Modelling event scale rainfall erosivity across European climate regions

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Background

Long-term annual average estimates of soil erosion fundamentally limit our understanding and mitigation capacity of highly variable erosive storm events in Europe. Event-scale rainfall erosivity (raindrop kinetic energy and consequential overland runoff) is a first order driver of soil erosion with distinct timings and magnitudes, statistically best described by the (R)USLE EI₃₀ parameter. Using rainfall erosivity from homogenised high resolution rainfall data (5-60 min Δt) in the REDES database (Panagos et al., 2015), we assessed several simple regression model configurations on a monthly basis across European climatic regions. The derived models allow the use of abundant low temporal resolution precipitation products to determine rainfall erosivity for a range of time and spatial scales in Europe.

Fig 1: The Rainfall Erosivity Database on the European Scale (REDES) contains the most comprehensive collection of rainfall erosivity (EI₃₀) events from high resolution rain gauge data in Europe. Circles represent the data record length (size) and R-factor (colour).

Fig 2: Environmental strata (EnS) allow the spatial upscaling of point scale data records. The total record length and N(events) vary with gauge density and the REDES national data record length.

Fig 3: EnS show distinct North-West to South-East spatial trends in extreme event intensity (99th percentile value and 5-year recurrence interval magnitude). Rainfall erosivity shows a characteristic positively-skewed distribution in each EnS.
Rainfall EI was calculated from high resolution rain gauge records via:

\[ EI = a \cdot I^p + e, \]

Where \( I_{30} \) is the maximum 30-minute intensity (mm h\(^{-1}\)) of the storm. For each period (r) contributing to the event, \( e_r \) is the empirically calculated unit rainfall energy (MJ ha\(^{-1}\) mm\(^{-1}\)) and \( v_r \) is the rainfall volume (mm).

The number of analysed environmental strata (EnS) with REDES coverage (total = 74). The EnS database (Metzger et al., 2005) used for upscaling consists in a total of 84 EnS in 13 EnZs, statistically delineated from 20 environmental variables. Environmental Zones (EnZs) represent the broad climatic zone encompassing numerous Environmental Strata (EnS).

**Fig 4:** Box-plots of rainfall EI distribution per EnZ.

**Fig 5:** Workflow to stratify and model rainfall erosivity as a function of rainfall depth per month.

- Rainfall EI was calculated from high resolution rain gauge records via:

\[ EI30 = \left( \frac{\sum_{r=1}^{9} e_r v_r}{I_{30}} \right) I_{30} \]

- Where \( I_{30} \) is the maximum 30-minute intensity (mm h\(^{-1}\)) of the storm. For each period (r) contributing to the event, \( e_r \) is the empirically calculated unit rainfall energy (MJ ha\(^{-1}\) mm\(^{-1}\)) and \( v_r \) is the rainfall volume (mm).

- Optimized non-linear least squares power-law based fits were used to capture the spatial and temporal relationship between event precipitation depth and rainfall EI. Models were generated and evaluated on a monthly basis using 4 model configurations; 4 with singular annual parameter sets and 1 with 12 monthly parameter sets. The best model configuration was selected and further analysed.
Outcomes:

- Established environmental strata (EnS) allow the upscaling and modelling of event rainfall erosivity from heterogeneous national gauge data.
- The model configuration with 12 monthly alpha and beta parameter sets outperformed singular annual parameter sets with associated oscillatory functions.
- Inclusion of the most extreme events reduces model performance: The prediction capacity and number of parameterised months (%months) was higher and more robust against overfitting when 99% of events were used in the model fitting process (NS-ME$_{\text{mean}}$ = 0.47, MAE$_{\text{mean}}$ = 15.4, %months = 82), compared with 99.9% (NS-ME$_{\text{mean}}$ = 0.46, MAE$_{\text{mean}}$ = 15.4, %months = 80) and 100% (NS-ME$_{\text{mean}}$ = 0.46, MAE$_{\text{mean}}$ = 15.2, %months = 76).
- The NS-ME per EnS positively correlated with the data record length ($r = 0.26, p < 0.05$) and the magnitude of the 5-year recurrence interval event ($r = 0.42, p < 0.01$).
- Model efficiency varies both spatially (according to the rainfall stochasticity) and temporally (according to the seasonal predictability of events).
- Further work will explore the application of these parameter surfaces alongside a variety of open-access precipitation products (hourly to daily) across a range of spatial and temporal scales.