, H.G., Navas, A., 2015. Comparing catchment sediment fingerprinting procedures using an auto-evaluation approach with virtual sample mixtures. *Science of The Total Environment* 532, 456–466. https://doi.org/10.1016/j.scitotenv.2015.05.003

Understanding individual tracers and tracer selection | CTS and CR methods

- Latorre, B., Lizaga, I., Gaspar, L., Navas, A. 2021. A novel method for analysing consistency and unravelling multiple solutions in sediment fingerprinting. *Science of The Total Environment* 789, 147804. https://doi.org/10.1016/j.scitotenv.2021.147804
- Lizaga, I., Latorre, B., Gaspar, L., Navas, A. 2020. Consensus ranking as a method to identify non-conservative and dissenting tracers in fingerprinting studies. *Science of The Total Environment* 720, 137537. https://doi.org/10.1016/j.scitotenv.2020.137537

Artificial samples for testing FingerPro model

- Gaspar, L., Blake, W.H., Smith, G.H., Lizaga, I., Navas, A. 2019. Testing the sensitivity of a multivariate mixing model using geochemical fingerprints with artificial mixtures. *Geoderma* 337, 498-510. https://doi.org/10.1016/j.geoderma.2018.10.005

Combining geochemistry and isotopic tracers | CB method

- Lizaga, I., Latorre, B., Gaspar, L., Navas, A. 2022. Combined use of geochemistry and compound-specific stable isotopes for sediment fingerprinting and tracing. *Science of The Total Environment* 832, 154834. https://doi.org/10.1016/j.scitotenv.2022.154834

Particle size effect

- Gaspar, L., Blake, W.H., Lizaga, I., Latorre, B., Navas, A. 2022. Particle size effect on geochemical composition of experimental soil mixtures relevant for unmixing modelling. *Geomorphology* 403, 108178. https://doi.org/10.1016/j.geomorph.2022.108178

Exceptional storm events effects

- Gaspar, L., Lizaga, I., Blake, W.H., Latorre, B., Quijano, L., Navas, A. 2019. Fingerprinting changes in source contribution for evaluating soil response during an exceptional rainfall in Spanish pre-pyrenees. *Journal of Environmental Management* 240, 136-148. https://doi.org/10.1016/j.jenvman.2019.03.109
- Lizaga, I., Gaspar, L., Blake, W.H., Latorre, B., Navas, A. 2019. Fingerprinting changes of source apportionments from mixed land uses in stream sediments before and after an exceptional rainstorm event. *Geomorphology* 341, 216-229. https://doi.org/10.1016/j.geomorph.2019.05.015

Sediment source fingerprinting in Mediterranean Environments

- Lizaga, I., Gaspar, L., Latorre, B., Navas, A. 2020. Variations in transport of suspended sediment and associated elements induced by rainfall and agricultural cycle in a Mediterranean agroforestry catchment. *Journal of Environmental Management* 272, 111020. https://doi.org/10.1016/j.jenvman.2020.111020
- Palazón, L., Gaspar, L., Latorre, B., Blake, W.H., Navas, A., 2015. Identifying sediment sources by applying a fingerprinting mixing model in a Pyrenean drainage catchment. *Journal of Soils Sediments* 15, 2067–2085. https://doi.org/10.1007/s11368-015-1175-6

Sediment source fingerprinting in Glacial Landscapes

- Navas, A., Ramírez, E., Gaspar, L., Lizaga, I., Stott, T., Rojas, F., Latorre, B. and Dercon, G. 2024. The impact of glacier retreat on Andean high wetlands: Assessing the geochemical transfer and sediment provenance in the proglacial area of Huayna-Potosí (Bolivia). *Geomorphology* 460, 109250. https://doi.org/10.1016/j.geomorph.2024.109250
- Golosov, V., Navas, A., Castillo, A., Mavlyudov, B., Kharchenko, S., Lizaga, I., Gaspar, L., Dercon, G. 2024. Sediment source analysis in the korabelny stream catchment, King George Island, maritime Antarctica: Geomorphological survey, fingerprinting and delivery rate assessment. *Geomorphology* 461, 109312. https://doi.org/10.1016/j.geomorph.2024.109312
- Navas, A., Lizaga, I., Santillán, N., Gaspar, L., Latorre, B., Dercon, G. 2022. Targeting the source of fine sediment and associated geochemical elements by using novel fingerprinting methods in proglacial tropical highlands (Cordillera Blanca, Perú). *Hydrological Processes* 36(8), 4662. https://doi.org/10.1002/hyp.14662
- Navas, A., Lizaga, I., Gaspar, L., Latorre, B., Dercon, G. 2020. Unveiling the provenance of sediments in the moraine complex of Aldegonda Glacier (Svalbard) after glacial retreat using radionuclides and elemental fingerprints. *Geomorphology* 367, 107304. https://doi.org/10.1016/j.geomorph.2020.107304

Combining catchment modelling and sediment fingerprinting

- Palazón, L., Latorre, B., Gaspar, L., Blake, W.H., Smith, H.G., Navas, A. 2016. Combining catchment modelling and sediment fingerprinting to assess sediment dynamics in a Spanish Pyrenean river system. *Science of the Total Environment* 569, 1136-1148. https://doi.org/10.1016/j.scitotenv.2016.06.189
- Palazón, L., Gaspar, L., Latorre, B., Blake, W.H., Navas, A. 2014. Evaluating the importance of surface soil contributions to reservoir sediment in alpine environments: a combined modelling and fingerprinting approach in the Posets-Maladeta Natural Park. *Solid Earth* 5, 963–978. https://doi.org/10.5194/se-5-963-2014

Pollutants

- Mohammadi, M., Egli, M., Kavian, A., Lizaga, I., 2023. Static and dynamic source identification of trace elements in river and soil environments under anthropogenic activities in the Haraz plain, Northern Iran. *Science of the Total Environment*, 892, 164432. https://doi.org/10.1016/j.scitotenv.2023.164432

Mining

- Crespo, J., Holley, E., Guillen, M., Lizaga, I., Ticona, S., Simon, I., Garcia-Chevesich, P.A. Martínez, G. 2023. Tracking Sediment Provenance Applying a Linear Mixing Model Approach Using R's FingerPro Package, in the Mining-Influenced Ocoña Watershed, Southern Peru. *Sustainability* 15(15), 11856. https://doi.org/10.3390/su151511856