ACRP

Final Report – Activity Report

Program control:

Climate and Energy Fund

Program management:

Kommunalkredit Public Consulting GmbH (KPC)

1 Project Data

Short title	EROS-A	
Full title	Soil erosion in Austria – from mean to extreme	
Project number	C162210	
Program/Program line	ACRP 13th Call for Proposals	
Applicant	BOKU University, Institute of Soil Physics and Rural Water Management, Vienna, Austria - **BOKU-SOPH**	
Project partners	BOKU University, Institute of Statistics, Vienna, Austria - **BOKU-STAT** Institute for Land and Water Management, Federal Agency for Water Management, Ministry for Agriculture, Forestry, Environment and Water Management, Austria - **BAW-IKT** Federal Institute for Geology, Geophysics, Climatology and Meteorology - **GeoSpehere** (former ZAMG) Faculty of Geographical Science, Beijing Normal University, China - **BNU** Czech Technical University, Czech Republic – **CTU**	
Project start and duration	Project start: 01.01.2022	Duration: 48 months (initially 36 months + 12 months no-cost extension)
Reporting period	from 01.01.2022 to 31.12.2025	

Synopsis: Five- to ten-line synopsis in English (updated version according to the progress of the project)

EROS-A investigated (extreme) erosive rainfall events and their impacts on soil erosion in key agricultural production zones of Austria. The clustering of rainfall events, based on various rainfall characteristics, and the development of hybrid extreme value distributions served both (i) to extend high spatio-temporal resolution gridded datasets, and (ii) to evaluate extreme rainstorm occurrence frequencies. Innovative methods and newly generated datasets will continue to serve as crucial inputs for soil erosion modeling, enabling the assessment of erosion and the corresponding mitigation measures in response to both mean and extreme rainfall events.

2 Technical /Scientific Description of the Project

2.1 Project abstract (max. 2 pages)

The project abstract, providing a survey of the project and its content, is based of the following structure:

- Brief description of the project (initial situation, targets, methodology – activities)
- Results and conclusions of the project
- Outlook and summary

Soil erosion driven by rainfall threatens agricultural productivity and degrades key soil functions and services, including carbon storage, water regulation and purification, and biodiversity. In conventional agricultural systems, erosion rates exceed soil formation by an order of magnitude or more. Yet standard assessments often rely on averages from small plots, complex catchments, or long-term annual models that mask rare, high impact events. These extremes can reshape land and dominate overall erosion risk. EROS A addressed this gap by focusing on the event scale: where and when erosive and extreme rainfall occurs across Austria’s Main Agricultural Production Zones (MAPZ).

The project pursued four objectives: (i) identify rainfall characteristics that drive erosion using long-term, high resolution station data; (ii) determine return periods and map the spatial pattern of extreme rainfall erosivity; (iii) assess probabilities and spatial distribution of extreme erosion events; and (iv) evaluate erosion damage records and the potential of new gridded datasets for intensity focused early warning. Five work packages integrated event characterization, extreme value modeling (Generalized Extreme Value and Generalized Pareto), embedding of extremes in empirical and process-based erosion models, map production, and assessment of high resolution gridded rainfall for erosivity applications. EROS A showed that short, intense, convective storms, identified via event clustering, are key drivers of extreme erosivity. Hybrid extreme value approaches provided robust return levels and periods, supporting consistent comparisons across MAPZ. We evaluated the INCA gridded dataset (15 minute, 1 km × 1 km) for estimating EI30 and developed an INCA-based extension tailored to erosivity and erosion uses, with relevance for early warning. These data and methods were implemented in both process-oriented and simplified (USLE type) models. Engagements with stakeholders, such as field days in Mistelbach, supported interpretation, contextualized uncertainties, and enhanced usability for practitioners and decision makers.

Overall, explicitly accounting for extremes improves erosion risk representation beyond long term averages. Combining high resolution precipitation data, convective diagnostics, event clustering, and extreme value models yields actionable inputs for erosion modeling, risk assessment, and early warning at landscape to regional scales.

Building on EROS A, the INCA based datasets and methods will continue to support advanced soil erosion modeling and risk analysis in Austria. We will further develop early warning concepts using INCA's 15 minute products, publish methodological advances on the INCA extension, and extend work beyond MAPZ into different ecosystems. Collaboration with Austrian and international partners (e.g., TU Wien, BNU) will ensure that gridded EI30 data and design storms inform response modeling and planning. EROS A strengthens Austria's capacity to characterize extreme rainfall erosivity and its erosion impacts, delivering a knowledge base for risk assessment, mitigation planning, and early warning that remain valuable beyond the project's lifetime.

2.2 Contents and results of the project (max. 20 pages)

This part of the report provides thorough information about the project targets defined by the applicant, as indicated in the project application, and the methods employed to achieve these targets.

1. Initial situation / motivation for the project
2. Objectives of the project
3. Activities performed within the framework of the project, including methods employed
4. Description of the results and project milestones (also on work package basis)
5. Description of difficulties, if any, encountered in the achievement of project targets
6. Description of project "highlights"
7. Description and motivation of deviations from the original project application

2.2.1 Initial situation / motivation for the project

Why do extremes matter more than averages? Soil erosion by water is a natural geomorphic process, but it is greatly accelerated by human land use, especially when protective vegetation cover is removed and soils are tilled. Because soils are a finite and slowly renewing resource, accelerated losses cannot be recovered within a human lifetime, making erosion a critical threat to the delivery of soil functions and services that underpin food production, carbon storage, and water regulation. Erosion on cultivated land exceeds natural soil formation by one to two orders of magnitude, highlighting a chronic imbalance between loss and renewal. Despite this imbalance, management and policy frequently rely on long term average erosion estimates to assess risk and set priorities. While averages are useful for benchmarking, they do not capture the dynamics that actually drive damage on the ground. The main reason is that soil loss is highly episodic: a small number of high intensity rainstorms can dominate annual to multi decadal erosion budgets. In many agro ecosystems, especially those with erodible soils or steep slopes, a few convective cloudbursts cause disproportionately large runoff and sediment transport compared to the remainder of the year. Long term averages smooth these pulses, obscuring both the magnitude of losses and the mechanisms that produce them. This has two practical consequences. First, averages can underestimate the true risk of soil degradation and off site impacts (e.g., muddy floods, reservoir siltation) because they

mask low frequency, high impact events. Second, they provide limited guidance for designing mitigation that must perform during the short windows when most damage occurs.
The erosive power of rainfall is governed not only by how much rain falls, but by how it falls—its intensity, duration, and temporal pattern at the event scale. High intensity bursts impart greater kinetic energy to the surface, promote detachment, exceed infiltration capacity, and trigger concentrated flow that transports sediment. The index of rainfall erosivity (EI30) used in the Universal Soil Loss Equation (USLE) and its successors is the product of event kinetic energy (E) and the maximum 30 minute intensity (I30). This event based metric translates the rainfall processes into erosion. When aggregated to the R factor, it quantifies the climatic erosivity regime that drives long term average soil loss in empirical models. However, the very construction of EI30 points to an essential point: erosivity is fundamentally an event level. If the heaviest 30 minutes of rain within an event are decisive, then any approach that dilutes or undersamples those peaks risks misinterpreting the hazard. Capturing event peaks requires sufficient temporal and spatial resolution in rainfall data. Errors in EI30 propagate quickly when records are coarsened beyond 10-15 minutes, and long records, ideally spanning at least a decade, are required to represent variability in erosive events and their return periods. Spatially, station networks often undersample convective cores and orographic enhancement, particularly in mountainous terrain where gauges are valley biased. As a result, gridded products derived from sparse station networks can misplace erosive hotspots. High resolution radar and integrated analyses, such as Austria's INCA system, offer an approach by merging ground observations, remote sensing, topography, and numerical weather prediction to improve the event detection and intensities at fine scales. For erosion applications, the key is not simply better averages, but sharper representation of the tails: those rare, intense bursts that do most of the damage.
Multiple long term monitoring programs and plot scale studies confirm that a small number of events account for a large share of soil loss. BOKU research showed, in eastern Austria, three storms over a 25 year period produced 79% of the cumulative soil loss measured on plots, a pattern that would be invisible in annual averages alone. Similar dominance by a handful of storms has been reported across different climates and land uses, indicating a pervasive heavy tailed behavior in erosion drivers. These findings reinforce a key message: to understand risk, we must understand extremes. Management decisions based on long term averages may appear adequate yet fail during rare events.
Looking ahead, the stakes are rising. A warmer atmosphere holds more water vapor, and the intensities of the heaviest precipitation events increase with temperature at rates near the Clausius–Clapeyron scaling of 6–7% per degree, with observed local peaks often exceeding this benchmark. In colder regions, transitions from snowfall to rainfall dominated regimes at the margins of winter can extend the season of erosive events, further elevating risk. Superimposed on climate change are evolving land uses and management practices - such as expanded row cropping or bare soil periods - that can increase susceptibility if not paired with protective cover.

Together, these trends imply that historical averages are an increasingly unreliable guide to future risk. Assessments and plans must move from static means to dynamic, risk informed approaches that consider the joint probability of extremes in rainfall and vulnerable surface conditions. This shift affects how we choose and design measures. For example, contour buffer strips, cover crops, and residue management can reduce detachment and slow runoff under moderate storms, but gully control, safe overland flow conveyance, and reinforced waterways may be necessary to prevent catastrophic failure during rare events. At larger scales, catchment planning can prioritize critical source areas and flow paths that are repeatedly activated during extremes, optimizing investments where they deliver disproportionate benefits. Policy targets framed only in terms of average annual soil loss, while important, risk complacency in landscapes where one in ten or one in twenty year storms cause decades' worth of damage in a single afternoon. European benchmarks of average erosion (e.g., ~2.5 Mg ha^{-1} yr^{-1} on average across the EU, with substantial areas exceeding 5 Mg ha^{-1} yr^{-1}) mask localized hotspots and do not convey the operational reality that most loss occurs during a handful of events. Similarly, tolerable soil loss thresholds, whether grounded in soil formation rates or sustained productivity, are more meaningful when paired with a probabilistic understanding of how often they will be exceeded by extremes. Climate change further underscores the need to anchor soil conservation in an explicit treatment of extreme rainfall, because both the magnitude and the frequency of high intensity bursts are increasing.

2.2.2 Objectives of the project

The objectives of the EROS-A project tackle the understanding and assessment of the occurrence patterns of extreme rainfall events, their erosive power, and their implications for soil erosion - particularly in predominant agricultural lands in Austria - spatially defined by the most important Main Agricultural Production Zones (MAPZ); with the eventual aim to enhance the scientific and decision maker knowledge and information-base through our generated outputs and products. Building on the insights gained during the project, the Objectives (O) were sharpened as the following:

O1: Determine the dominant erosivity-descriptive rainfall characteristics across selected MAPZ using long-term in situ datasets.

O2: Investigate the occurrence probability and spatial distribution of extreme rainfall erosivity.

O3: Assess the spatial distribution of extreme soil erosion magnitudes across MAPZ.

O4: Investigate patterns of erosion-related agricultural damage and evaluate the suitability of emerging high-resolution gridded rainfall datasets as a basis for erosion-targeted early warning.

2.2.3 Activities performed within the framework of the project, including methods employed

Project Workflow Plan (PWP), revised version (2025), was designed as the following overview of Work Packages and Tasks; Tasks that were slightly adapted and sharpened during the project are marked with an asterisk (*).

WP1: This work package focused on evaluating the characteristics of rainfall events (from mean to extreme) and determining their empirical occurrence probabilities using long-period, high-temporal-resolution rainfall station data. The key rainfall event characteristics examined included defining rainstorms (separating individual rainfall events), measuring precipitation amounts, rainfall intensities, durations, and calculating rainfall kinetic energy and erosivity. WP1 tasks were completed as proposed, with no alterations during the project.

- Rainfall erosivity calculations
- Determination of return periods

WP2: This work package targeted the extension of the high–spatio-temporal-resolution INCA dataset and the subsequent facilitation of mapping extreme rainfall erosivity across the MAPZ regions in Austria. Several theoretical extreme value distributions were tested and applied for a harmonized prediction of extreme erosivity magnitudes with their particular return frequencies. WP2 tasks were completed as proposed; moreover, inspired by discussions among the consortium partners, this task was intensified, e.g., by integrating new/upcoming rainfall information, such as flashlight data.

- Generation and analysis of extended rainfall time series
- Extreme frequency analysis* (Alteration: Enhanced investigation through innovative datasets)
- Calculation of extreme rainfall erosivity return periods

WP3: This work package modeled extreme erosion in selected settings of Austrian MAPZ. WP3 focused on applying a daily erosion model based on the Universal Soil Loss Equation (USLE), calibrated and validated against selected monitoring data (erosion sites) and verified through process-based Water Erosion Prediction Project (WEPP) simulations. WP3 tasks were largely completed as proposed, with the minor alteration of embedding the extreme soil erosion simulation in WP4 (as originally proposed under the task 'Simulation of return periods of extreme soil erosion rates').

- Model selection, calibration, and validation
- Erosion modeling for long-term climate stations
- Definition of return periods of extreme soil erosion rates* (Alteration: Task conducted through WP4)

WP4: This work package regionalized extreme erosion across the MAPZ and built directly on the harmonized rainfall erosivity mapping generated in WP2. Building on the advanced model validation from WP3 (USLE), a daily-based model was applied at a regional scale to produce high-resolution outputs (e.g., maps) throughout Austria's MAPZ. WP4 tasks were largely completed as proposed, with the minor alteration of waiving the simulation of long-term average soil erosion patterns (as these were already addressed through concurrent research during the implementation of the EROS-A project), and instead focusing on extreme erosion patterns across MAPZ facilitating WP2 outputs.

- Compilation of grid-based USLE factors
- Simulation runs with modified USLE* (Alteration: Task waived as already conducted through other research)
- Simulation of return periods of extreme soil erosion rates

WP5: This work package targeted validation of upcoming gridded datasets for extreme erosivity assessment and extreme erosion events through reported damage. WP5 tasks were completed in the proposed spirit, with the alteration of decreasing the focus on historical damage reports (due to various reasons, including uncertainty in data definitions and confidentiality) while enhancing the assessment of upcoming high-resolution Austrian gridded datasets for erosivity assessment and potential forecasting.

- Presence-absence data preparation
- Comparison of simulated extreme soil losses and damage reports* (Alteration: Task was initially conducted, but due to limited plausibility was not further intensified)
- Feasibility assessment of early erosion warning system* (Alteration: In-depth assessment of gridded INCA dataset performance)

Methods applied in the according WPs comprise various monitoring, statistical assessment and modelling techniques. The following outlines a synthesis of our applied methods; detailed methodological descriptions may be largely obtained from the EROS-A generated publications, attached to the appendix of this report.

WP1, we analyzed 27 long-record rainfall stations across Austria's Main Agricultural Production Zones (MAPZ), each recording at 5-min intervals with 0.1 mm resolution. All data were provided and quality-controlled by the Federal Ministry of Agriculture and Forestry, Climate and Environmental Protection, Regions and Water Management. Rain–snow partitioning used daily snow accumulation (24 stations) or temperature (3 stations). Rainfall events were separated using the 1.27 mm in 6 h criterion, and only events with total depth >10 mm were considered potentially erosive. For each event, kinetic energy was calculated using the universal Van Dijk et al. (2002) formulation validated for Austria, summing energy per unit depth times incremental depth over the event (see EROS-A produced publication of Vasquez et al. (2024) attached to the appendix). Annual rainfall erosivity followed USLE conventions as the sum of event energy times the peak 30-min intensity, averaged over n years for the long-term mean; Erosivity density was computed as the ratio of long-term erosivity to mean annual precipitation. Event characteristics (depth, duration, I30, E, event-scale ED) were derived at each station. Return periods of extreme erosivity were estimated using tested extreme value distributions, and gridded INCA data supported spatial mapping. To identify event types, we applied k-means clustering to standardized features (depth, duration, I30); the elbow method guided the choice of k. Distributional assumptions were screened with the Kolmogorov–Smirnov test; between-cluster differences were evaluated with the Wilcoxon–Mann–Whitney test. Spatial autocorrelation of cluster occurrences was assessed using Global and Local Moran's I (LISA) to identify high-high, low-low, and low-high patterns across MAPZ. Intra-event rainfall structure was summarized via modified Huff curves, yielding dimensionless cumulative hyetographs by exceedance probability (10%, 50%, 90%) for each cluster.

WP2 developed and operationalized a methodology to extend the high resolution INCA precipitation record (1×1 km) and to conduct regional frequency analysis of extreme erosivity. We first stratified in situ 5 min precipitation series from MAPZ stations into event types with flash data used as a proxy for convective detection. We implemented an event based clustering framework that augments binary thunderstorm occurrence with features grounded in Yevjevich's runoff theory: event duration, severity (maximum depth), magnitude (total depth), average intensity (magnitude/duration), and time to peak. Two clustering algorithms, model based clustering and PAM, were compared using Manhattan distance, and the optimal number of clusters was selected by average silhouette width. For each event cluster, we fitted a hybrid distribution, using a Gamma distribution for the lower tail and a Generalized Pareto distribution for extremes, which improved the approximation of observed rainfall distributions. The same mixed distribution framework was then applied to each INCA grid cell across Austria, enabling gridded return period mapping (e.g. , 15 min events). Finally, we derived erosivity metrics from the gridded simulations. For each grid cell and selected return periods (2, 10, 50 years), the event erosivity index was computed, based on scaled peak 30 min intensity and event energy. Annual maxima series were extracted and fitted with a generalized extreme value distribution to obtain return levels of erosivity.

WP3 implemented a process-based erosion modeling workflow at three selected MAPZ locations, benchmarking the Water Erosion Prediction Project (WEPP) model against a daily USLE-type approach. For the long-term erosion-plot monitoring research sites in Lower Austria, WEPP was set up using site-specific soils, topography, land cover/management, and co-located high-resolution rainfall inputs. The model was calibrated and validated against plot-scale runoff and erosion observations from the monitoring program, complemented by an artificial rainfall simulation to verify event-scale process representation. At one site, scenario design included synthetic extreme storms (e.g., 100-year return period) with alternative intra-storm intensity distributions obtained from WP1 and prescribed antecedent soil moisture states, enabling systematic testing of storm structure and initial conditions. Model performance was evaluated using Nash–Sutcliffe efficiency (NSE) and R^2 for runoff and erosion, with identical metrics and preprocessing applied across calibration and validation periods. In parallel, a daily USLE-type model was configured using consistent inputs and event delineation, and applied to the same sites to derive operational thresholds for erosion initiation based on rainfall depth, peak 30-minute intensity (I30), and event erosivity (EI30). Threshold identification followed a data-driven procedure tied to observed/simulated event outcomes and serves as a basis for the tailored daily USLE-based erosion assessment approach.

WP4, under the lead of BNU, compiled and operationalized a comprehensive input dataset for regional application of a daily, modified Universal Soil Loss Equation (USLE) across Austria's MAPZ. Gridded inputs included terrain (DEM derived slopes and flow lengths for LS), soils (erodibility, K), land use/cover and management (for P), and daily crop cover factors (C) for major MAPZ rotations (e.g., wheat, barley, maize, soybean) provided by CTU Prague. A fully functional workflow was established to preprocess, harmonize, and grid all factors, and to run the daily USLE at regional scale. The framework ingests temporally resolved erosivity from WP2, including return frequency–specific extreme events (i.e. 2, 10, 50 years return periods). At basin scale, a complementary Soil and Water

Assessment Tool (SWAT) setup was developed (BOKU-SOPH) to evaluate surface runoff, erosion occurrence, and the effectiveness of Soil and Water Conservation (SWC) measures. The SWAT configuration included watershed delineation, Hydrologic Response Unite (HRU) definition from soils and land use, and climate forcing from EROS A precipitation datasets. Scenario design specified SWC interventions (e.g., contouring, cover crops, buffer strips) as management alternatives.
WP5, GeoSphere-lead, compiled a comprehensive dataset of reported damage from local fire brigade records, created by filtering coded incident logs and conducting meticulous manual verification of each entry to retain events plausibly linked to rainfall-driven erosion and runoff. This archive provided an independent reference for assessing the ability of high-resolution gridded data to identify erosive events. We then evaluated the Integrated Nowcasting through Comprehensive Analysis (INCA) precipitation dataset, which provides 1 km × 1 km grids at 15-minute resolution since 2003. For comparability, 26 INCA grid cells co-located with rain gauges were extracted, and all calculations were performed at the grid-cell level. We compared the number of erosive events, average annual erosivity, and the average annual maximum erosivity. Extreme events were selected as the top decile of gauge-derived erosive events (>90th percentile), consistent with recommended extreme-event definitions. These events served as references to identify corresponding INCA events using a ±6-hour matching window. For each matched event, we derived duration, rainfall amount, peak 30-minute intensity, and event erosivity for subsequent comparison. To assess occurrence probabilities of extreme erosivity, annual extreme value series were fitted with a generalized extreme value model using L-moments, estimating return levels for both gauge and INCA data. We also examined the effect of coarser temporal resolution by aggregating 5-minute gauge data to 15- and 30-minute intervals, recalculating erosivity, intensities, and event counts to quantify scaling impacts. Performance metrics included percent bias, root mean square error, coefficient of determination, and relative deviation, applied to both the INCA-gauge comparison and the temporal aggregation tests. For extreme-event characteristics, only cases with non-zero INCA counterparts were retained, and distributional differences between INCA and gauge estimates were tested using the Wilcoxon rank sum test. Together, these procedures established a consistent, event-focused framework to validate gridded precipitation for erosivity applications, subsequently usable in short-range forecast products provided by INCA.

2.2.4 Description of the results and project milestones (also on work package basis)

The following provides a WP-based overview of key results, with highlight figures depicting evaluation procedures and delivered outputs. For each WP, one specific milestone was selected and elaborated.
WP1 key results include identifying three dominant rainfall types (clusters C1-C3) from erosivity relevant characteristics (amount, intensity, duration). The highly erosive C1 type combines particularly large intensities with short durations, whereas C2 and C3 exhibit longer durations, lower intensities, and lower erosivities (Figure 1). C1 contains the most erosive events, with the largest EI30, I30, and EDmeans of 216 MJ mm ha^{-1} $h-^{1}$, 30.7 mm h^{-1}, and 7 MJ ha^{-1} h^{-1}, respectively, and the

shortest mean duration (around 8 h). C1 events occur more frequently near the High Alps, especially south eastern pre alpine areas (Figure 2), mainly from May to September, suggesting a link with summer thunderstorms. By contrast, C3 events, prevalent in northern pre alpine areas, exceed C1 in cumulative rainfall amount. Sub event timing, summarized by 10%, 50%, and 90% isopleths, shows that C1 typically concentrates 60-90% of event rainfall in the first third of duration, though some end pronounced cases occur. C2 and C3 display more uniform temporal distributions, with the 50% isopleths indicating approximately constant intensity over the event. Our set milestone 'Return periods of rainfall erosivities determined' was achieved via empirical exceedance probability curves for all clusters. For rainfall amount, C2 peaks at 50 mm and only 5% of events exceed 30 mm, whereas >80% of C3 events exceed 30 mm; C1 lies between C2 and C3. In contrast, EI30 is by far largest in C1: all events exceed 90 MJ mm ha^{-1} h^{-1}, and 10% may excied 500 MJ mm ha^{-1} h^{-1}, while only very few C3 events reach 100 MJ mm ha^{-1} h^{-1}.

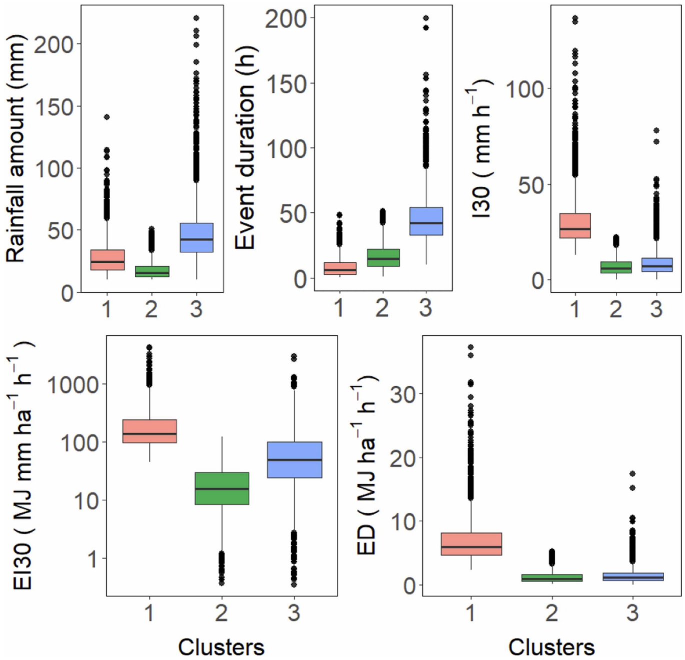


Fig.1. Boxplots of EI30, ED, and rainfall characteristics (I30, EDur, rainfall amount) of three rainfall types/clusters (C1, C2, C3) across Austrian MAPZ. Obtained from Vazquez et al. (2024).

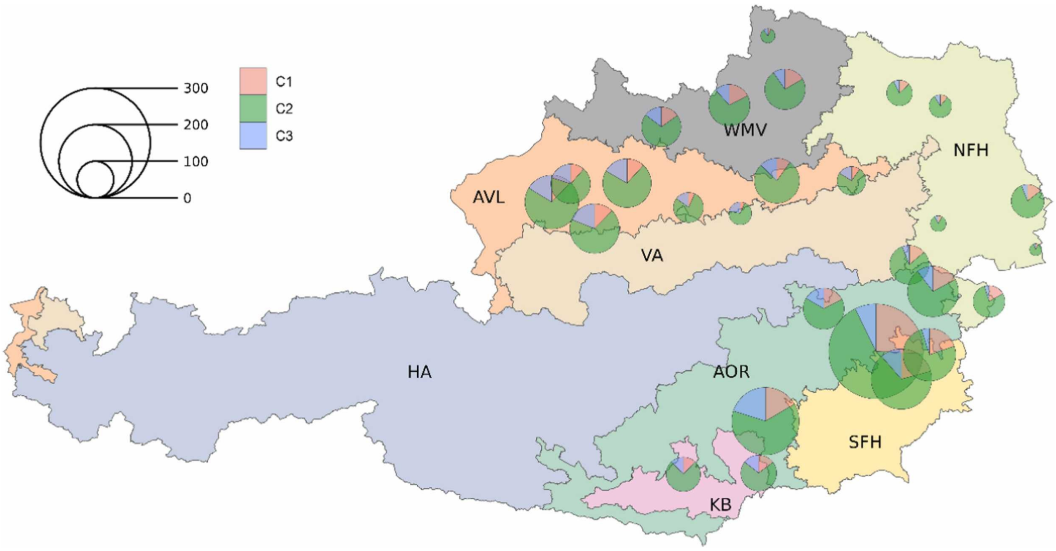


Fig.2. Spatial distribution of erosive rainfall events per cluster. Each pie chart contains the clusters C1 to C3 and shows the percentage of events of each cluster. The pie chart's size relates to the number of events in C1. Obtained from Vazquez et al. (2024).

WP2 key-results include the WP2 key results include extending the INCA gridded precipitation dataset (1×1 km, available since 2003) back to the mid-1980s. Two clustering algorithms were compared for distinguishing rainfall events, a model-based clustering and a robust partitioning method (PAM). This event-based classification was applied to 27 stations within the MAPZ study area (Figure 3). Our results demonstrate that clustering rainfall events improves the approximation of rainfall distributions. The generated events were then used for extending the data series. The according key-milestone 'Rainfall erosivity time series generated and analysed for spatial characteristics in the study area' extended gridded dataset is available at BOKU-STAT and supports evaluation of return periods up to 50 years. The BOKU-SOPH developed R-Script for EI30 calculation was applied to the extended data. Theoretical extreme value series were derived using both the Annual Maxima Series (AMS) and Peak Over Threshold (POT) approaches; assumptions of stationarity and independence were tested, with no significant deviations detected. Generalized Extreme Value (GEV, for AMS) and Generalized Pareto (GPD, for POT) distributions were fitted using L-moments and maximum likelihood. Threshold selection for POT proved critical; sensitivity analyses, including assessing convergence of GPD-based estimates to GEV (AMS) results, were used to determine robust thresholds. Across stations and return periods, the POT approach for daily cumulative precipitation was most accurate in 69% of cases, AMS in 8%, and both performed similarly in 23%. For I30 , success rates were 80% (POT), 8% (AMS), and 12% similar performance. Finally, gridded EI30 return-period products (2, 10, and 50 years) were produced for the INCA domain, with NetCDF files available at BOKU University. Figure 4 exemplarily depicts the 10-years EI30 return level dataset generated.

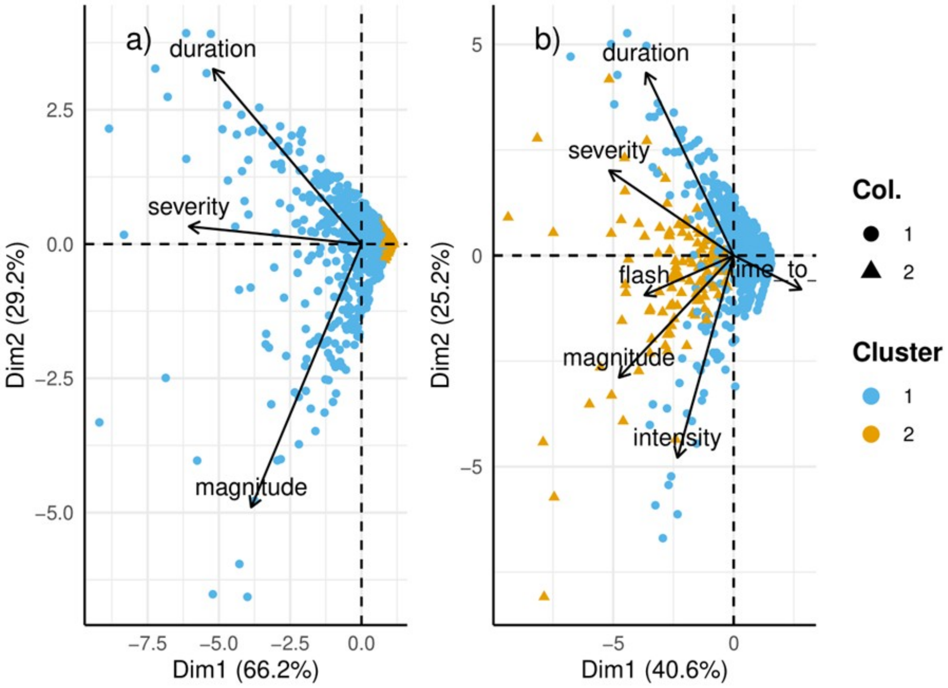


Fig.3. Comparison of model-based clustering (a), and the PAM (b) clustering algorithm for clustering rainfall events.

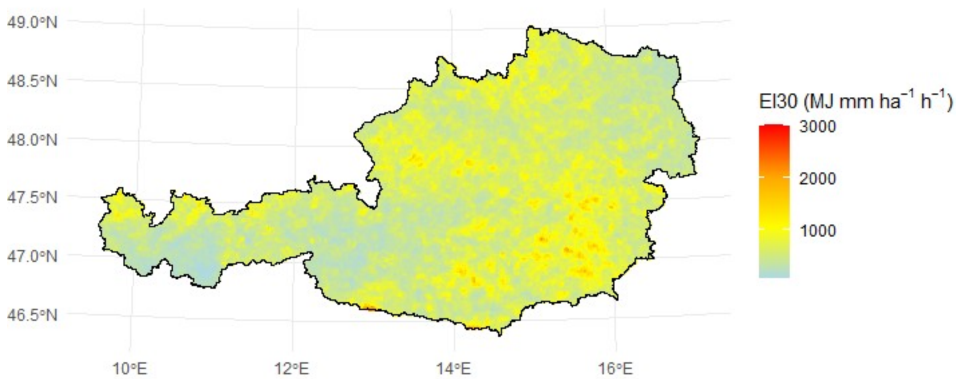


Fig.4. Map of the 10-year return period EI30 magnitude derived through the extended INCA dataset.

WP3 tackled the modeling of extreme erosion events at selected MAPZ locations to test process-based erosion models, such as the Water Erosion Prediction Project (WEPP), against a daily-based USLE approach. The WEPP model was set up, calibrated, and validated for the long-term erosion monitoring site and co-located in situ rainfall station in Pyhra, Lower Austria. Additionally, an artificial rainfall simulation was used to verify model performance, set at 50-100 year return period event level. The performances of the calibrated and uncalibrated models were compared using Nash–Sutcliffe efficiency (NSE). WEPP accurately depicted runoff and erosion processes from rainfall simulations at small time steps, with NSE = 0.91 for runoff and 0.81 for erosion during calibration.

When validated with long-term runoff plot data, the calibrated model achieved NSE = 0.74 for runoff and 0.54 for erosion. In contrast, modeling without calibration resulted in NSE = 0.19 for runoff and 0.45 for erosion. WEPP was subsequently also set up for two additional research sites in Lower Austria, associated with different MAPZ: Pixendorf and Mistelbach. Using local long-term monitoring data (surface runoff and soil loss), a daily-based USLE-type approach was applied and tested to (i) investigate the performance of USLE-type equations and (ii) assess critical thresholds of rainfall and erosivity for erosion initiation. Results indicate ageneral applicability of a USLE-based approach expressed by R2 values of 0.2, 0.4, and 0.5 for Pixendorf, Pyhra, and Mistelbach, respectively, based on double-logarithmic plots and low C-factor seasonality to avoid masking processes by vegetation. The scatterplot of observed and USLE-modelled erosion occurrence is shown in Figure 7. On the linear scale, a fitted regression indicates the best-estimate EI30 threshold for erosion initiation in our daily-based USLE approach, with EI30,crit approximating 15 MJ mm ha^{-1} h^{-1}.

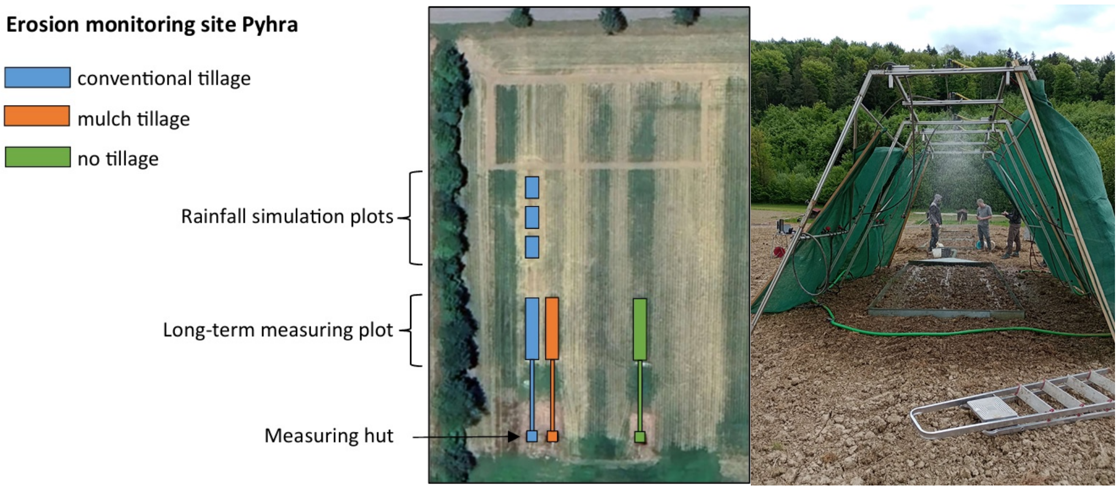


Fig.5. Overview of the erosion experiment in Pyhra, Lower Austria (left); rainfall simulation experiment, conducted in May 2023. Figures modified from the Master Thesis of Jeremias Maier (2024).

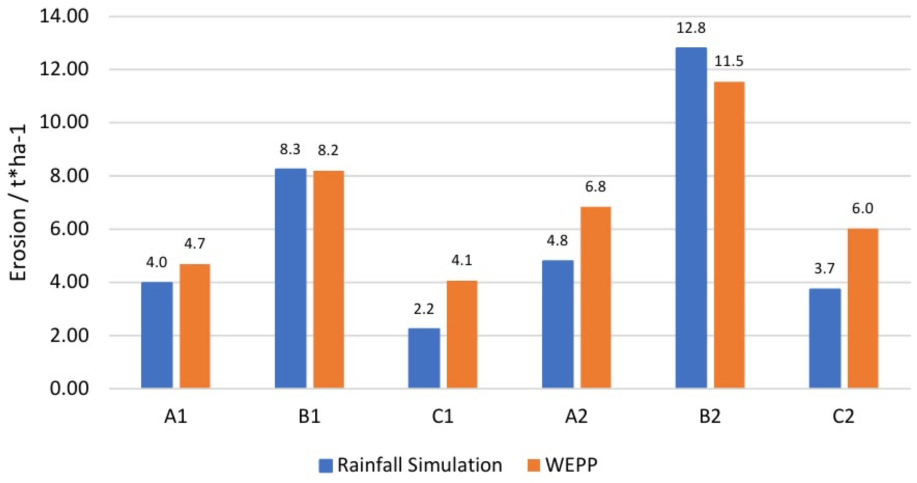


Fig.6. Performance assessment of experimental erosion (monitored) versus process-based erosion simulation (WEPP) for a 50-100-year return period storm with different intensity-distributions (A,B,C) and soil wetness pre-conditions (1,2). Figures modified from the Master Thesis of Jeremias Maier (2024).

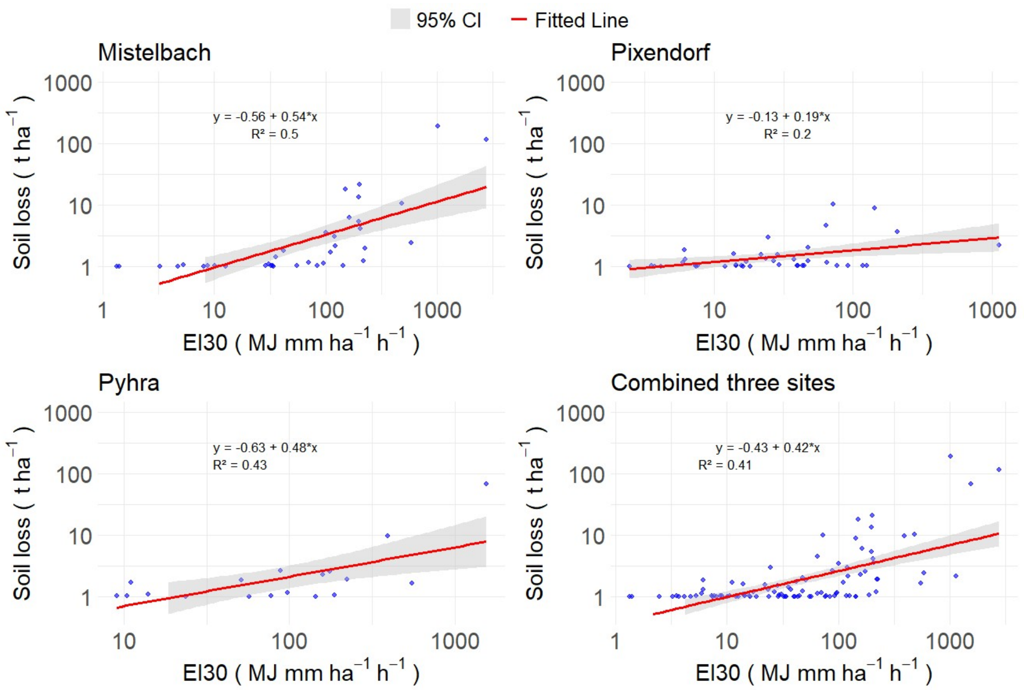
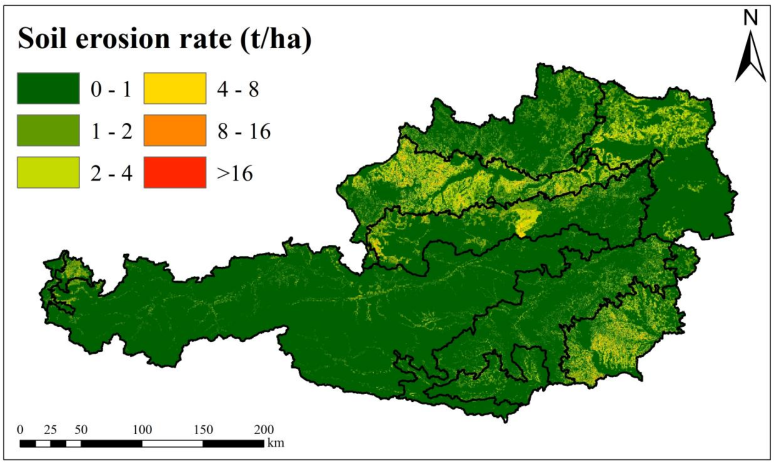


Fig.7. Event-based USLE approach comparing modelled with observed from erosion plots located in Mistelbach, Pixendorf and Pyhra.

WP4 generated spatial soil erosion information using an event-based USLE approach. The input datasets included high-resolution gridded terrain (DEM), soils (erodibility), land use/cover, and land management. In particular, daily crop cover factor (C-factor) data for major MAPZ rotations (e.g., wheat, barley, maize) were provided by CTU Prague and validated through field observations in 2023-2024. The GIS-supported USLE approach, equipped with EI30 threshold values obtained from WP3, was run for the entire extended INCA time series (WP2) as well as for defined extreme erosivity events at 2-, 10-, and 50-year return frequency across Austrian MAPZ. Figure 8 shows exemplary results for the scenarios of the 50-year return-frequency EI30 event for two extreme crop-cover stages: bare soil (seedbed conditions) and maximum cereal crop cover representing the key-Milestone of 'Generation of the return period maps for soil erosion'. The resulting extreme-event maps depict the spatial pattern of erosion and, thus, land vulnerability to degradation at a 1 x 1 km spatial resolution. The generation of various return-frequency extreme EI30 layers enabled us to systematic compare the groups of return-period maps and highlight according changes in soil loss magnitudes. Our spatial assessment located particular erosion hot spots in MAPZ closer to the alpine areas – super positioning large EI30 magnitudes with steep terrain and often times silty textured soils.

As an add-on study, the Soil and Water Assessment Tool (SWAT) was set up for the Mistelbach watershed (37.46 ha), Lower Austria. The study aimed to assess the long-term effects of various tillage practices on surface runoff, erosion, and soil health at both plot and watershed scales, driven by gridded INCA data generated through WP2. A field experimental monitoring program was carried out at three plots from 2002 to 2021 under Conventional Tillage (CT; plow and seedbed preparation, without green cover crops), Mulch Tillage (MT; green cover crops, with plow and seedbed preparation), and No-Till (NT; green cover crops, without plowing and seedbed preparation). Long-term runoff-plot monitoring is being coupled with process-based hillslope modeling (WEPP) and scaled through a small watershed-level hydrological assessment using SWAT. Preliminary results show that conservation tillage systems substantially decrease runoff and erosion by 25-55% (MT) and by 49-60% (NT), respectively. This study complements the purely empirical USLE-based analysis through a combined empirical–process-based SWAT application.



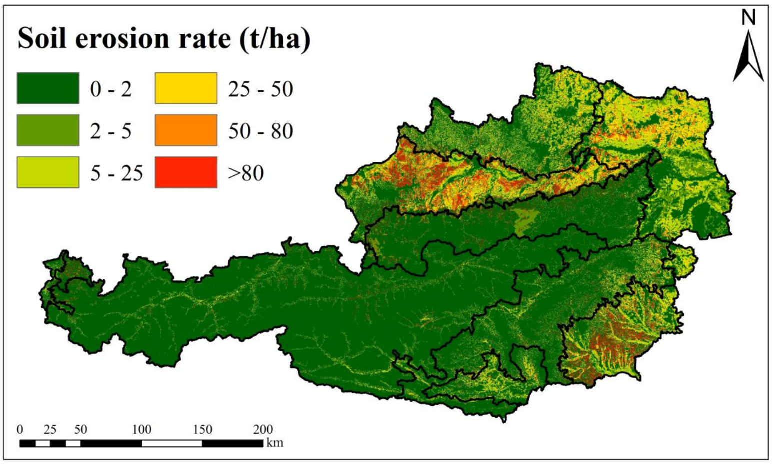


Fig.8. Spatial event-based USLE modelling of extreme soil erosion events using 50-year return frequency extreme erosive events (EI30) for mature cereal crop-cover (top) and bare (bottom) scenarios.

WP5: GeoSphere has successfully completed the compilation of a comprehensive reported damage dataset, which was tested for linkage with extreme erosivity (WP2) and extreme erosion events simulated in WP4 across target MAPZ. The dataset has been readily compiled, hosted at GeoSphere. Preliminary matching of reported damage with peak erosivities and erosion was only partially conclusive, also due to lack of attributability of reported data (i.e., whether damage was purely water- or sediment-related). The consortium therefore investigated gridded high spatio-temporal data (INCA) for its linkage with in situ extreme erosivity and erosion at experimental sites in Lower Austria. INCA showed strong potential for average annual EI30 event counts, with a slight underestimation of 3% and an overestimation of 8% relative to gauges, and captured extreme magnitudes well in pre Alpine areas with the highest erosivity. Overall alignment was better in northern and southern Austria, with less accuracy in the east (Figure 9). However, event scale analysis revealed discrepancies for specific extremes, despite high resolution; still, INCA detected over 95% of extreme events (90th percentile) recorded by gauges. Generalized Extreme Value (GEV) distributions were fitted to both datasets to estimate return levels across MAPZ. Gauge based extreme EI30ranged from 142.6 to 2762 MJ mm ha^{-1} h^{-1} for return periods of 2-40 years (east to north, respectively). In 98% of cases, the average annual maximum erosivity fell within the 2 year return level range for both gauges and INCA. Relative deviation between gauges and INCA highlighted regional differences: north and south performed well for 2-20 years, whereas the east showed overestimation that increased with return period. Using coarser temporal data reduced I30, E, and EI30, with I30being the dominant source of EI_30underestimation. More than 5% of erosive events were missed with 15 min data and over 17% with 30 min data, underscoring the advantage of the newly generated 15 min INCA dataset in limiting EI30 underestimation through enhanced temporal resolution. Our matching of INCA and in-situ data with recorded erosive events at the plot level showed acceptable matches (Figure 10), opposed to the matches to the damage reports.

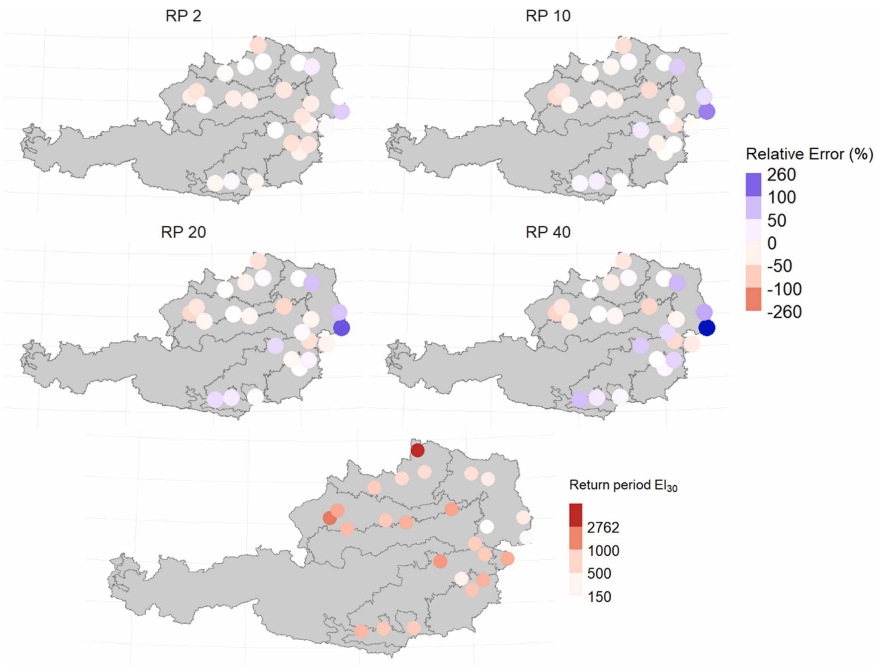


Fig.9. Relative Deviation (%) of spatial distribution in the MAPZ for four predicted return periods (RP) (2, 10, 20, and 40) of EI30, and EI30 Return Periods values comparing data from rain gauge and INCA (2003-2020). Obtained from Vasquez et al. (2026).

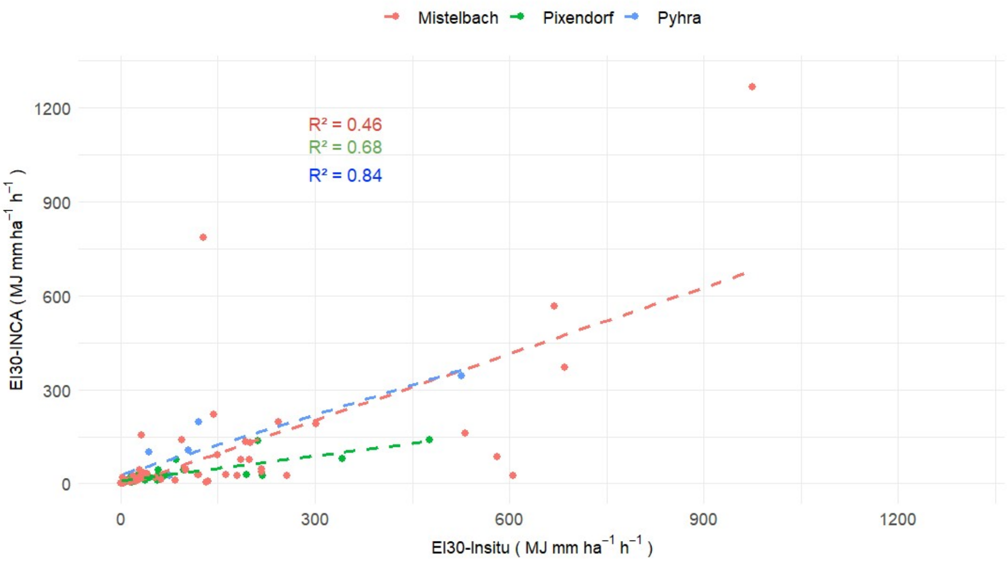


Fig.10. Matching reported erosion at long-term erosion plots in Mistelbach, Pixendorf and Pyhra with in-situ and INCA-based EI30 data.

2.2.5 Description of difficulties, if any, encountered in the achievement of project targets

The EROS-A project was a highly successful partnership between Austrian and international institutions (Czech Republic and China). The international setting greatly enhanced knowledge exchange, diversity of viewpoints, and dissemination. It did, however, require increased flexibility for partner meetings. This was effectively addressed through early-morning online consortium meetings (CET), enabling the Chinese partners (BNU) to join in their late afternoon. BNU also showed strong flexibility, accommodating even later meeting times. In-person interactions were possible at major conferences, such as EGU Vienna (financed through other sources), which served as an additional co-benefit.

Regarding project management, the initial PI, Prof. Andreas Klik (BOKU), retired, and his successor, Dr. Stefan Strohmeier, took over leadership of the project. This change was transparently communicated and approved by Kommunalkredit Public Consulting GmbH (KPC) and the ACRP. The transition was smooth and highly supportive, with Prof. Klik remaining an integral part of the project, research, and joint publications (co-author on all publications). As the proposal writing was decoupled from project management, some interpretations of project structure and deliverables naturally evolved. Overall, the transition was highly positive; tasks were fine-tuned to better align with the updated leadership, without any negative impact on the quantity or quality of outputs. Nevertheless, partly due to the leadership transition, some project outputs deviated slightly from the original intent.

A second personnel change involved a PhD student (Ms. Nur Banu Özcelik) under the BOKU-STAT lead, who did not complete her PhD and thus concluded her project support at a late stage of the project (in 2024), prior to its finalisation. The EROS-A consortium sincerely thanks Ms. Özcelik for her contributions and dedication; her departure was, of course, a loss. It also required a transition of data, knowledge and workforce. The consortium had prepared for personnel changes through a risk-mitigation plan. All data were transferred, securely stored, and handed over (through handover meetings and research discussions), and collaborating colleagues and her supervisory team bridged the temporary research gaps.

A final scientific challenge concerned the assessment of damage reports caused by erosion (WP5), sourced from local Austrian fire brigades. This activity proved more time-consuming and harder to interpret than initially anticipated. Nevertheless, it was completed (with slight delays), and the resulting dataset is finalised and hosted by the GeoSphere consortium partner. The data's usability is somewhat limited due to ambiguity in attributing damage to specific causes and confidentiality constraints that limit publication. However, the dataset remains valuable, and the consortium continues to explore beneficial uses for knowledge generation and potential publication.

2.2.6 Description of project "highlights"

The project delivered as planned highly ambitious research outputs; beyond that, the project engaged in dissemination and publication activities not foreseen in the proposed project plan. The three carefully selected highlights include two such not directly planned but highly successful outputs.

Highlight 1: Extreme erosive event data (return level maps); This output (deliverable) was planned, but the final product and the inputs and considerations applied go beyond the initial proposal. For example, the inclusion of lightning data substantially enhanced distinguishing the type of rainfall (i.e., convective), which allowed us to generate and adjust the corresponding distribution algorithms. Moreover, direct exchange among all consortium scientists led to discussions about future data product needs, particularly with reference to upcoming ÖKS26 climate data and the temporal resolutions needed to derive rainfall erosivity EI30, based on generated research (e.g., Vasquez et al., 2024). The final output is a highly advanced netCDF data product reflecting high-resolution extreme erosivities (2-, 10-, and 50-year return periods), readily available for future research—with already concrete interest and uptake (e.g., TU Vienna has referenced it in a new proposal to ACRP). On demand, the base-dataset can be used to generate other return frequency levels of interest.

Highlight 2: Extreme event field experimentation and dissemination; With support from a BOKU Master student (Master thesis), a rigorous field experiment was conducted in Pyhra, Lower Austria, in spring 2023. The experimentation was beyond EROS-A's planning and required resources (i.e., materials and labor) not budgeted, but these were kindly provided by EROS-A partners BAW and BOKU-SOPH. During the field campaign, and thanks to Chinese partners (BNU) visiting for the EGU conference in Vienna, the experiment was conducted with active on-site support from BNU staff. The experiment was highly impactful, bringing the 'theory' of EROS-A to application and demonstration on the ground. An artificial rainfall simulator was set up for around two weeks of research at a long-term experimental site in Pyhra, jointly conducted by BOKU and the agricultural school (LFS) of Pyhra. LFS Pyhra visited the experiments and actively interacted with BOKU and BAW staff during a field day. A LFS-led communication post and letter were also produced (Figure 11). This highly successful activity led to twofold output and impact: 1) bringing science to the field and verifying theoretical data, and 2) actively engaging young and future land managers (LFS students) in demonstration, discussion, and co-learning. We sincerely thank the LFS system of Lower Austria for their continuous support and engagement.

Fig.11. Extreme rainfall simulation in Pyhra and LFS-Pyhra visit in spring 2023. Pictures taken and published by LFS-Pyhra (https://lfs-pyhra.ac.at/blog/2023/05/30/3463/).

Highlight 3: Scientific publication from China; EROS-A joint research was actively supported by BNU scientific staff. Their engagement and contribution were essential. Our research in Austria sparked the idea to apply some of the rainfall erosivity assessment approachs to Chinese conditions. With full acknowledgment of the ACRP project, the consortium jointly published a research article, 'Disproportionate contributions and spatiotemporal patterns of extreme rainfall and erosivity events across mainland China' (Chen et al., 2025), in the journal International Soil and Water Conservation Research, which has an impact factor of 7.3.

2.2.7 Description and motivation of deviations from the original project application

The project delivered on all proposed WPs and key-tasks. In line with the reasons outlined above, the i) the transition of project lead (PI) from proposal writing to project management, ii) concurrent advances and partial coverage in science from partners and other institutions (e.g., daily-based vs. average-annual USLE approaches; publishing average annual soil loss rates in Austrian agriculture), and iii) new findings during EROS-A (e.g., ambiguity in reported erosion-damage data), the project focus was slightly re-adjusted, and corresponding tasks and deliverables were updated and fine-tuned to address actual pressing needs. This did not compromise delivery of the proposed knowledge outputs; together with concurrent scientific advances, it effectively enhanced the depth and scope of the research; for example, through top-up on-site scientific and demonstration experiments (pt. 2.2.6, Highlights 2 and 3). Concrete alterations and updates were pursued for the following tasks and deliverables:

WP2, Task 'Extreme frequency analysis': We enhanced the proposed techniques by adding new and innovative datasets. Accordingly, the produced outputs (i.e., extreme erosivity data) are upgraded.

WP3, Task 'Definition of return periods of extreme soil erosion rates': We found this task and its outputs to be partly overlapping or redundant with WP4's task 'Simulation of return periods of extreme soil erosion rates'. Since both WPs (3 and 4) focus on modelling, the definition of erosion return rates is largely driven by the climate input set by the user. We therefore addressed the simulation of extreme events in WP4 and increased efforts on in-situ experimentation in WP3 instead. In-situ conditions (e.g., soil moisture preconditions, vegetation cover, etc.) are certainly important but can be addressed through scenario creation, as demonstrated by the rainfall simulator experiment. Also, the EROS-A developed daily crop cover factor (C-USLE) supports the context specific set-up of extreme event analyses when using USLE-type modelling approaches. In that sense, the project generated the required inputs for extreme event assessment, delivering user-applicable datasets. This switch more than compensated for waiving one minor task in WP3 in terms of labour, effort, and potential impact through dissemination.

WP4, Task 'Simulation runs with modified USLE': This was pursued as a standard model setup using the extended gridded INCA dataset anyways; however, the production of according output maps and related investigations and discussion were largely reduced, due to Schmaltz et al. (2023), who investigated average annual soil erosion rates in Austrian MAPZ with and without erosion control measures using a RUSLE approach. While this is not a strictly daily or event-based approach, it uses similar input data and was rigorously conducted, with important results and strong linkages to EROS-A theme. Instead, the EROS-A consortium focused further on extreme-event assessment and mapping the contribution of those rare events, to discuss those extreme impacts in the context of Schmaltz et al. (2023) research and related works.

WP5, Task 'Comparison of simulated extreme soil losses and damage reports': As discussed in previous sections, due to ambiguity, limited reliability and potential confidentiality issues of the data, this task was initially undertaken but reduced at a later stage. Nevertheless, the dataset has been compiled and is readily available (GeoSphere) and may be valuable for future research once, for example, coding interpretation is clearer. Instead, we strengthened the following task in WP5.

WP5, Task 'Feasibility assessment of early erosion warning system': We enhanced this research through an in-depth assessment of INCA's fitness to estimate rainfall erosivity compared with in-situ data; published by EROS-A consortium through Vasquez et al. (2026). Our study found that INCA estimates average annual EI30 with only 3% underestimation and the number of erosive events with 8% overestimation, and it detects over 95% of extreme events (90th percentile) recorded by gauges, with good performance especially in northern and southern regions and for 2- to 20-year return periods, though extreme event magnitudes are overestimated in the east as return period increases. The analysis of temporal aggregation shows that using coarser data leads to substantial underestimation of EI30 (loss of >5% of events at 15-min and >17% at 30-min), underscoring the advantage of the new 15-min INCA data for rainfall erosivity calculations. Furthermore, we directly verified in-situ and INCA-based EI30 interpretations using erosion plot records from our three long-term monitoring sites in Lower Austria. This approach, at least for the three selected points, allows a more direct EI30-erosion investigation compared to fire brigade damage data, where attribution is unclear (e.g., sediment-related damage may stem from channel flooding, breaches of retention measures, or other remobilised sources rather than in-field erosion).

In sum, we are confident that our modifications were pursued to achieve the best possible project performance.

2.3 Conclusions to be drawn from project results (max. 5 pages)

– Which findings have been derived from the project by the project team?
– Which further steps will be taken by the project team on the basis of the results obtained?
– Which other target groups can draw relevant and interesting conclusions from the project results and who can continue working on that basis?

2.3.1 Findings derived by the project team

Across Austria's main agricultural production zones, we found that extreme rainfall erosivity is shaped by short, high-intensity storms with pronounced spatial and seasonal structure. Using long-term, 5-minute rain-gauge records from 27 high-quality stations, our study unveiled three characteristic event types, of which the short-duration, high-intensity class is the most erosive. We observed that these events occur more frequently near the High Alps - especially in the southeast - and peak in summer, consistent with convective thunderstorm dynamics; we further corroborated their convective character through the co-occurrence of cloud-to-ground lightning. We also found that this 'few events dominate' signature is not unique to Austria. At the continental scale in China, our group identified severe erosivity hotspots along terrain transition zones from lowlands to mid-elevation slopes, where uplift compresses storm duration and amplifies intensity; there, a small fraction of events contributes the bulk of annual erosivity. Together, these results led us to conclude that erosivity risk is governed less by annual totals and more by short, intense convective bursts tied to orography and seasonality.
Accurate quantification of those bursts, we found, hinges on temporal resolution. When coarsening rainfall time steps from 5 minutes to 15 or 30 minutes, event erosivity EI30 is systematically underestimated, primarily because peak 30-minute intensity I30 is smoothed. While correlations with 5-minute baselines rmain high at 15-minute resolution (for example, R2>0.93 across key parameters), I30 degrades fastest and drives the bias in EI30. Using 15-minute data already leads to a measurable loss of erosive events and underestimation of total erosivity; at 30 minutes, both effects become substantial, and we observed errors in EI30 roughly doubling to tripling relative to 15 minutes. These findings lead us to a clear requirement: for operational and research applications, temporal resolution must be no coarser than 15 minutes (i.e, ≤15 min) - and ideally 5-10 minutes- to capture peaks and retain the full population of erosive events. In this context, we found that the new 15-minute INCA archive meets this threshold and materially reduces underestimation compared with coarser products. At regional scales, our analysis showed that the INCA gridded dataset reproduces the spatial pattern and climatology of erosivity well. Average annual EI30 shows only a slight underestimation relative to rain gauges (on the order of a few percent), and the total number of detected erosive events is modestly overestimated; we found that skill is strongest in the pre-Alpine, northern, and southern regions, with weaker performance in the east. INCA also captures most extremes in a statistical sense: more than 95% of gauge-based extreme events (≥90th percentile) are detected, and generalized extreme value analyses indicate that annual maxima typically fall within the 2-year return level band for both gauges and INCA in the vast majority of cases. However, our event-by-event comparisons show that for specific high-impact storms, the gridded product can diverge in timing and magnitude from point observations, even when it flags the same event. This divergence matters for design and forensics, where local peak intensity and exact timing drive decisions.
These strengths and weaknesses translate directly into early-warning potential. We found that gridded data can reliably identify most extreme erosivity episodes, with practical thresholds emerging: a lower detection boundary near EI30 is around 100 MJ mm ha^{-1} h^{-1} at most stations

(about 65 MJ mm $ha^{-1} h^{-1}$ in parts of the northeast and east), and an upper bound near 3,300 MJ mm $ha^{-1} h^{-1}$; associated I30 can exceed 80 mm h^{-1} in southern hotspots. Crucially, INCA's operational offering - nowcasting over 0–4 hours and short-range forecasts to roughly 12 hours at 15-minute resolution - enables near-real-time screening at scales relevant for agricultural operations and soil conservation. At the same time, our event-to-event assessments confirm that field-scale fidelity remains limited due to spatial representativeness and storm-core misalignment (point gauges sample 500 cm^2, whereas grids represent 1 km^2), along with known challenges in reproducing the exact timing and magnitude of extremes. Taken together, our study shows that extreme erosivity in Austria is controlled by short, convective bursts clustered in specific terrains and seasons. We conclude that a temporal resolution of ≤15 minutes is essential to capture I30 and avoid bias in EI30 while finer resolutions further improve peak detection. INCA provides robust spatial patterning, strong detection of most extremes, and actionable nowcasting and short-range forecasts, supporting climatological assessments; but its applicability may be limited for event level early warning.

2.3.2 Further steps to be undertaken

We will operationalize the project's outputs, especially the extreme EI30event magnitudes by return level into map products and design guidance for ongoing research and new proposals. Concretely, we will facilitate Austria-wide extreme erosivity maps for use at BOKU and EROS-A partner institutions, with immediate application to the design of landfill revegetation measures, where EROS-A design storms will serve as a reference (with EROS-A acknowledgement) and short-range forecasts (~12 h) to support screening and prioritization in operational settings.

Beyond the agricultural MAPZ focus, we will extend analyses into higher-altitude pre-Alpine and Alpine areas, including disturbed grass- and forestlands. Erosivity and erosion in natural landscapes have long been underassessed, yet disturbance zones - such as roads, forest clearances, and intensive tourism infrastructure - leave pronounced footprints. Our next phase research may characterize extreme-event sensitivity in these settings, using the return-level EI30 library as design input and validating against local gauges and, where available, radar and disdrometers to better parameterize rainfall energy E and peak intensities. In parallel, we will address the climate-change dimension. While spatial resolution has improved via downscaling (e.g., CORDEX; forthcoming ÖKS26 for Austria), temporal resolution remains a bottleneck for erosivity because sub-hourly peaks are smoothed in daily to 3-hourly outputs. We propose AI-supported downscaling that leverages historical station data and environmental covariates to translate daily GCM projections into sub-hourly series from which storms can be segmented and I30, E, and EI30estimated, with disdrometer observations used to anchor physical realism.

We will also embed these outcomes in teaching and capacity building. Specifically, we will integrate the erosivity maps, return-level datasets, and INCA-enabled workflows into GIS-based modeling exercises within the long-standing OeAD-supported BOKU Vienna–CTU Prague exchange. Students will work with documented, open workflows to compute EI30 under present and future scenarios, with all materials acknowledging EROS-A. This will accelerate uptake of extreme erosivity concepts in both Czechia and Austria, while providing a pipeline of trained users who can apply the tools in research, consulting, and public administration.

2.3.3 Target groups for relevant results and continuation

Science: We will continue to serve and expand the EROS-A scientific network by translating our outputs. We are already aligning with TU Vienna to co-apply for proposals on erosion and eutrophication of water bodies via sediment and phosphorus transport, where EROS-A design storms and erosivity maps will underpin source-to-receptor analyses. Internationally, our collaboration with BNU and colleagues in China has demonstrated how Austrian insights generalize to other orographic transition zones - and how lessons from large-scale Chinese datasets sharpen Austrian methods and interpretation. We will leverage this two-way exchange to attract joint PhD projects, visiting scholars, and international students to Austria, strengthening our research competitiveness and visibility. All shared datasets and scripts will follow transparent, citable practices to ease uptake beyond EROS-A partners.

Decision making: Together with BAW, we will facilitate the project's applied findings into mitigation and adaptation guidance. We will present actionable case studies and demonstration at BAW Open Science Days and related fora, inviting stakeholders from Austrian policy and administration. Our aim is to couple science-based products with clear decision pathways.

End users: We will continue our close collaboration with the Lower Austria Agricultural School (LFS) system - especially Mistelbach and Pyhra - to translate EROS-A outputs into classroom and field practice. This includes hands-on modules where students and teachers use erosivity maps, design storms, and real-time INCA guidance to plan soil conservation measures, complemented by on-site demonstrations and continued operation of our long-term erosion plots. By maintaining a regular presence and co-developing teaching materials, we aim to build preparedness and foster sustainable land management among future farmers and land managers. Joint high-quality studies arising from these plots will be co-authored with LFS partners, ensuring that practice-led questions inform our research pipeline and that results flow back as practical guidance for the region.

2.4 Work and time schedule (max. 2 pages)

- Presentation of the final work and time schedule
- Explanations of deviations, if any, from the original work and time schedule contained in the project application

Figure 12 below illustrates the originally proposed Project Workflow Plan (PWP) in grey and the successive alterations in green cells, which were transparently communicated and positively acknowledged in the interim reports submitted. Worth noting, EROS-A requested a 12-month no-cost extension with the 2023 interim reporting (both in the report and via email communication with the ACRP management at Kommunalkredit Public Consulting GmbH), which was approved by KPC in a letter dated 04.03.2024. The previously communicated deviations marked in green (Figure 12) stem from enhanced discussions and advanced dataset development in WP2, and later also from changes in the PhD trajectory of one PhD student (Ms. Nur Banu Özcelik). As a result, other WP tasks that relied on the required climate inputs were likewise delayed (i.e., WP3 and WP4 modelling tasks). Secondly, as explained above, the damage report data proved to be an unclear source of information, and a shift of effort toward investigating high-resolution datasets and erosion plot data from long-term monitoring sites was necessary. These changes proved highly beneficial but required some time for reorientation and successful completion.

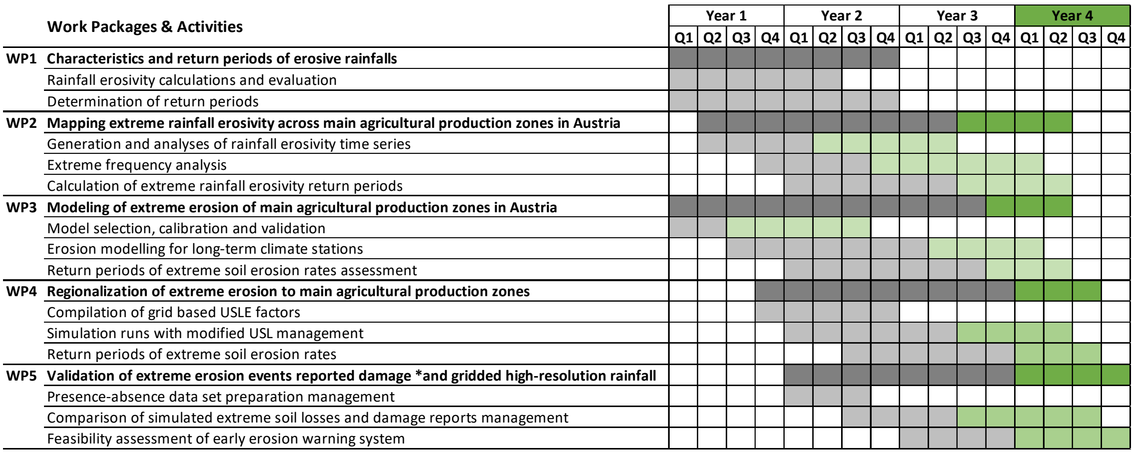


Fig.12. Project Workflow Plan (PWP) in grey cells, and modifications successively approved in green cells; a one year no-cost extension (year 4) was also granted by the ACRP-management of KPC.

2.5 Annex

All scientific publications resulting from the ACRP project have to be included in the annex. Furthermore a list of planned, but not yet released publications has to be included (indicate, title, abstract, journal, date of submission, etc).

Any supplementary information, which is necessary to complete the final report but cannot be included in the main body of the report on account of its volume, is to be presented in the Annex. This includes studies (possibly as a “final product” of the project itself), **test reports, publications, guidelines produced, training material, etc.**

The bibliography, the list of photographs/diagrams and the list of tables are to be included in the Annex, if relevant to the project.

Note: We attached Annex Publications at the end of the report.

3 Presentation of Costs

3.1 Table of costs for the entire project duration

The following table provides an aggregated overview of the costs incurred by the applicant and the project partners throughout the entire project duration, broken down by staff costs, capital expenditure, travel expenses, administrative and material expenses, and third-party costs. It must correspond to the cost accounting form (annexed to the support contract and/or available for downloading under **www.publicconsulting.at/acrp**).

All figures in EURO.
Please add further columns for additional partners or start a new table.

Cost category	**Eligible total costs according to contract**	**Cumulative costs during the project term** Total costs for the consortium*	**Applicant BOKU-SOPH** Costs incurred during the project term 2022-2025	**Co-Appl. Partn. 1 BOKU-STAT** 2022-2025	**Partner 2 BAW** Costs incurred during the project term 2022-2025	**Partner 3 GeoSphere** Costs incurred during the project term 2022-2025	**Partner 4 CTU** Costs incurred during the project term 2022-2025	**Partner 5 BNU** Costs incurred during the project term 2022-2025
Staff costs	299916	329877	179550	103976	0	28083	7009	11259
Capital expenditure								
Travel expenses								
Administrative and material expenses								
Third-party costs								
Total	299916	329877	179550	103976	0	28083	7009	11259

* Sum total of costs incurred / cost category of the applicant and all partners

3.2 Statement of costs for the entire project duration

The costs incurred in the outstanding reporting period and over the entire duration of the project must be stated for each partner and/or each set of activities according to the cost schedule specified in the contract and the underlying application.

We attached the excel overview of cost-statement of each partner. We also provide the signed cost stamen (as .pdf).

3.3 Cost reclassification

- Presentation and motivation of cost reclassifications, if any (between partners and/or cost categories), during the duration of the project.

Please note the following: for the purposes of final reporting, copies of invoices (e.g. for capital expenditure, travel expenses, etc.) as well as detailed information on staff costs must be annexed to the cost accounting form. The ACRP Program Management reserves the right to perform random checks of the invoices submitted within the framework of the examination of the reports.

Based on the proposal, the entire project budget was allocated to personnel with no other direct costs. However, during the transfer of the partner budget to BNU (China), minor bank transfer fees (< EUR 50) were incurred; these are readily covered by the project's indirect costs. Accordingly no cost reclassification was required for EROS-A.

4 Utilization (max. 5 pages)

- **Publication**: Please describe the publication and dissemination activities carried out during the project term (project workshops, publications and presentations at external events).
- **Market**: Please outline the market outlook and the economic potential as perceived at the end of the reporting period.
- **Patents**: Please list the applications for patents filed during the reporting period on the basis of the project.
- **Doctoral dissertations**: If applicable, please list the names of the doctoral students involved in the project and indicate the status of their dissertations (doctoral dissertation started, in progress, terminated).

4.1 Publications

Project meetings and workshops

Consortium-internal "all-team" meetings

- 2022: Four hybrid/online meetings (Jan 20: Kickoff; Apr 21; Oct 13; Nov 29). The November meeting focused on ACRP reporting and Klimatag 2023 abstract development.
- 2023: Four hybrid meetings (Mar 2; Jul 3; Sep 17 hosted by BNU in Beijing; Dec 15). The December meeting focused on ACRP reporting and 2024 planning.
- 2024: One hybrid meeting (Apr 4, hosted by BNU in Beijing).
- 2025: Three meetings held (Jan 27; Jun 18; Nov 3).

Consortium-internal "specific" meetings

- 2022: Multiple in-person work sessions among BOKU-SoPhy, BOKU-Stats, and BAW-IKT, including a 2-day paper-writing workshop at BAW-IKT (Scharfling).
- 2023: Frequent targeted meetings supporting PhD research and the first manuscript (C. Vásquez).
- 2024: Nine focused meetings (Vienna) centered on manuscript development and methods; additional ad hoc discussions during EGU 2024.
- 2025: Four focused meetings (Vienna) continuing coordination around manuscripts and analyses.

Exchanges and external network meetings

- Online meeting with Iowa State University (Mar 18, 2022), attended by BAW-IKT, BOKU-SoPhy, CTU, and BNU.
- WTZ Austria-China mobility visit by Dr. Wenting Wang (BNU) to Vienna (completed by June 2024), advancing joint EROS-A research and leading to publication invitations.

Field and societal activities

- Field experiments and demonstration day at LFS Pyhra (Lower Austria) during rainfall simulations (May 2023; documented in LFS blog): https://lfs-pyhra.ac.at/blog/2023/05/30/3463/
- LFS Hollabrunn colloquium: EROS-A progress presentation (Feb, 2024).
- "30 Years Erosion Monitoring" anniversary field day and workshop at LFS Mistelbach (June, 2024), co-organized with BOKU; covered by local media (NÖN): https://bauernzeitung.at/archiv/30-jahre-erosionsforschung-in-niederoesterreich
- Netzwerk Zukunftsraum Land annual conference "Region in Focus: Precious Resource Water" (Mistelbach, Oct, 2024), with BOKU contributions and on-site demonstrations at erosion plots.

Scientific publications and conference outputs

Conference abstracts and presentations

- Klimatag Conference, Leoben (Apr 2023): ACRP project update and dissemination.

- EGU General Assembly, Vienna (Apr 2023): two abstracts/posters i) Vásquez et al. (EGU23-2588): Erosive rainfall clustering across Austria's agricultural areas. https://doi.org/10.5194/egusphere-egu23-2588 ii) Özcelik et al. (EGU23-12635): Extreme value statistics of erosive rainfall events in Austrian MAPZ. https://doi.org/10.5194/egusphere-egu23-12635
- EGU General Assembly, Vienna (Apr 2024): two abstracts/posters i) Özcelik et al. (EGU24-16545): Comparing classification methods for precipitation-event typologies. https://doi.org/10.5194/egusphere-egu24-16545 ii) Chen et al. (EGU24-19636): Extreme rainfall erosivity over mainland China. https://doi.org/10.5194/egusphere-egu24-19636
- SWAT Conference, Strasbourg (July 2024): one abstract/poster i) Vásquez Ojeda et al.: Scaling conservation agriculture from plots/hillslopes to watershed in Lower Austria. Book of Abstracts: https://swatconference.tamu.edu/#/book-of-abstracts/2024-france

Peer-reviewed SCI-publications

1. Vásquez, C., Klik, A., Stumpp, C., Laaha, G., Strauss, P., Özcelik, N., Pistotnik, G., Yin, S., Dostal, T., Gaona, G., & Strohmeier, S. (2024). Rainfall erosivity across Austria's main agricultural areas: Identification of rainfall characteristics and spatiotemporal patterns. Journal of Hydrology: Regional Studies, 53, 101770. https://doi.org/10.1016/j.ejrh.2024.101770
2. Laaha, G., Laimighofer, J., Özcelik, N. B., Fischer, S. (2024). The Role of Process Heterogeneity in Statistical Modeling. ESS Open Archive. https://doi.org/10.22541/essoar.173395745.52004395/v1
3. Klaus, V., Laimighofer, J., & Lehner, F. (2025). Brief communication: How extreme was the thunderstorm rain in Vienna on 17 August 2024? A temporal and spatial analysis. Natural Hazards and Earth System Sciences, 25(12), 4807–4814. https://doi.org/10.5194/nhess-25-4807-2025
4. Chen, L., Xiao, Y., Yin, S., Wang, W., Strohmeier, S., Vásquez, C., Klik, A., & Strauss, P. (2025). Disproportionate contributions and spatiotemporal patterns of extreme rainfall and erosivity events across mainland China. International Soil and Water Conservation Research, 100596. https://doi.org/10.1016/j.iswcr.2025.11.004
5. Vásquez, C., Klik, A., Stumpp, C., Strauss, P., Laaha, G., Özcelik, N. B., Pistotnik, G., Yin, S., Wang, W., Dostal, T., & Strohmeier, S. (2026). From means to extremes: Evaluating high-resolution gridded data for rainfall erosivity estimation in Austria. Journal of Hydrology: Regional Studies, 64, 103270. https://doi.org/10.1016/j.ejrh.2026.103270
6. Strohmeier, S., Liebhard, G., Strauss, P., Stumpp, C., Nolz, R., Vásquez, C., Schmaltz, E., Konzett, M., Brunnhuber, L., & Klik, A. (2026). Der Boden als Speicher: Landwirtschaftliche Retentionsmaßnahmen im Einzugsgebiet. Österreichische Wasser- und Abfallwirtschaft. https://doi.org/10.1007/s00506-026-01230-7

4.2 Market

The EROS-A project is oriented toward basic-to-applied research and does not pursue direct commercialization. Nevertheless, selected outputs, particularly extreme erosivity datasets/maps and return-level information, have clear application potential for agricultural insurance (e.g., risk zoning, pricing, and claims validation) and for public-sector decision support as a transparent evidence base on rainfall-disaster severity. These products could also underpin advisory services for early warning and soil conservation planning by agencies, consultants, and farmer organizations.

4.3 Patents

The EROS-A project focuses on scientific knowledge and data products and does not target patents; no patent applications were pursued or are planned.

4.4 Doctoral dissertations

EROS-A personnel support enabled the engagement of two main PhD students:

- Ms Cristina Alejandra Vásquez Ojeda; main supervision: BOKU-SOPH
- Ms Nur Banu Özcelik; main supervision: BOKU-STAT

Ms. Cristina Alejandra Vásquez Ojeda (start: January 2022) has completed the core research for her dissertation, including two first-author SCI-publications and multiple conference presentations; a third chapter on watershed modeling is outlined for manuscript development. She has met BOKU's requirements for the PhD defense, which is scheduled for April, 2026. At stage of the revised report (July 2026), Dr. Cristina Alejandra Vásquez Ojeda has been successfully defended her Dissertation. Ms. Nur Banu Özcelik (start: March 2022) initiated her dissertation with successful conference contributions and first manuscript development but terminated her PhD studies in 2024 without defense. Her early work, duly acknowledged, provided a substantive basis for the project's extreme statistical analyses.

5 Outlook (max. 1 page)

Please draft recommendations for follow-up research and development activities.

- Operational products and early warning: Convert extreme EI30 return-levels into Austria-wide maps and site-level design storms; build conservative alert workflows that combine gridded detection with local gauge anchoring for prioritizing fields and small catchments ahead of extreme events.
- Beyond MAPZ: extend to pre-Alpine/Alpine and disturbed natural landscapes: Expand analyses into higher-altitude pre-Alpine and Alpine areas, including roads, forest clearances, and tourism infrastructure.
- Climate-change robustness with temporal downscaling: Address the sub-hourly bottleneck by AI-supported downscaling that translates daily GCM outputs into sub-hourly series.

Calibrate against historical stations and disdrometers, and quantify uncertainty for return-level shifts and early-warning thresholds.

- Environmental resistance and co-drivers of erosion: Move beyond climatic forcing to quantify landscape resistance; soil erodibility (including SOC-climate interactions), vegetation/cover dynamics and phenology, and management adaptations. Couple projected SOC trajectories and crop shifts with climate to assess how changing erodibility and cover modify future erosion risk.

6 Signature

I herewith confirm that the report in its entirety has been accepted by the project partners.

Vienna, 23.07.2026

________________________________ ______________________________________

Place, date Signature of the applicant (coordinator)

Please note: the signature has to be scanned in and inserted into the document.

ANNEX (Publications)