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Rainfall input generation for the European Soil Erosion Model

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Abstract

A procedure to generate rainfall input for the EUROpean Soil Erosion Model is presented. To develop such a procedure, first of all the influence of rainfall event amount, rainfall event duration, and time to peak intensity of event rainfall on soil losses, calculated with EUROSEM, has been tested for several rainfall stations. Results revealed that every tested rainfall parameter had highly significant influence on computed soil loss. Therefore, distributions for each station of the dataset and for each of these rainfall parameters were calculated. To simulate rainfall event amounts, a mixed exponential distribution was applied. After transformation of rainfall event durations, their distribution could be simulated using a normal distribution. The location of the peak intensity was estimated using a kernel estimator, because no specific distribution characteristics could be identified. According to the respective distribution functions, parameter values for each of the tested rainfall event characteristic were then generated. These values were used to select rainfall events with identical parameter values out of the rainfall station-specific dataset. Computed soil losses for events selected this way were compared with soil losses calculated with available station specific rainfall event data. Comparisons for the respective means and medians generally revealed good agreement. A comparison of 75% quartiles resulted in less good agreement, especially for test conditions with high soil losses. In general, the applied procedure was capable of simulating station-specific soil losses and of reflecting different environmental conditions for the respective stations. Therefore, it seems possible to produce site specific appropriate rainfall input for EUROSEM, only with the knowledge of distributions for the investigated basic rainfall parameters. These are normally easier to obtain than long term rainfall information with high temporal resolution which would otherwise be necessary. In order to improve the procedure and make it practically useful, it will be necessary to account for seasonal changes of distributions of basic rainfall event parameters.

Introduction

EUROSEM, the **EURO**pean **S**oil **E**rosion **M**odel, is designed to compute sediment transport and soil erosion/deposition for individual fields and small catchments on a single event basis (Morgan, 1994). Because of its ability to calculate soil loss in small time steps within an event, it can be considered as a temporally dynamic model. As most of the erosion in a year occurs in a small number of events (Tropeano, 1984; Zuzel *et al.*, 1993; Strauss *et al.*, 1994), EUROSEM attempts to assess the erosion risk by simulating these dominant events (Chisci and Morgan, 1988).

With respect to the necessary input parameters, rainfall data of high temporal resolution are necessary to use the model; simulation results of EUROSEM depend mainly on the rainfall intensity pattern within an event and such data are generally not available to potential users. This restricts the use of EUROSEM in predicting long term erosion hazards. Therefore, simplified rainfall input procedures with better data availability are desirable.

Methodology

CONSIDERATIONS FOR MODEL SELECTION

Rainfall breakpoint data for erosion modelling have been applied in various ways.

One approach is the use of design storms (Huff, 1967; Brown and Foster, 1987), which is also widely applied by hydrologists for purposes of extreme event predictions.

Arnold and Williams (1989) calculated 0.5 hour rainfall rates, based on the assumption that event intensities follow a double exponential distribution on both sides of the storm peak intensity. The same method—part of the commonly known weather generator Cligen (Nicks and Lane, 1989)—was used to produce rainfall input for the WEPP model (Lane and Nearing, 1989). Evaluation of Cligen revealed that rainfall amounts were not modelled entirely satisfactorily (Johnson *et al.*, 1996; Favis-Mortlock, 1995), especially with respect to events with higher rainfall amounts. In contrast to WEPP and other erosion models, EUROSEM is designed to produce erosion and runoff output for very small time steps within an event. In addition, EUROSEM uses infiltration excess to compute overland flow and is therefore very sensitive to rainfall intensity changes. Neither of the above approaches is, therefore, suitable for EUROSEM.

To disaggregate rainfall events stochastically into storm increments two main methods are common. Ngyuen and Rousselle (1981), Woolhiser and Osborn (1985), and Katz and Parlange (1995), considered intrastorm rainfall intensity as a continuous process, where intensities can be represented with Markov chains of varying properties. One main problem associated with such models is the high number of parameters that are necessary to simulate time-rainfall data pairs with sufficient temporal resolution. In contrast, Rodriguez-Iturbe (1988), Onof and Wheater (1994), and Glasbey *et al.* (1995), simulated intrastorm intensities as independent point processes. Such approaches have lower parameterisation demands. They have been applied mainly to rainfall-time data pairs with hourly resolution, which is not sufficient for the current objective. Verhoest *et al.* (1997), used 10 min rainfall data to simulate design storms with success.

Due to the difficulties encountered with existing approaches, the influence of basic rainfall event information on EUROSEM's performance was evaluated. If the influence of selected basic rainfall parameters on computed soil losses was sufficiently high, the selection of appropriate rainfall events for long term erosion simulation could be based on values chosen according to the respective distribution function of these parameters at a specific station. Any rainfall event with identical parameter values could then be used as rainfall input for EUROSEM. For long-term simulations, the results of EUROSEM's calculations would give a distribution of possible soil losses, for a specific site in a particular environment, with limited data availability.

As a first approach, the distributions of the basic rainfall parameters were estimated on a yearly basis. Although this does not necessarily reflect reality, it would permit general conclusions about the capability of the procedure to generate rainfall input data for EUROSEM.

DATA SET

34 raingauge stations located throughout Austria and Bavaria were chosen (Table 1). Only events of more than 15 mm precipitation were included. Events were separated by 6 hours of less than 1.27 mm precipitation amount (Wischmeier, 1959). Following the work of Woolhiser and Osborn (1985), events were truncated at 95% of their final energy to avoid long tails of low intensities.

SELECTION OF BASIC RAINFALL INFORMATION

Although various attempts to find one index for the classification of rainfall erosivity have been undertaken (Wischmeier, 1959; Hudson, 1965; Seuffert *et al.*, 1988), the underlying basic rainfall information always was some parameter representing rainfall intensity and its closely related rainfall energy. Total rainfall energy is almost directly proportional to rainfall amount (Richardson *et al.* 1983; Bagarello and D'Asaro, 1994). Mean rainfall intensity can be calculated as rainfall amount divided by rainfall duration Thus for this work, event amount (A) and event duration (D) were assumed to be basic characteristics of every rainfall event.

Little information is available on the relationship between soil loss and the relative location of the maximum rainfall intensity (T_p) within a storm. This may be attributed to the fact, that the simulation of intrastorm soil losses is a relatively new matter of investigation in comparison to the simulation of total storm losses. For every erosion model which is capable of simulating intrastorm erosion, T_p appears to be an important rainfall characteristic. This assumption is supported directly by the work of Flanagan and Foster (1989) and indirectly by studies about the effect of cumulative rainfall energy on surface seal development (Le Bissonais *et al.*, 1989; Mualem *et al.*, 1990c; Römkens *et al.*, 1990). Therefore, T_p was also included as an influencing characteristic.

To justify the preselection of basic rainfall parameters and to prove their influence on soil loss computed by EUROSEM, six stations from the dataset (Baden, Aflenz, Graz, St.Pölten, Augsburg, München) were chosen. All their registered events (n = 554) were used as input for EUROSEM. Selection of the stations ensured that the sample was representative and reflected the different climatic conditions of the dataset. Tests with two different values of saturated hydraulic conductivity (test 1 = 10 mm h^{-1}, test 2 = 5 mm h^{-1}) were conducted. Other necessary input parameters for EUROSEM were chosen to reflect typical conditions for maize during springtime. This is generally known to be the most critical time for erosion by water in Central Europe (Strauss *et al.*, 1995).

Finally, the Spearman correlation coefficient (r_s) was used to test the influence of the preliminarily chosen basic rainfall parameters on the computed soil loss of the events. (Table 2). This was necessary because the parameters tested were not normally distributed and the relationship between tested parameters was not linear.

The influence of preselected parameters on computed soil loss was highly significant. The results for the two values of saturated hydraulic conductivity varied only slightly (not shown). Nevertheless, correlations for A and T_p were rather low. For T_p, this can be explained partially by the fact that, although computing intra-event soil losses, EUROSEM at the moment does not account for soil sealing. T_p, which is assumed to have great influence on saturated hydraulic conductivity, is therefore, at the moment, of less importance than expected. It is intended to include dynamic changes for the saturated hydraulic conductivity into the next versions of EUROSEM. This test assessed

Table 1. *Name, recorded years and number of events of the investigated stations.*

Station	recorded years	number of events	recording type
Neusiedl	13	59	no winter records *
Baden	16	88	winter records
Aflenz	16	93	no winter records
Weiz	15	151	no winter records
Graz	14	133	winter records
Rohrmoos	15	160	no winter records
Schwarzenau	16	71	no winter records
St.Pölten	15	87	no winter records
Steyr	16	140	winter records
Liebenau	15	107	no winter records
Schlägl	15	123	no winter records
St.Wolfgang	15	188	no winter records
Lienz	20	181	no winter records
Kufstein	20	291	no winter records
München	10	101	winter records
Nürnberg	10	47	winter records
Freising	10	75	winter records
Kempten	10	123	winter records
Würzburg	10	56	winter records
Hof	17	92	winter records
Passau	10	102	winter records
Augsburg	10	92	winter records
Mühldorf	14	108	winter records
Berchtesgaden	10	123	winter records
Weiden	10	48	winter records
Regensburg	10	112	winter records
Weißenburg	10	56	winter records
Bad Kissingen	10	47	winter records
Bamberg	13	75	winter records
Coburg	10	56	winter records
Oberstdorf	13	75	winter records
Darmstadt	9	118	winter records
Mannheim	9	65	winter records
Füssen	14	120	winter records

* winter period normally lasts from November to end of March

the influence of only single rainfall parameters on the computed soil loss; after evaluation of a combined parameter (mean rainfall intensity), correlation coefficients improved considerably. In addition, rainfall amount was highly correlated with rainfall energy ($r_s = 0.84$, $n = 554$). It was therefore decided to keep the preselected parameters for the simulation procedure. A Spearman correlation procedure was executed for these 3 factors, because rainfall amount and duration are generally considered to be correlated. Results show that correlations between A, D, and T_p were generally very low (only about 10% of the variance of duration and rainfall amount could be explained). Correlation between T_p and the other parameters was even worse. To prove the hypothesis of independence a Hotteling-Pabst statistic (Hartung and Elpelt, 1995) was calculated. For all stations and pairs of preselected parameters independence was confirmed ($\alpha = 0.02$) with the exception of the relationship duration–amount where independence was narrowly rejected for 3 stations.

Table 2. Spearman correlation coefficient (r_S) for computed soil loss versus selected basic rainfall parameters of the respective events for the selected stations (significance level < 0.0000001).

	D	T_p	A	Mean intensity
r_S	− 0.63	− 0.26	.23	.77

DISTRIBUTION SIMULATION

Event amount

Using a partial series of events (only rainfall amounts over 15 mm are considered), a typical distribution for event amounts is of the negative exponential type, which does not exhibit values below the mode. This characteristic can also be found for Pareto distributions, generalised Pareto distributions and mixed exponential distributions. Following the work of Smith and Schreiber (1974) and Richardson (1982), a mixed exponential distribution of the form was used:

$$f(y) = \frac{a}{\phi} e^{-\frac{y}{\phi}} + \frac{b}{\psi} e^{-\frac{y}{\psi}} \qquad (1)$$

with $\phi \geq 0$, $\psi \geq 0$, $a > 0$, $b > 0$, $a + b = 1$, where y refers to the excess of the rainfall amount over the threshold of 15 mm.

To parameterise the mixed exponential distribution the EM-algorithm of Redner and Walker (1984) was used. To prove the goodness of fit, a Kolmogorov-Smirnov test was used (Table 3): one half of the sample was used for parameter estimation and the Kolmogorov-Smirnov test was applied to the other half, to prove the goodness of fit. Equality of distributions could not be rejected for any of the tested stations. Figure 1 shows the empirical and simulated distributions for the station of Baden.

Table 3. Parameter values for the mixed exponential distribution (a, ϕ, ψ) and significance level (p) of the Kolmogorov-Smirnov statistic for the respective stations.

Station	a	ϕ	ψ	p
Neusiedl	0.60	9.77	9.95	0.64
Baden	0.87	6.40	28.44	0.55
Aflenz	0.66	5.70	13.94	0.59
Weiz	0.26	3.05	12.63	0.41
Graz	0.59	6.83	18.01	0.31
Rohrmoos	0.97	9.46	63.54	0.95
Schwarzenau	0.69	6.94	9.80	0.97
St.Pölten	0.95	9.54	54.99	0.99
Steyr	0.61	7.39	13.01	0.69
Liebenau	0.66	6.81	12.62	0.89
Schlägl	0.61	8.72	12.77	0.96
St.Wolfgang	0.81	8.80	30.10	0.91
Lienz	0.64	7.72	33.23	0.99
Kufstein	0.55	9.02	19.80	0.76
München	0.67	6.95	14.20	0.07
Nürnberg	0.66	4.32	10.92	0.64
Freising	0.54	4.91	18.73	0.90
Kempten	0.65	5.33	18.46	0.85
Würzburg	0.67	5.40	12.04	0.94
Hof	0.65	6.75	11.45	0.83
Passau	0.65	6.43	15.51	0.65
Augsburg	0.66	6.40	13.70	0.64
Mühldorf	0.62	7.86	15.87	0.76
Berchtesgaden	0.62	8.23	17.66	0.90
Weiden	0.70	5.53	9.51	0.97
Regensburg	0.65	8.05	10.10	0.80
Weißenburg	0.69	6.63	7.60	0.83
Bad Kissingen	0.66	8.29	9.22	0.87
Bamberg	0.65	5.59	14.83	0.86
Coburg	0.67	6.59	10.04	0.40
Oberstdorf	0.24	4.51	17.27	0.90
Darmstadt	0.56	4.81	14.46	0.99
Mannheim	0.89	4.28	30.51	0.84
Füssen	0.62	9.03	16.35	0.99

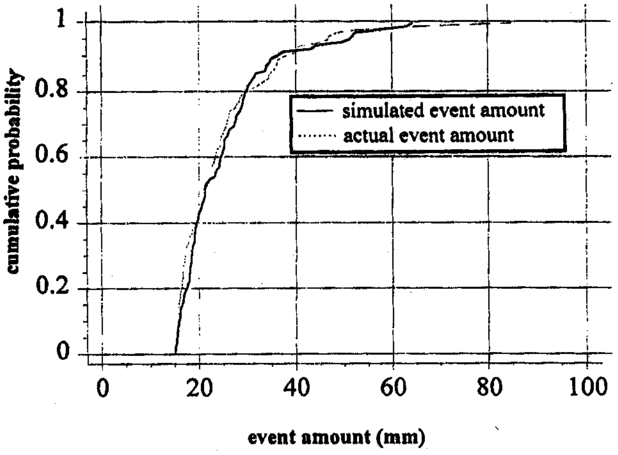

Fig. 1. *Empirical distribution function of observed versus simulated event amount for the station of Füssen.*

Event duration

After transformation of D to $D' = \sqrt{D'}$, a test of normality of D' with unknown parameters D' and $\sigma_{D'}$, using a Kolmogorov-Smirnov statistic (Lilliefors, 1967) could not be rejected for any of the stations (Table 7). Therefore, a normal distribution of the form

$$f(D') = \frac{1}{\sigma_{D'}\sqrt{2\pi}} e^{-\frac{(D'-\bar{D}')^2}{2\sigma_{D'}^2}} \qquad (2)$$

was used to generate arithmetic means and standard deviation values for D' (Table 4).This was done by application of the transformation method. Figure 2 shows the empirical versus fitted distribution for the station of Mannheim.

Relative location of the event peak intensity

If T is the time between the start of an event and the occurrence of the maximum intensity, then $T_p = T/D$ with values within the interval [0,1]. As no specific distribution characteristics could be identified, the probability density function of T_p was estimated non-parametrically, using a kernel estimator (Silverman, 1986):

Table 4. Arithmetic mean ($\bar{D}'$) and standard deviation ($\sigma_{D'}$) of the normal distribution for D' for the respective stations

Station	D'	$\sigma_{D'}$
Neusiedl	22.7	9.8
Baden	26.4	9.4
Aflenz	24.9	9.2
Weiz	22.6	8.7
Graz	25.2	8.5
Rohrmoos	29.4	9.0
Schwarzenau	25.1	9.3
St.Pölten	29.0	9.3
Steyr	28.6	10.2
Liebenau	28.1	8.4
Schlägl	30.1	10.2
St.Wolfgang	32.8	9.7
Lienz	28.2	9.5
Kufstein	30.7	10.4
München	28.5	10.1
Nürnberg	25.5	11.0
Freising	29.2	9.2
Kempten	26.9	9.5
Würzburg	26.9	7.9
Hof	25.0	9.9
Passau	28.7	8.6
Augsburg	27.3	9.2
Mühldorf	28.7	8.8
Berchtesgaden	29.9	9.4
Weiden	24.1	9.3
Regensburg	26.5	9.3
Weißenburg	26.2	9.0
Bad Kissingen	26.1	8.8
Bamberg	25.9	8.4
Coburg	26.5	8.6
Oberstdorf	31.2	9.3
Darmstadt	24.9	9.2
Mannheim	24.9	9.5
Füssen	28.8	8.5

$$f(x) = \frac{1}{nh}\sum_{1}^{N} K\left(\frac{x - Tp}{h}\right) \tag{3}$$

To estimate the density function of T_p, the Epanechnikov kernel was used

$$K(t) = \tfrac{3}{4}(1 - \tfrac{1}{5}t^2)/\sqrt{5} \qquad -\sqrt{5} < t < \sqrt{5} \tag{4}$$

$$K(t) = 0 \qquad \text{otherwise.}$$

The bandwidth was chosen with $h = 1.06sn^{-1/5}$ (Silverman, 1986), where s denotes the standard deviation and n the sample size. This bandwidth is only optimal for the Gaussian kernel; nevertheless it is commonly used as a reasonable bandwidth for other kernels. According to Table 5, the frequency distributions of T_p behaved very similarly for the respective stations. The most probable T_p of the respective stations occurred within the second quartile, having a median for all stations of 0.38, which is close to the value suggested by Arnold and Williams (1989). A median test could not detect differences (p = 0.01) between the individual stations with the exception of the station of Lienz. No attempt was made to unify the frequency distributions of T_p for the respective stations. Figure 3 shows the estimated probability density function of T_p for the station of Graz.

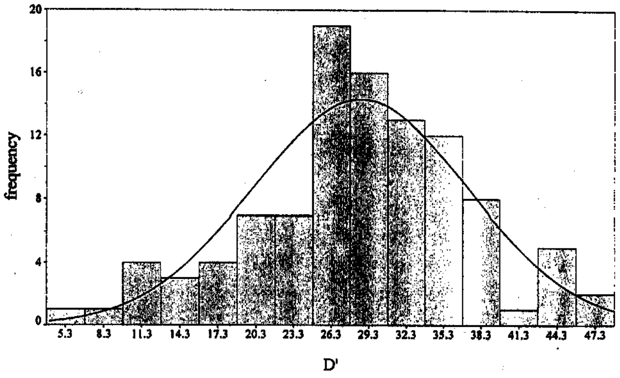

Fig. 2. *Empirical distribution function of observed versus simulated event duration (D′) for the station of Passau.*

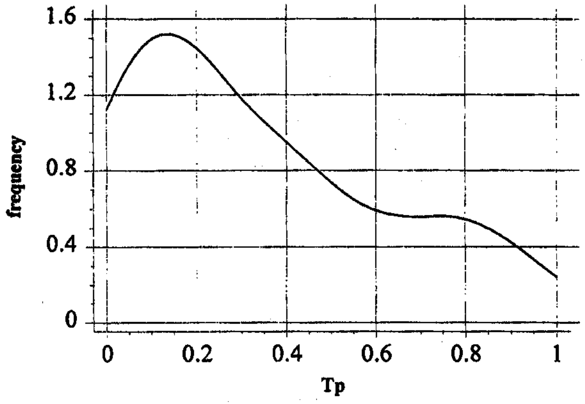

Fig. 3. *Computed relative location of the event peak intensity (T_p) for the station of Graz, using kernel density estimation.*

Evaluation of the rainfall generation procedure

To prove the assumptions about the rainfall generation procedure, erosion calculations with EUROSEM were carried out, using the existing rainfall event information for the respective station. In a second run, erosion calculations were performed with EUROSEM by applying the rainfall generation procedure, and the results were compared. Rainfall

Table 5. Percentile values and medians ($\tilde{x}$) of T_p for the respective stations.

Station	20% percentile	40% percentile	60% percentile	80% percentile	$\tilde{x}$
Neusiedl	.05	.15	.46	.61	.36
Baden	.11	.28	.41	.58	.33
Aflenz	.07	.21	.39	.60	.38
Weiz	.06	.17	.35	.59	.24
Graz	.07	.19	.37	.64	.27
Rohrmoos	.07	.22	.37	.62	.29
Schwarzenau	.09	.20	.37	.65	.31
St.Pölten	.12	.31	.50	.69	.37
Steyr	.09	.25	.46	.69	.35
Liebenau	.05	.22	.49	.70	.37
Schlägl	.06	.25	.43	.65	.29
St.Wolfgang	.06	.24	.45	.66	.32
Lienz	.19	.39	.54	.72	.48
Kufstein	.04	.17	.40	.68	.27
München	.07	.17	.37	.61	.25
Nürnberg	.11	.25	.51	.78	.43
Freising	.05	.26	.45	.75	.35
Kempten	.11	.27	.41	.65	.35
Würzburg	.10	.27	.51	.79	.41
Hof	.11	.23	.43	.64	.35
Passau	.11	.35	.56	.81	.45
Augsburg	.09	.21	.41	.72	.31
Mühldorf	.07	.23	.47	.77	.32
Berchtesgaden	.07	.15	.41	.59	.33
Weiden	.07	.31	.47	.79	.37
Regensburg	.12	.25	.52	.69	.38
Weißenburg	.17	.36	.57	.79	.48
Bad Kissingen	.11	.31	.59	.77	.47
Bamberg	.12	.27	.43	.71	.34
Coburg	.17	.27	.41	.57	.33
Oberstdorf	.15	.31	.49	.63	.40
Darmstadt	.11	.38	.51	.66	.45
Mannheim	.09	.25	.43	.69	.37
Füssen	.09	.17	.37	.55	.24

data of 6 stations (Aflenz, Baden, Graz, München, Augsburg, St. Pölten) were used, under the same testing conditions as already described (test 1, test 2). To get a good comparison with the existing rainfall data, an overall evaluation period of 20 years was chosen. The steps for the application of the rainfall generation procedure were:

- Determination of the number of erosive events (n) for the simulation period. This was calculated by the mean annual occurrence of events for the selected stations. Therefore, n varied between 100 (Baden) and 164 (Graz).
- Stochastic generation of values for the basic rainfall parameters for each of n events, according to the distribution functions for the respective station. This resulted in a set of parameter values of T_p, D', and A for each event to be simulated.
- Comparison of each generated set of parameter values with the respective parameter values of rainfall events in a database of existing rainfall events. The database consisted of all recorded rainfall events of each station of the dataset (n = 3563).
- The first event of a station whose values of rainfall parameters fitted the generated set of parameter values (tolerance values were 10% for amount, 30 min for duration and 0.1 for time to peak intensity) was selected.
- Using these tolerance values, for about 90% of the generated sets of rainfall parameter values a corresponding database rainfall event could be found. The remaining

10% of cases without a corresponding database rainfall event were discarded. Many of these cases consisted of unrealistic combinations of generated parameter values, i.e. very low rainfall amounts with very long durations.

- These selected database events were now used to calculate soil loss with EUROSEM, applying it under test conditions 1 and 2.
- The procedure was repeated five times using different starting values for the random number generator (Press *et al.*, 1994), to get five possible realisations of simulated soil losses.

As a result, Figs. 4 and 5 show the frequency distribution of soil loss simulated with the rainfall generation procedure versus soil loss calculated with existing rainfall data for the respective stations. The simulated results are given as a band of arithmetic mean ± standard deviation ($\bar{x} \pm s_{\bar{x}}$) for the five repetitions of simulation.

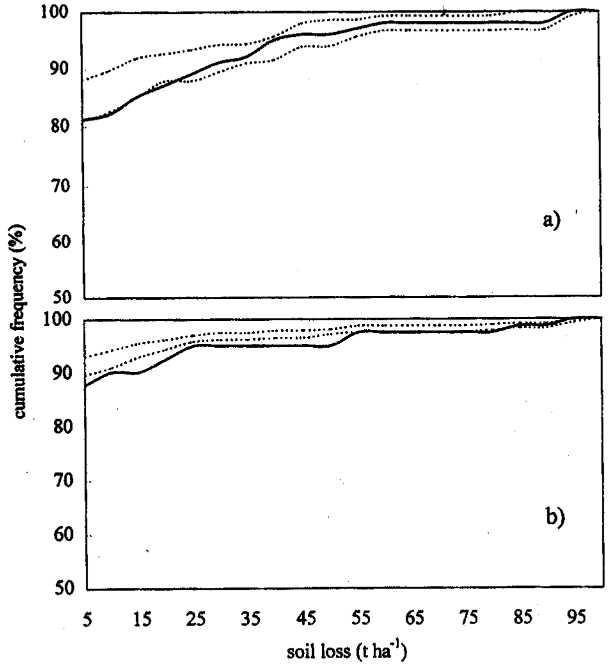

Fig. 4. *Cumulative frequency distributions of soil loss simulated with the rainfall generation procedure and soil loss, calculated with existing rainfall data for the station of Aflenz (a) and St.Pölten (b) using conditions of test 2. Simulated data are shown as bands of* $\bar{x} \pm s_{\bar{x}}$ *(n = 5).*

Generally, the simulated soil losses reflected the differences of risks of soil loss between the respective stations as well as differences due to changes in saturated hydraulic conductivity. Means and medians compared well for all stations tested but the simulated losses were consistently lower than the actual losses. For the station of Graz, the difference betwen simulated and actual losses was already high for both tests. Nevertheless, it was not possible to detect a statistical difference between means of simulated and actual soil losses for any of the stations. Independently of the station investigated, greater differences were observed for the 75% quartiles of test 1. For stations with a higher risk of soil loss, the differences between generated and observed maximum losses appeared to be greater. According to Tables 6 and 7, the soil losses for the 50 % and 75% quartiles can be interpreted as station-specific risks of soil loss in an event for probabilities of 50% and 75%, respectively, under the specified conditions.

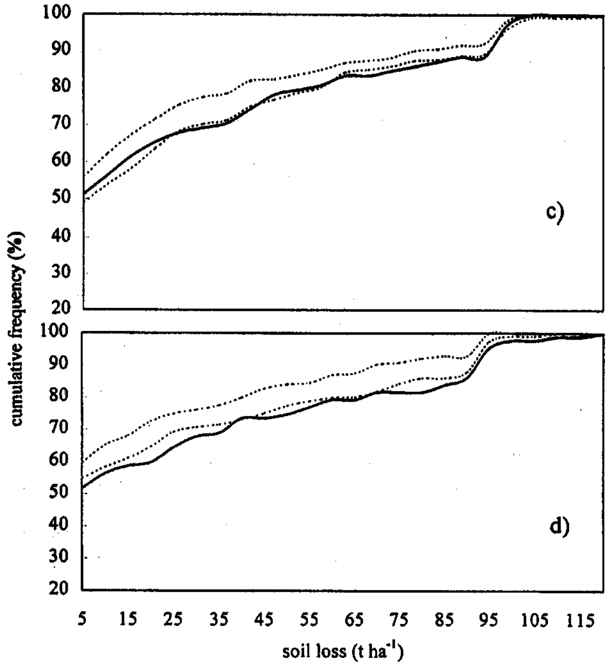

Fig. 5. *Cumulative frequency distributions of soil loss simulated with the rainfall generation procedure and soil loss, calculated with existing rainfall data for the station of Augsburg (c) and Baden (d) using conditions of test 1. Simulated data are shown as bands of* $\bar{x} \pm s_{\bar{x}}$ *(n = 5).*

Conclusions

The evaluation of the rainfall generation procedure revealed that a combination of the independent rainfall parameters, event amount, event duration, and relative time to peak intensity had a dominating influence on the calculated soil loss using EUROSEM. Therefore, it seems to be one possible way to select appropriate rainfall event data for soil risk assessment at a specific site, given only a knowledge of the distribution functions for each of these parameters. For long-term risk assessment, this offers the possibility of using event information of rainfall, independently of the location where this information was gathered. This is of special importance, as many stations do not record rainfall data with high temporal resolution, or only have a small number of years with that kind of data available.

Although the rainfall generation procedure reflected soil losses well under the conditions of evaluation, it is now necessary to simulate changes of basic rainfall parameters

Table 6: Comparison between statistical characteristics of soil loss in tons ha^{-1} (= arithmetic mean) produced with the rainfall generation procedure, and those computed with station-specific rainfall data for conditions of test 1. Simulated data are means of five repetitions of simulation.

Station	$\bar{x}$		95% CI of $\bar{x}$		maximum		50% quartile		75% quartile	
	sim.	obs.	sim.	obs.	sim.	obs.	sim.	obs.	sim.	obs.
München	21	21	± 5	± 7	103	100	1	0	32	30
Baden	21	27	± 6	± 8	100	115	1	4	36	51
Augsburg	22	24	± 5	± 7	111	96	3	3	32	40
Graz	26	34	± 5	± 7	100	132	6	18	43	63
Aflenz	28	33	± 7	± 8	100	100	7	12	53	75
St.Pölten	18	22	± 6	± 7	103	106	1	1	26	32

Table 7: Comparison between statistical characteristics of soil loss in tons ha^{-1} ($\bar{x}$ = arithmetic mean) produced with the rainfall generation procedure, and those computed with station-specific rainfall data for conditions of test 2. Simulated data are means of five repetitions of simulation.

Station	$\bar{x}$		95% CI of		maximum		50% quartile		75% quartile	
	sim.	obs.	sim.	obs.	sim.	obs.	sim.	obs.	sim.	obs.
München	4	7	± 2	± 4	95	95	0	0	0	0
Baden	4	5	± 3	± 3	93	93	0	0	0	0
Augsburg	3	3	± 2	± 3	101	76	0	0	0	0
Graz	5	9	± 2	± 4	94	106	0	0	0	0
Aflenz	6	7	± 3	± 3	93	94	0	0	0	0
St.Pölten	2	5	± 2	± 3	77	92	0	0	0	0

throughout the year. To overcome this problem, more years of rainfall data will be added to the database. In combination with an event occurrence model, it should be possible to account for seasonal changes in the distribution of erosion risks.

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