MAGNITUDE AND OCCURRENCE PROBABILITY OF SOIL LOSS: A RISK ANALYTICAL APPROACH FOR THE PLOT SCALE FOR TWO SITES IN LOWER AUSTRIA

SOIL LOSS RISK ANALYSIS: A PLOT-STUDY IN LOWER AUSTRIA

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ABSTRACT

In the course of an erosion plot experiment, variable rainfall events can occur, leading to variable magnitudes of soil loss. The long-term contribution of the soil loss events depends on both – the magnitude and the occurrence probability - but oftentimes, a limited observation period impedes the assessment of the temporal soil loss distribution.

In this research, the event based soil loss from two plot-locations in Lower Austria (Mistelbach and Pixendorf) was linked with the event based rainfall erosivity (EI_{30}), to assess the temporal soil loss distribution using long-term rainfall data from two meteorological stations in Lower Austria. For both plot-locations, a risk analysis was performed to i) assess the long-term average annual soil loss, and to ii) evaluate the contribution of incremental erosion events according to different event return periods. The risk analysis showed that in Pixendorf, the events < 20 years return period dominatingly contribute to long-term soil loss, since the contribution of the events > 20 years return period is progressively reduced through the low occurrence probability. On the contrary, in Mistelbach the soil loss magnitudes of the extreme events overcome the effect of the low occurrence probability and consequently the contribution of the extreme events (> 20 years return period) is large. The spatially variable contribution of the erosion events reveals the need for spatially customized soil conservation strategies. A risk analytical approach may help to allocate the driving events – and thus to define proper design-magnitudes for local soil conservation planning.

INTRODUCTION

Soil erosion is a world-wide phenomenon that determines the fate of the soils, landforms, vegetation and the humankind (Haregeweyn et al., 2013; Ziadat & Taimeh, 2013). It is necessary to gain insight into the relation of the magnitude and the occurrence probability of soil erosion to become aware of the risk of land degradation. Different experiments in the field enable the linkage between the rainfall erosive forces and soil erosion, but besides the different effects through the field experimental conditions (Stroosnijder, 2005; Boix-Fayos et al., 2006; Bagarello et al., 2011a), the temporal variability of rainfall affects the comparability of different research results (Nearing et al., 1999; Boix-Fayos et al., 2006). Various studies on the characteristics of rainfall (Cerdá, 1997; Diodato et al., 2012; Nunes et al., 2014) show that the low frequent extreme events tend to generate higher erosivities, also because of the larger raindrops occurring during the heavy events. The temporal variability of the rainfall erosive forces (Renschler et al., 1999) and the seasonal changing soil, crop and management conditions (Meyer & Harmon, 1992) control the temporal distribution of the soil loss. Various studies indicate that large erosion amounts source from few extreme events (Edwards & Owens, 1991; Larson et al., 1997; Boardman, 2006; González-Hidalgo et al., 2009; González-Hidalgo et al., 2012), and therefore the large extreme events control the geomorphologic formation of the land (Foster et al., 2012; Martínez-Casasnovas et al., 2013; Serrano-Muela et al., 2013).

In the past, soil conservation measures were oftentimes designed based on average annual soil loss rates (Baffaut et al.,1998), but field experimental soil loss data may be considerably affected by the occurrence (or non-occurrence) of extreme events within defined observation period (Burwell & Kramer, 1983). Soil conservation measures designed for average annual soil loss rates might fail inherent of the assessment method, and besides that, the level of protection against the extreme events is unclear. Larson et al. (1997) and Bagarello et al. (2010) proposed to design soil conservation measures with respect to defined event return periods rather than average annual soil loss rates, but in many cases the field experimental data lacks the large return period events (Boradman & Favis-Mortlock, 1999), essential for the assessment of the temporal soil loss distribution. However, there is a link between the rainfall erosive impacts and the soil erosion response. Based on plot experimental data, Bagarello et al. (2011b) verified that the normalized occurrence probability of soil loss was comparably distributed to the normalized occurrence probability of rainfall erosivity. This implies that long-term rainfall records may be used for the assessment of the temporal soil loss distribution - which is the basic idea of this paper.

In this study, soil loss data from two plot-locations in Lower Austria were linked to the event based rainfall erosivity (EI_{30}) - and long-term rainfall erosivity data, from two meteorological stations of the ZAMG, the Central Institute for Meteorology and Geodynamics in Austria, were used to assess the occurrence probability of the rainfall erosivity. A risk analytical approach (Kaplan & Garrick, 1981; Merz & Thieken, 2004) was set up to evaluate the risk of soil loss $R(SL)$ by the equation $R(SL) = E\langle SL\rangle = \int_{EI_{30,crit}}^{\infty} SL(EI_{30})\, f(EI_{30})\, dEI_{30}$. The equation shows that the expectation of the soil loss $E\langle SL\rangle$ is based on the relation of soil loss and rainfall erosivity $SL(EI_{30})$ and the temporal distribution of the rainfall erosivity $f(EI_{30})$. Considering a wide range of rainfall erosive events, the expectation of the soil loss $E\langle SL\rangle$ approximates the average annual soil loss. However, the explanatory capacity of the risk approach relates to the risk-curve development rather than the accumulated risk of soil loss

$R(SL)$ (Kaplan & Garrick, 1981). Based on the incremental formation of the risk-curve, the most affective erosion events can be identified. This allows to design potential soil conservation measures with respect to the magnitude and the return period of the driving events of a study area.

MATERIALS AND METHODS

Erosion plot experiment

The erosion sites in Mistelbach and Pixendorf, Lower Austria, were established in 1994 and 1997 (Klik, 2003). The sites are located in hilly agricultural areas, approximately 40 km north (Mistelbach), and 30 km west (Pixendorf) of Vienna. Event based surface runoff and soil loss is observed on 15 m long and 3 m wide plots in Mistelbach, and on 15 m long and 4 m wide plots in Pixendorf (Figure 1). Runoff and sediments are routed by a pipe system to an automated erosion wheel to quantify the runoff-suspension in approximately 0.1 mm resolution (Klik et al., 2004). A multi-tube divisor routes a fraction of the runoff-suspension to a storage tank, where representative samples are taken for sediment and nutrient analyses. Each erosion site consists of three plots to monitor soil erosion from agricultural fields treated by different tillage practices (Klik & Strohmeier, 2011). Average hill slope is 13.2 % in Mistelbach and 5.0 % in Pixendorf. Both sites are equipped with a meteorological station recording air temperature and on-site precipitation by a tipping bucket rain gauge. Average annual precipitation in Mistelbach is 559 mm and average annual temperature is 9.8 °C, and in Pixendorf, average annual precipitation is 637 mm and annual average temperature is 9.5 °C (Table 1). The soils in Mistelbach and Pixendorf are a silt loam, specified as Arguidoll and Entic Hapludoll, respectively.

The plot experiments are carried out during the vegetation periods from spring (after crop seeding) to autumn (harvest). Both sites are part of an agricultural research program, where the crop rotations alternate between row crops (maize, sunflower and sugar beet), planted in approximately 0.50 - 0.80 m row distance, and small grains (winter wheat, oats and summer barley), planted by drill seeding. All crops are planted in hill slope direction. The plot experiments show that the dominant soil loss occurs on the conventional tilled plots using row crop cultivation (Klik & Strohmeier, 2011). At both sites, the average annual soil loss from the conventional tilled plots using row crop cultivation exceeds 10 Mg ha^{-1}, which indicates considerable risk of land degradation. On the contrary, the average annual soil loss on the conventional tilled plots using small grains is smaller than 1 Mg ha^{-1} in Mistelbach and approximately 1 Mg ha^{-1} in Pixendorf. To assess the risk of soil loss related to agricultural conditions most vulnerable to land degradation, the present research focuses on row crop cultivation and conventional tillage practices only.

Rainfall data and rainfall erosivity

Rainfall data from the on-site rain gauges, and long-term rainfall data from two meteorological stations of the ZAMG, the Central Institute for Meteorology and Geodynamics in Austria, were used to calculate the event based rainfall erosivity (EI_{30}), using the Rainfall Intensity Summarization Tool (RIST; USDA ARS, 2011). The on-site rain gauges provide continuous rainfall data in 0.1 mm rainfall resolution. The ZAMG stations in Poysdorf, Lower Austria, approximately 11 km north from the erosion site in Mistelbach, and Langenlebarn, Lower Austria, approximately 10 km northeast from the erosion site in Pixendorf, provide continuous rainfall data in ten minute interval, ranging from 1993 to 2013.

Rainfall erosivity (EI_{30}) was calculated by the product of the single event rainfall energy and the maximum 30 minute rainfall intensity (Wischmeier & Smith,1978):

$$r_S = EI_{30} \quad (1)$$

where r_s is the rainstorm erosivity in MJ mm ha^{-1} h^{-1}, E is the rainstorm energy in MJ ha^{-1} and I_{30} is the maximum 30 minute rainfall intensity in mm h^{-1}. The rainstorm energy E was calculated by the equation of Renard et al. (1997):

$$E = \sum_{k-1}^{m} e_k \, \Delta V_k \quad (2)$$

where e_k is the energy per unit area in MJ mm^{-1} ha^{-1} and unit rainfall depth in mm of the k^{th} period, ΔV is the rainfall depth in mm of the k^{th} period, and m is the number of the presumed uniform rainfall intensity intervals (k) during the rainstorm. e_k was calculated by the equation of Brown & Foster (1987):

$$e_k = 0.29 \, [1-0.72 \exp(-0.05 \, i_k)] \quad (3)$$

where e_k is the unit rainstorm energy in MJ mm^{-1} ha^{-1} and i_k is the rainfall intensity in mm of the k^{th} period. In this research, long-interval rainfall was assigned to single events, when the incremental six hour rainfall was less than 1.27 mm (0.05 inch), which is default rainstorm event criterion of the RIST software.

Relation of soil loss and rainfall erosivity $SL(EI_{30})$

In this research, event based soil loss was related to event based rainfall erosivity, and a linear regression model $SL(EI_{30})$ was fitted to logarithmic scale data of both sites:

$$\text{LOG } SL = \alpha + \beta \text{ LOG } EI_{30} \quad (4)$$

where SL is the event based soil loss in Mg ha^{-1}, α is the intercept, β is the regression coefficient and EI_{30} is the event based rainfall erosivity in MJ mm ha^{-1} h^{-1}. The $SL(EI_{30})$ model is based to the USLE model (Wischmeier & Smith,1978), where the long-term mean annual soil loss gets assessed by the product of a rainfall and runoff factor, and multiple factors describing the soil, topography, vegetation and management. In this context, the event based rainfall erosivity (EI_{30}) used in Equation 4 corresponds to the rainfall and runoff factor of the USLE, while the regression coefficient β represents the cumulative effect of the USLE resistance-factors. However, the $SL(EI_{30})$ model differs from USLE methodology, since the logarithmic scale data used for the $SL(EI_{30})$ model causes a non-linear $SL(EI_{30})$ relation on a natural scale, when α ≠ 0 or β ≠ 1. In fact, the USLE was designed for mean annual soil loss assessment rather than process based soil erosion modelling (Kinnell 1997). On the contrary, the $SL(EI_{30})$ model was set up using event based soil loss and rainfall erosivity data to model the plot-specific soil loss response to the rainfall erosive impacts on the event level. A threshold value for incipient soil loss SL_{crit} was fixed to define the critical rainfall erosivity ($EI_{30,crit}$) at which incipient soil loss generates. The $SL(EI_{30})$ model was fitted using the statistical software R (R Core Team, 2013).

Occurrence probability of rainfall erosivity

Rainfall erosivity strongly relates to the type of rainfall, variable in space and time (Diodato et al., 2012). In the literature, different concepts are used to assess the temporal distribution of the rainfall erosivity for different study areas (Edwards & Owens, 1991; Ferro et al. 1991; Renschler et al., 1999; Bagarello et al., 2011b;

Taguas et al., 2013), which points out the spatial dependence of the process. In this research, a Generalized Extreme Value (GEV) distribution as well as a Generalized Pareto Distribution (GPD) was used to assess the occurrence probability of the rainfall erosivity using Maximum-likelihood fitting procedure (Stephenson, 2012). The Generalized Extreme Value density function can be expressed as follows:

$$f(x;\mu,\sigma,\xi) = \frac{1}{\sigma}\left[1+\xi\left(\frac{x-\mu}{\sigma}\right)\right]^{-1-\frac{1}{\xi}} exp\left\{-\left[1+\xi\left(\frac{x-\mu}{\sigma}\right)\right]^{-1/\xi}\right\} \quad (5)$$

where μ is the location parameter, σ is the scale parameter and ξ is the shape parameter. The GEV distribution requires block maxima data, whereas the GPD can be fitted to peak over threshold data (Coles, 2001). The GPD density function can be expressed as follows:

$$f(x;u,\sigma,\xi) = \frac{1}{\sigma}\left[1+\xi\left(\frac{x-u}{\sigma}\right)\right]^{-1-\frac{1}{\xi}} \quad (6)$$

where σ is the scale parameter, ξ is the shape parameter, and u is the user-adjusted threshold value. In this study, return levels up to 50 years of return period were computed using 21 years of rainfall data - conform to the advice of the DVWK (1998) to limit the range of the return period prediction to maximum two to three times the range of the observation data. The GEV distribution has a lower limit of return period prediction of one year, while the prediction range of the GPD depends on the adjusted threshold value. Both extreme value distributions (GEV and GPD) and the respective confidence bounds were computed by the statistical software program R using the packages 'ismev' (Stephenson, 2012) and 'extRemes' (Gilleland & Katz, 2011).

Soil loss risk analysis

According to the concept of risk analysis (Kaplan & Garrick, 1981; Merz & Thieken, 2004), the risk of soil loss $R(SL)$ equals the expectation of the annual soil loss $E\langle SL\rangle$. The soil loss risk was calculated by the equation:

$$R(SL) = E\langle SL\rangle = \int_{EI_{30,crit}}^{EI_{30,50}} SL(EI_{30})\, f(EI_{30})\, dEI_{30} \tag{7}$$

where, $SL(EI_{30})$ is the relation of the event based soil loss and rainfall erosivity (Equation 4) and $f(EI_{30})$ is the density function of the rainfall erosivity (Equation 5 and 6). Because of the limited range of consideration - from the incipient soil loss event ($EI_{30,crit}$) to the 50 year return period event ($EI_{30,50}$) - Equation 7 does not consider the extreme events > 50 years return period. In cases where the extreme events > 50 year return period effectively contribute to the long-term soil loss, $R(SL)$ tends to under-estimate the average annual soil loss. However, the gradient of the risk-curve at the 50 year return period gives insight the coverage of the long-term soil loss based on the range of consideration.

RESULTS AND DISCUSSION

Plot experimental data

The seasonal soil loss from the conventional tilled and row crop cultivated plots in Mistelbach and Pixendorf is given in Table 2. By far largest seasonal soil loss took place in Mistelbach in 1994, where 317.10 Mg ha^{-1} of soil loss were observed. On the contrary, several seasons exist where the observed soil loss was less than 5 Mg ha^{-1}. Based on the plot experimental data, the average annual soil loss is 38.09 Mg ha^{-1} in Mistelbach and 16.24 Mg ha^{-1} in Pixendorf.

Assessment of the relation of soil loss and rainfall erosivity $SL(EI30)$

The seasonal distribution of the rainfall amount, rainfall erosivity and soil loss was analyzed on a monthly time scale (Table 3). Rainfall erosivity corresponds to rainfall amount on an intense scale, with large values from May to August and low values in winter. In fact, the rainfall erosivity in winter might be even lower as rainfall occasionally turns into snowfall, which is not considered by the calculation of the rainfall erosivity. The seasonal soil loss distribution is shifted compared to the seasonal distributions of rainfall amount and rainfall erosivity. In Lower Austria, dominant soil erosion takes place in spring and early summer, when intensive rainstorms occur and crop cover is low (Strauss et al., 1995). The apparent transition of the $SL(EI_{30})$ relation, from the initial crop cover stage (May and June) to the well-developed crop cover stage (July, August and September) is shown in Table 3. Based on the plot experimental data, 96 % (Mistelbach) and 81 % (Pixendorf) of the soil loss was observed in May and June, even though the rainfall erosivity peaks in July. Because of this, the $SL(EI_{30})$ relations were fitted to the May and June soil loss conditions only, neglecting the low soil loss contribution during July, August and September.

The Figures 2a and 2b show logarithmic scale rainfall erosivity and soil loss data from Mistelbach and Pixendorf, labelled for month (May and June) and row crop (maize, sugar beet and sunflower). Both scatter plots (Figure 2a and 2b) approximate linear relation, and crop and month specific effects on the soil loss seem small compared to the overall variance of the data. In Mistelbach, the rainfall erosivity ranges from 14.10 to 2766.73 MJ mm ha^{-1} h^{-1}, and the soil loss ranges from 0.01 to 188.00 Mg ha^{-1}. Focusing on the large events (> 10 Mg ha^{-1}), the soil loss in

Mistelbach tends to be larger in May compared to June, but for the small events no trend is evident from Figure 2a. In Pixendorf (Figure 2b), the rainfall erosivity ranges from 5.64 to 417.84 MJ mm ha^{-1} h^{-1}, and the soil loss ranges from 0.01 to 56.64 Mg ha^{-1}. Conform to the observations in Mistelbach, no clear trend concerning crop or month specific impacts on the event based soil loss is evident from the scatter plot.

The fitted $SL(EI_{30})$ model of Mistelbach is: LOG SL = -3.952 + 1.932 LOG EI_{30}. The adjusted R^2 of the model is 0.720; the p-value for α is 1.00E-05 and the p-value for β is 1.02E-05. The fitted $SL(EI_{30})$ model of Pixendorf is: LOG SL = -3.214 + 1.841 LOG EI_{30}. The adjusted R^2 of the model is 0.767; the p-value for α is 1.70E-08 and the p-value for β is 5.72E-08. The incipient soil loss criterion SL_{crit} was set to 0.05 Mg ha^{-1}. Consequentely, $EI_{30,crit}$ for Mistelbach is 23.56 MJ mm ha^{-1} h^{-1}, and $EI_{30,crit}$ for Pixendorf is 10.94 MJ mm ha^{-1} h^{-1}. Based on long-term rainfall data from the ZAMG stations in Poysdorf and Langenlebarn, 2.14 (Mistelbach) and 3.71 (Pixendorf) events per May and June period exceed the set $EI_{30,crit}$ criterion. This matches to 2.88 (Mistelbach) and 3.50 (Pixendorf) soil erosion events recorded per May and June period in the course of the erosion plot experiments.

Assessment of the occurrence probability of rainfall erosivity

The occurrence probability of the rainfall erosivity in Mistelbach and Pixendorf was assessed based on long-term rainfall data from the ZAMG stations in Poysdorf and Langenlebarn. Generalized Extreme Value (GEV) distributions (Equation 5) and Generalized Pareto Distributions (GPD) (Equation 6) were fitted to block maxima (GEV) and peak over threshold (GPD) data, representing the May and June time-interval. Based on this, the term of the ‘event return period’ in years relates to the probability of a specific event to occur in the May and June time-interval of a year.

The fitted GEV distribution for Mistelbach has the parameters: location μ = 53.44, scale σ = 49.88 and shape ξ = 0.78. The positive shape parameter ($\xi > 0$) indicates a type-III (Weibull) extreme value distribution. The fitted GPD distribution for Mistelbach has the parameters: scale σ = 20.38 and shape ξ = 0.83. The threshold value u adjusted for Mistelbach is 22.0 MJ mm ha^{-1} h^{-1}, including 3.83 % of the data.

The fitted GEV distribution for Pixendorf has the parameters: location μ = 93.87, scale σ = 69.52 and shape ξ = 0.11. The positive shape ($\xi > 0$) indicates a type-III (Weibull) extreme value distribution. The fitted GPD distribution for Pixendorf has the parameters: scale σ = 65.40 and shape ξ = 0.09. The threshold value u adjusted for Pixendorf is 30.0 MJ mm ha^{-1} h^{-1}, including 3.82 % of the data.

The most apparent difference using either GEV or GPD model refers to the predicted return levels of return periods T < 2 years (Figure 3). Since the GEV distribution is unable to compute return levels T < 1 year, the GEV model may lack the ability to predict the $EI_{30,crit}$ level for Mistelbach and Pixendorf. However, $EI_{30,crit}$ for Mistelbach is 23.56 MJ mm ha^{-1} h^{-1} wherefore the optimum shaped GEV predicts a 1.12 year return period and the GPD predicts a 0.46 year return period. Both return level predictions (GEV and GPD) approximate at the 2 year return period, at which the GEV predicts 74.62 MJ mm ha^{-1} h^{-1} and the GPD predicts 85.58 MJ mm ha^{-1} h^{-1}. The 50 year return level is 1344.34 MJ mm ha^{-1} h^{-1} using GEV distribution, and 1268.93 MJ mm ha^{-1} h^{-1} using GPD, while the confidence bounds range from approximately 833 to 1855 MJ mm ha^{-1} h^{-1}.

The GEV and GPD predictions for Pixendorf differ particular at $EI_{30,crit}$, as the GEV distribution onsets at the 1.10 year return level, which is related to 35.88 MJ mm ha^{-1} h^{-1}, while the $EI_{30,crit}$ assessed for Pixendorf is 10.94 MJ mm ha^{-1} h^{-1} (Figure 3b). However, the GEV and the GPD model approximate at the 2 year return period, where the GEV model predicts 119.78 MJ mm ha^{-1} h^{-1} and the GPD predicts 137.75 MJ mm ha^{-1} h^{-1}. The 50 year return level is 431.99 MJ mm ha^{-1} h^{-1} using GEV distribution and 415.52 MJ mm ha^{-1} h^{-1} using GPD, while the confidence bounds range from approximately 363 to 494 MJ mm ha^{-1} h^{-1}.

The different extreme rainfall characteristics of Mistelbach and Pixendorf confirm the spatial variability of the rainfall erosivity in Lower Austria discussed by Klik & Konecny (2013). Both sites are located within 50 km distance, but the temporal distributions of the rainfall erosive forces differ significantly. In Mistelbach, the mean monthly rainfall amount is lower, but the rainfall erosivity of the low frequent extreme events in May and June tends to be larger compared to Pixendorf. In particular the rainfall erosivity of the 50 year return period event is three times larger in Mistelbach compared to Pixendorf.

Assessment of the occurrence probability of soil loss

The occurrence probability of the soil loss was assessed through the linkage of the $SL(EI_{30})$ model (Equation 4) and the extreme value distribution of the rainfall erosivity $f(EI_{30})$ (Equation 5 and 6). Figure 4 illustrates the event based soil loss of Mistelbach and Pixendorf, plotted against its return period T. The soil loss distribution of Mistelbach (Figure 4a) demonstrates low soil losses for T < 10 years, but the soil losses apparently increase for T > 10 years. The predicted return level for the 50 year return period in Mistelbach is 123. 67 Mg ha^{-1} using the GEV, and 110.62 Mg ha^{-1} using the GPD model. On the contrary, the soil loss distribution of Pixendorf (Figure 4b) indicates a moderate increase of the soil loss curve with increasing return periods. The predicted return level for the 50 year return period in Pixendorf is 43.44 Mg ha^{-1} using the GEV and 40.44 Mg ha^{-1} using the GPD model. However, the development of the confidence bounds given in Figure 4 foreshadows a fast-growing area of prediction uncertainty.

Assessment of the soil loss risk

A risk analytical approach was used to assess the contribution of incremental soil loss events for given return periods T. The risk-curve of Mistelbach shows a constant gradient over the whole range of consideration (Figure 5a), which indicates a uniform soil loss contribution of incremental return periods. In fact, the steep risk-curve gradient at the 50 year return period implies that the extreme events > 50 year return period may contribute effectively to the long-term soil loss. As a consequence, the risk analytical approach tends to under-predict the average annual soil loss of Mistelbach. The total risk of soil loss $R(SL)$ of Mistelbach is 3.62 Mg ha^{-1} using the GEV, and 3.40 Mg ha^{-1} using the GPD model. The risk-curve formation shown in Figure 5a implies the dominant impact of the large extreme events in Mistelbach. However, specific quantification of the impacts of the large extreme events (T > 50 years) requires prolonged rainfall data.

The risk-curve of Pixendorf (Figure 5b) shows a steep gradient up to approximately 10 to 20 years of return period and a distinct flattening from 10 to 50 years of return period. This indicates that the risk analysis - bounded by the 50 year return period -

covers the dominant soil loss occurrence of Pixendorf. Based on the risk-curve, 85 % (GEV) and 89 % (GPD) of the expectation of the annual soil loss refers to the events where T < 20. This is in opposite to the findings from other study (Edwards & Owens, 1991; Larson et al., 1997; Boardman, 2006; González-Hidalgo et al., 2009; González-Hidalgo et al., 2012), where few extreme events are most effective on entire soil loss. However, the risk-curve points out the cumulative effect of incremental return periods rather than the impact of a specific erosion event. In fact, a few extreme events between 10 and 50 years return period cause one third of the long-term soil loss, whereas multitudes of events < 10 years return period accumulatively may cause two thirds of the long-term soil loss in Pixendorf. However, Figure 5b shows apparent difference whether using the GEV or the GPD model to assess the risk of soil loss in Pixendorf. This refers to the limitation of the GEV model to predict events related to return periods > 1 year, whereby the soil loss contribution from the events T < 1 year is neglected. The expectation of the annual soil loss in Pixendorf is 6.49 Mg ha^{-1} using the GEV, and 9.03 Mg ha^{-1} using the GPD model.

Usage of a risk analytical approach for soil conservation design

A risk analysis can help to identify the driving erosion events of a study area to be used as a basis for technical soil conservation design. The soil loss risk-curve discloses the accumulative contribution of the erosion events related to its statistical return periods T. Once the risk-curve flattens out within the range of consideration (Figure 5 b) the risk-curve development provides information about the soil loss contribution (on an annual basis) of the return period increments. According to this, each point at the risk-curve separates the expected soil loss contribution into an undershooting and an exceeding part. A critical event can be determined where the exceeding part of the risk-curve matches the tolerable annual soil loss rate of the study area. The technical design of a soil conservation structure such as a hill slope intersecting and/or runoff routing measure (e.g. terraces, stone bunds, grass buffer strips) can be implemented with respect to the surface runoff and sediment yield rates generated by the critical event. As a consequence, the conservation structure prevents from soil erosion up to the critical event-magnitude. Few extreme events might generate runoff and sediment yield rates exceeding the conservation-capacity of the structure, leading to long-term soil loss within acceptable range.

CONCLUSIONS

A risk analytical approach was used to gain a deeper insight into the temporal distribution of the soil loss at two plot-locations in Lower Austria (Mistelbach and Pixendorf). Plot experimental data shows that 96 % (Mistelbach) and 81 % (Pixendorf) of entire soil loss generates in May and June when intensive rainstorms occur while the crop cover is low. However, the risk analysis indicates different erosion regimes for Mistelbach and Pixendorf. In Mistelbach, the magnitudes of the large extreme events overcome the effect of its low occurrence probabilities, and therefore the large extreme events effectively contribute to the long-term soil loss. On the contrary, the long-term soil loss in Pixendorf is mainly caused by a large number of frequent erosion events (T < 20 years return period), while the contribution of the large extreme events is negligible. Since both sites are located within 50 km distance the obtained results point out the spatial variability of the soil erosion issue in Lower Austria. Spatially variable erosion reveals the need for spatially customized soil conservation. A soil loss risk analysis discloses information about the most effective erosion events of a study area usable for the definition of a critical event-magnitude.

Dimensioning of a soil conservation measure can be related to the surface runoff and sediment yield rates generated by the critical event. This allows the adjustment of the conservation level related to a tolerable soil loss rate or a specific soil loss prevention ratio.

However, the practicality of the risk analysis may be limited due to a couple of requirements. Wide range of soil loss data (including extreme events) is required to ensure robust modelling of the rainfall erosivity and soil loss relation. Moreover, long-term and high resolution rainfall data is needed for the extreme rainfall statistical procedures.

Anyhow, since the risk of land degradation is affected by both magnitude and occurrence probability of soil loss - including events of several return periods - limited soil loss data available may impede the long-term soil loss assessment in many cases. A risk analytical approach allows the identification of the driving erosion events of a study area, which enables the assessment of the local soil conservation needs for sustainable agriculture.

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Table 1. Description of the erosion sites in Mistelbach and Pixendorf.

Parameter	Mistelbach	Pixendorf
Location	lat 48° 35' N	lat 48° 17' N
	long 16° 35' E	long 15° 59' E
Elevation (m asl)	245	260
Average annual rainfall (mm)	559	637
Average annual temperature (°C)	9.8	9.5
Plot length (m)	15	15
Plot width (m)	3	4
Average slope (%)	13.2	5.0
Soil texture	Silt loam	Silt loam
Sand (%)	12.6	30.6
Silt (%)	69.5	63.1
Clay (%)	17.9	6.3
Organic matter content (%)	2.0	2.1
Rock fragments (%)	< 5	< 5

Table 2. Overview of the seasonal soil loss from the conventional tilled and row crop cultivated erosion plots in Mistelbach and Pixendorf. The alternating soil loss data refer to the row crop - small grain crop rotation, performed on both plot-locations.

Season	Crop	Location	
		Mistelbach	Pixendorf
		Mg ha^{-1}	Mg ha^{-1}
1994	Maize	317.10	-
1995	-	-	-
1996	Sugar beet	3.25	-
1997	Maize	-	3.19
1998	Sunflower	19.77	-
1999	Maize	-	20.50
2000	Maize	0.00	-
2001	Sugar beet	-	1.91
2002	Maize	12.10	-
2003	Maize	-	4.13
2004	Sunflower	0.04	-
2005	Sunflower	-	1.97
2006	Maize	0.34	-
2007	Maize	-	10.07
2008	Maize	0.21	-
2009	Maize	-	20.95
2010	Maize	6.14	-
2011	Maize	-	78.16
2012	Sunflower	21.99	-
2013	Sunflower	-	5.29
Average		38.09	16.24

Table 3. Monthly distribution of rainfall, rainfall erosivity and soil loss in Mistelbach and Pixendorf. The rainfall data source from the ZAMG stations in Poysdorf and Langenlebarn, and range from 1993 to 2012. The monthly distributed soil loss of Mistelbach differs slightly compared to Table 2 due to some non-assignable data.

	Mistelbach			Pixendorf		
	Rainfall	Rainfall erosivity	Soil loss	Rainfall	Rainfall erosivity	Soil loss
	mm	MJ mm ha^{-1} h^{-1}	Mg ha^{-1}	mm	MJ mm ha^{-1} h^{-1}	Mg ha^{-1}
January	29.0	8.3	-	28.8	7.6	-
February	25.9	8.3	-	26.3	6.7	-
March	41.9	15.1	-	43.9	16.4	-
April	38.1	21.6	-	43.3	25.9	-
May	59.4	102.4	19.41	65.3	97.9	1.72
June	68.3	145.5	16.15	88.3	186.8	11.36
July	82.3	222.3	1.18	93.8	198.3	2.27
August	61.7	90.8	0.34	78.3	130.5	0.75
September	51.6	51.5	0.01	62.6	64.6	0.14
October	32.5	14.8	-	37.7	16.2	-
November	34.4	10.2	-	34.4	11.1	-
December	33.4	7.5	-	34.5	7.4	-
Average	558.6	698.6	37.09	637.2	769.4	16.24

Figure 1. Conventional tilled erosion plot in Mistelbach showing seedbed conditions in April (a), and pre-matured maize crop stage in Pixendorf in end of May (b).

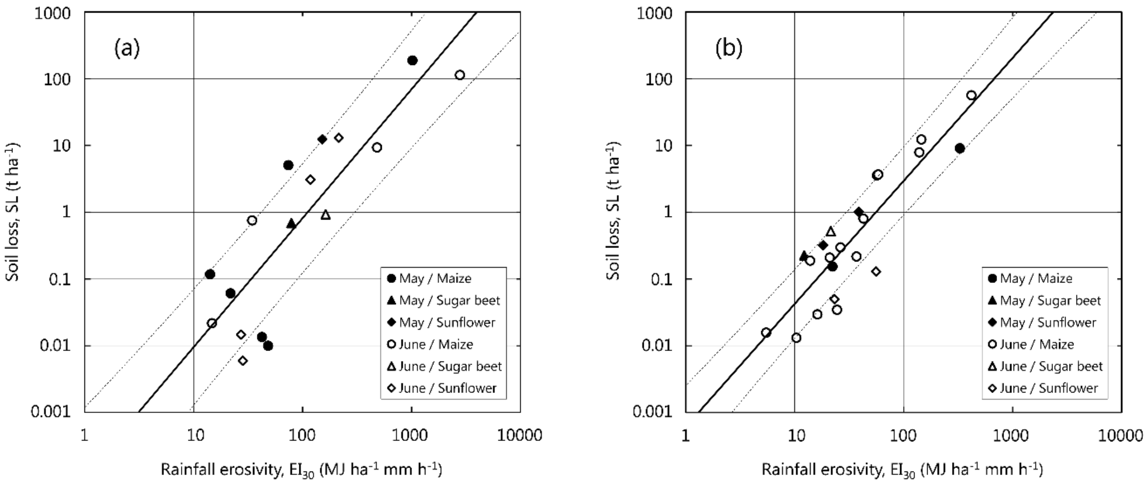

Figure 2. Event based rainfall erosivity (EI_{30}) and soil loss in Mistelbach (a) and Pixendorf (b). The solid lines indicate the fitted $SL(EI_{30})$ regression models and the dashed lines indicate the standard prediction errors (68.3 %).

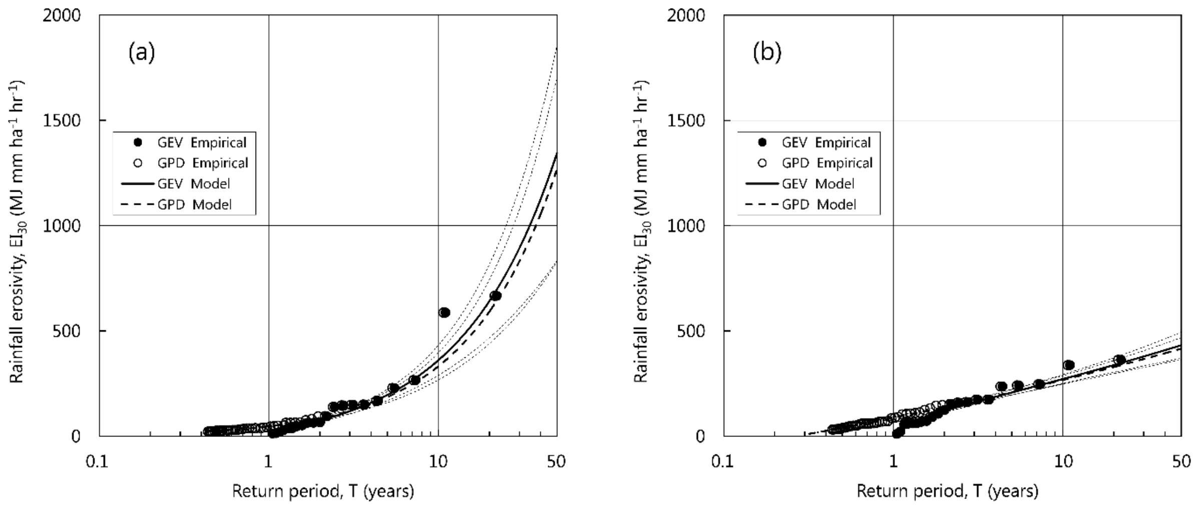

Figure 3. Return period plot of the rainfall erosivity (EI_{30}) in Mistelbach (a) and Pixendorf (b). The dashed lines indicate the GEV and the solid lines indicate the GPD models. The rainfall data source from the ZAMG stations in Poysdorf (a) and Langenlebarn (b) and range from 1993 to 2013. The confidence bounds indicate the standard prediction errors (68.3 %) of the GEV and the GPD models.

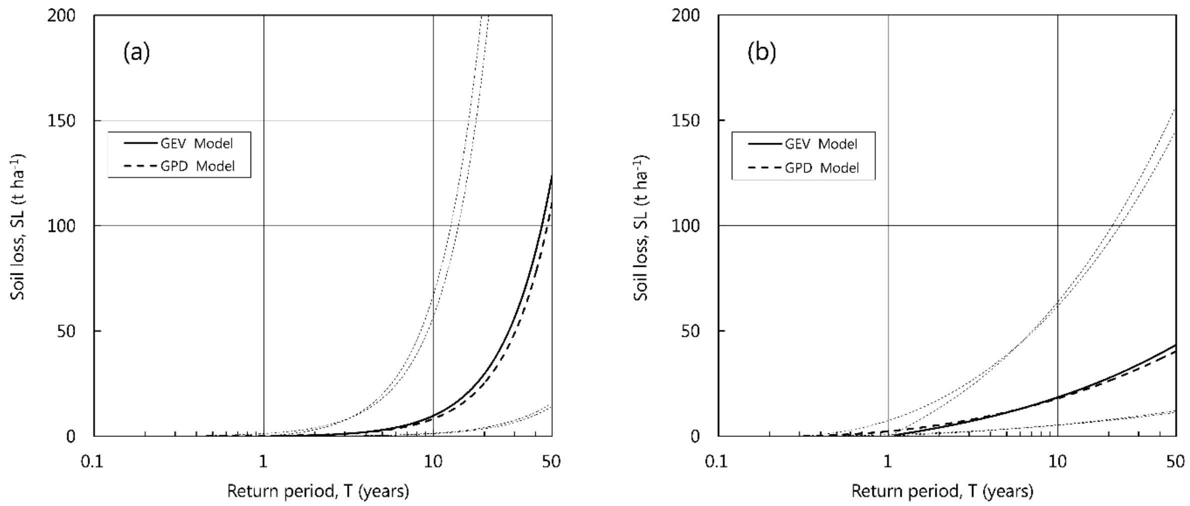

Figure 4. Return period plot of the soil loss (SL) in Mistelbach (a) and Pixendorf (b). The dashed lines indicate the GEV and the solid lines indicate the GPD models. The rainfall data source from the ZAMG stations in Poyssdorf (a) and Langenlebarn (b) and range from 1993 to 2013. The confidence bounds indicate the standard prediction errors (68.3 %) of the $SL(EI30)$ regression models.

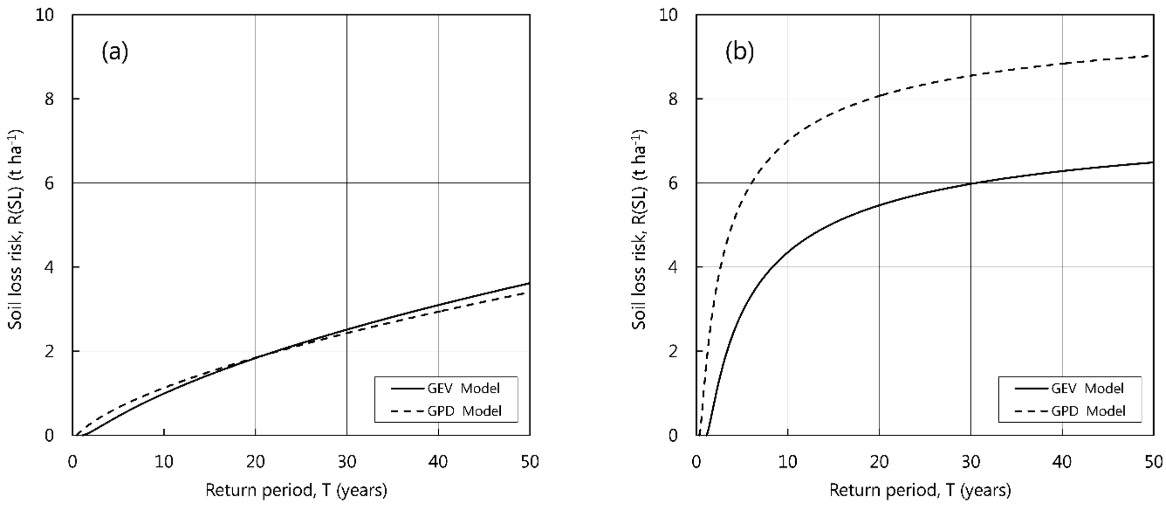

Figure 5. Soil loss risk curve ($R(SL)$) of Mistelbach (a) and Pixendorf (b). The dashed lines indicate the GEV and the solid lines indicates the GPD models.