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METHOD FOR ESTIMATION OF THE FREQUENCY OF SEDIMENT DISASTERS

METHODE ZUR ABSCHÄTZUNG DER HÄUFIGKEIT VON WILDBACH-KATASTROPHEN

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ABSTRACT

According to the assumption of temporal and spatial independence of torrent disaster events with sediment transport, a procedure of determination for magnitude-frequency-pairs will be developed and suggested. The procedure is modelled on frequency analysis, using records of disaster events in Austria for the period 1972 - 2001 of the Forest Technical Service. It derives a "specific sediment deposition amount" (SpA_{101}). By this factor it becomes possible, to compare and combine spatial distributed disaster events within a given time and to estimate the frequency-magnitude-couples. The comparison of events in uncontrolled and controlled or partially controlled torrents gives the possibility of an efficiency analysis. During a corresponding refinement of the procedure (development of Torrent Hazard Classes), a quantification of mitigation measures will be possible. Further the data have been analysed to get frequencies of different specific sediment-classes. The results allow the differentiation of the different causes, processes of the disaster and also a differentiation of areas. These results show a fractal behaviour.

Key words: debris flow, return period, fractal behaviour

ZUSAMMENFASSUNG

Unter der Annahme zeitlicher und räumlicher Unabhängigkeit von Wildbach-Ereignissen mit Sedimenttransport wird ein Verfahren für die Ermittlung von Ausmaß – Häufigkeitspaaren vorgeschlagen und zur Diskussion gestellt. Das Verfahren baut auf Häufigkeitsanalysen auf und verwendet Aufzeichnungen des Forsttechnischen Dienstes von Ereignissen in Österreich für den Zeitraum 1972 –2001. Für den Vergleich ungleich großer Einzugsgebiete wird eine „spezifische Größe“ (SpA_{101}) abgeleitet. Dieser Wert ermöglicht es, räumlich auseinander liegende Ereignisse zeitlich zusammenzuführen und dadurch die Beobachtungszeit scheinbar zu erweitern. Die vorliegenden Daten erlauben in Österreich für den SpA_{101}-Wert Frequenz–Magnitude-Werte anzugeben. Ein Vergleich der Häufigkeit von Ereignissen in unverbauten und verbauten/teilverbauten Wildbächen lässt eine Effizienzbetrachtung zu. Bei entsprechender Verfeinerung des Verfahrens (Ableitung von Wildbach-Gefährlichkeitsklassen) ist eine

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Quantifizierung der Leistung von Schutzmaßnahmen möglich. In diesem Zusammenhang werden auch Häufigkeiten für das Auftreten von bestimmten spezifischen Ablagerungsgrößen vorgestellt, welche die Analyse der Daten auch unter Gesichtspunkten der fraktalen Geometrie zulassen.

Schlüsselworte: Murgang, Jährlichkeit, fraktales Verhalten

INTRODUCTION

During the past decade great efforts have been undertaken in the German-speaking countries of Middle Europe, especially in Switzerland, to go ahead from the widely used subjective risk appraisal towards an objective appraisal (Gheorghe & Seiler, 1996). In particular Hollenstein (1997), Heinimann et al. (1998) and Ammann (2001) have provided contributions to the objectification of risk appraisal (integral risk-management) in the field of risk research dealing with natural hazards.

For a risk analysis, as desired for hazard mapping and for the planning of control works, and also for comparison of the yield of sediment during disasters, the occurrence probability of events of a certain size is required. Risk is defined as the product of the amount of damage multiplied by the occurrence probability (frequency) multiplied by the presence probability multiplied by an aversion factor. The method of frequency analysis, which after the selection of an extreme-value distribution allows an extrapolation of rare events, requires adequately long time series for the respective catchment area (interpretation of probability based on frequency, Gheorghe & Seiler, 1996). Often these time series are not available, particularly in the case of sediment disasters. Besides they are valid only in the catchment area from which they were derived.

Owing to the fact that the data material is very limited, the method of the traditional frequency analysis is rather unreliable and often even cannot be applied. Therefore a method will be offered using data records for some decades in a bigger area (Austria). The idea is to use ranks or relative frequency for different values of magnitude of the events. For this investigation data records of the Forest Technical Service (FTD) of Austria are used.

DESCRIPTION OF DATA RECORD

The FTD of Austria records floods and sediment disasters since 1972. The record is completed until 2001 and therefore covers 30 years. The data are managed by the Austrian Federal Office and Research Centre for Forests ("Bundesamt und Forschungszentrum für Wald") in Vienna (Andrecs, 1995a et b). These records are used to select 2648 sediment disasters from a total of 4122 events.

The data of the records are structured in serial number of the event, year, administrative characteristic feature, geographical feature, name of the torrent, size of catchment area [km²], date of the event, cause of the event, duration and amount of precipitation, kind of process, amount of erosion, amount of deposition and degree of control.

The records were checked before using. The accuracy of the estimated or measured data is different and depends on the kind of data. The size of the catchment area is a measured value. But there could be recognized some inconsistency for some torrents. The questionable values were checked and corrected in cases were the catchment areas were well known to the first author or it was selected the more plausible value of two or three values (the value of more accuracy). The used value of the amount of sedimentation is an estimation, done by the experts of the FTD. In this sense the accuracy of this values is low but because of the expert estimation it is much better than nothing. If some inconsistency in these values was recognized, the original records were compared with the data bank and corrected if necessary.

Some big events are lacking in the record, like the events of 1987 in the area of Saalbach in Salzburg or in other areas of Pinzgau/Salzburg. Therefore the record is incomplete. Nevertheless, for mainly parts of the investigation of this ***methodical work***, these circumstances are not important.

MOTIVE FOR THE INVESTIGATION:

Generally, the probability of the occurrence of an event is estimated on the basis of the experience of local experts - in Austria by the FTD - because only in very rare cases data for torrents and avalanches, which can be applied in the statistics, are available on discharges or sediment depositions over a longer period of time. Depending on how much responsibility the employee has and for how long he has already been working, various events will happen during the life-time of such an expert. The bigger events will be stored in the consciousness and, sinking into the subconsciousness after a while, become part of the rich experience of the expert. From the scientific point of view such a concept of probability belongs to the ***subjective interpretation*** of probability. Hazard mapping and the design of mitigation measures need an ***objective interpretation*** of the return period of events for calculation of the optimal economic conditions. Therefore there is a need of a method for appraisal of the magnitude and frequency pairs of disaster events.

A MEASURE OF THE SIZE OF AN DISASTROUS EVENT:

The risk analysis shows that the magnitude and the probability of occurrence of an event is a pair belonging together. Different disastrous processes have different size criterions. Events with sediment transport and sedimentation, either the material ready for erosion (debris potential) or the deposited yield of sediment suit best. In the flood and disaster records of the FTD yields of the sediment are recorded. These values are used. To compare different catchment areas it is necessary to create a specific yield of sediment (SpA_{ab}). To derive this value the general formula

$$SpA_{ab} = \text{amount of sedimentation } [m^3] / (A_E + b)^a \quad (1)$$

is used. A_E: size of catchment area [km²] (the area from where the amount of sediment is coming); a: exponent (0.333 to 1.0), b: parameter (0 to 1.0; mainly 0.1). The most appropriate parameters are: a = 1.0, b = 0.1.

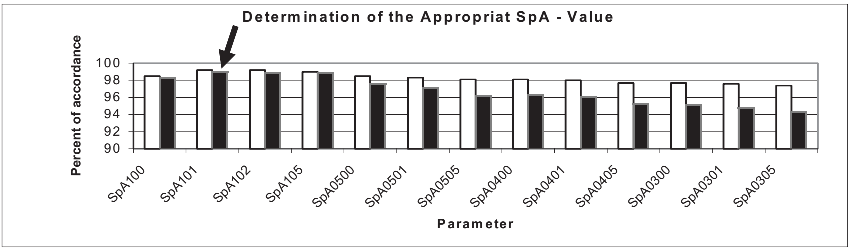

Fig. 1: Comparison of different SpA-values. The most appropriate combination of parameter a = 1 and b = 0,1 (SpA_{101} arrow) explain 99 % of the measured values and the predicted values. White columns: regression coefficient of SpA derived from measured values versus predicted values, black columns regression: regression coefficient measured sedimentation yield versus calculated yields.

Abb.1: Vergleich von verschiedenen SpA-Werten. Der SpA_{101}-Wert mit den Parametern a = 1 und b = 0.1 erklärt 99% aller kalkulierten Ergebnisse und erweist sich dadurch als am besten geeignet.

FREQUENCY ANALYSIS:

Basic considerations

Joining SpA-data from different areas of whole Austria is on the one hand a problematic venture because it is not possible to fulfil all conditions of the strong claims of mathematical statistic. The SpA-values can not be really independent, because every process in nature is unique and every erosion process leaves behind micro gullies which influence the following process of runoff and erosion. Therefore the next event in principle depends on the antecedent event. In this sense all hydrologic frequency analysis of runoff could be problematic in regard of strict mathematical statistics because of the influence of the micro river-net on the creation of floods. But some hints in the literature about dependence in data for frequency analysis look hopeful (e.g. Gumbel 1958, Kotz & Nadarajah 2000). To use values with weak dependence is possible, if events are spatially jointed, only if events have a sufficient spatial distance and also sufficient time difference, that means that they are not included in the same rain-event (censored data). The randomness of the data is given like any analysis of precipitation. An other possibility to get independent data is the use of randomly generated samples from the data-set (compare Table 1). The stationarity of the data seems to be given if one looks at the time record of the maxima (compare Fig. 4). The claim for identical distribution is difficult to fulfil in spatial distributed data. In literature there are hints to deal with this problem (Sveinsson et al. 2002, Gabriele & Villani 2002, Ashkar 1996). Regional homogeneity of the data (Torrent Hazard Classes) is a possibility to come over with this problem.

Because the data of SpA_{101} are developed from *measured* data (catchment area) and *estimated* values (sediment yield) with a relative low quality, and due to the aim of the investigation, to get only very rough estimations of the order of size of the SpA-values versus return periods, it seems to be allowed, to derive return periods with simple methods of frequency analysis like least square regression (compare van Gelder & Vrijling, 1998) with transformed variables (distribution of censored data or randomly generated subsets of the data). An accuracy frequency analysis with a sophisticated statistical distribution and different methods of parameter estimation like maximum likelihood, L-moments and so on would not be correct considering the quality of the data. Considering the sceptic attitude of Klemeš (1987) to sophisticated frequency analysis too, it seems permitted to use a method as simple as possible. For the purpose of this investigation the statistic software DataDesk vr. 6.1 was mainly used because of convenience, the easy possibility to transform the data, the visual presentation, and the simple possibility for calculations.

On the other hand we need estimated values of specific sediment yields to compare estimations for risk analysis, to compare different regions or countries with different geology or rain pattern.

At this time in Austria we have co-ordinates only of communities to use disaster events in a GIS. Therefore in this investigation all data with a geographical reference are managed on the community level.

Results of frequency analysis with censored data

Censoring of the ***restricted data-set*** (debris flow as process, catchment area between 0.4 and 25 km²) uses the following rules: events of the same datum are rejected if they are within an area of about 80 km. In this case only one value (the <u>highest one</u>) is included in the area of a community. If some periods of storm rains last some days in a region, one event is selected within about 5 days. This rule lead to very high SpA_{101}-values (worst cases).

To get straight lines for regression analysis the data are transformed as described here:

SpA_{101}-values in the square root, the ranks, frequencies or probabilities (plotting positions) in logarithm (basis 10). For the regression the SpA-values higher as the mean of the maximum are selected and employed for return period calculation.

The whole censored data set for Austria (East-Alps) encloses 332 events in 277 torrents. There are two possibilities to get values for magnitude / return period pairs.

Method used by Chegodayev ex Weingartner (1998)

The formula describing the risk (R) that an event of a special return period (rp) occurs within a time interval (ti: 30 years in our case) is

$$R = 1 - (1-1/rp)^{ti} \qquad (2)$$

The risk exceeding 50% within a time period of 30 years delivers a return period of about 43,7 years. This return period would belong to the highest SpA-value in the censored record.

The maximum SpA_{101}-value of all censored SpA-values is about 175.000. But in the torrent of this magnitude only two events in 30 years are reported. The amount of this high value is doubtful. The method described above is used for ***single*** rivers or precipitation measure stations.

In a data set with ***mixed data of a lot of rivers***, it seems that this method can not give correct results. A value of that size has occurred in one torrent of about 2605 dangerous torrents. It seems very unlikely that an event of a return period of about 50 years has a size of the order of 200 000 SpA_{101} or 200 000 m³ in a catchment with an area of 1 km². A rough estimation in the Alps for a 100 year event is about 50 000 m³/km² (Schlaepfer & Vischer, 1988, p. 18). In our data set are a lot of events with only one occurrence per river within 30 years, the magnitude of which are between SpA_{101} = 2.8 to 83 333. The mean of them is about SpA_{101} = 2080. Therefore an other method to estimate the magnitude / return period pairs seems to be necessary and should be developed.

Area frequency method

The SpA_{101}-values (X) are sorted in falling direction and ranked. The probability is calculated by the plotting position formula of Cunnane (1978, cit. by Salas et al. 1994)

$$P(X \geq x_i) = (i - \alpha) / (N + 1 - 2*\alpha) \qquad (3)$$

with $\alpha = 0$, well known as Weibull-formula. It is derived from the ranks (i), N: max(rank) = number of events (Chow et al., 1988, p. 396).

The idea of the procedure is, to unify the spatial data in ***one abstract torrent (standard river)*** of the area of investigation. One problem, which emerges due to the joining of different rivers is the increase of the number of events within the investigation period. The other problem is that the record only contains peak over threshold series (POT) and not annual-maximum-flood series (AMF) (compare Ashkar 1996). The recorded disasters count a maximum of 5 events per river and 241 rivers with only one event within 30 years. The average is about 1.2 events per river. So the sediment yield of the recorded disasters is much higher than the annual-maximum sediment yield. Therefore it is necessary to adapt the plotting position procedure for such a POT set. Salas et al. (1994) and Bayliss & Reed (2001) give some hints to deal with POT series and offer the plotting position formula

$$p_i = ((i - \alpha) / (k + 1 - 2*\alpha)) * (k / ti) \qquad i = 1, ..., k \qquad (4)$$

p_i: probability for index i (rank), ti: investigation period (30 years), k: number of events above a threshold (x_0).

These formulas (3, 4) are valid for one river. If we include numerous rivers we have to divide the p_i-value by the number of rivers involved in the POT set, to unify the data for a standard river. The formula (4) have to be extended by the term 1/number of rivers (n_r).

$$p_i = ((i - \alpha) / (k + 1 - 2*\alpha)) * (k / ti) * (1 / n_r) \qquad i = 1, ..., k \qquad (5)$$

For every river (torrent) in the censored data record we calculate the maximum value, the mean and the higher moments (DataDesk offer a lot of different possibilities of summary and order statistics). The threshold $\boldsymbol{x_0}$ of SpA_{101} will be defined as the ***mean of*** these ***maximum values***. In the set of SpA-values we look for the value which corresponds in size with the record. The corresponding rank will be determined. For this rank (c) the p_c is calculated by the formula (5). As a next step we calculate the average of events (m_r) for the rivers (e.g. if 100 events in 50 rivers occur, 2 events per river is the result). The average of events (m_r) in the investigation period (ti) delivers the occurrence-probability

$$p_o = m_r / ti. \qquad (6)$$

If we relate the p_i-value and the p_o-value we get a factor which allows a "parallel" displacement of the distribution density function to get probabilities of occurrence for the standard torrent. The formula

$$U = p_c / p_o \qquad (7)$$

with U: changing factor, is used to transform the plotting position values from the original distribution to the distribution of the standard river. The log-distribution of the standard river and the root of the SpA-values are used to create a regression. With the parameter of this regression, predicted values for different probabilities and therefore return periods can be drawn.

$$p_U = p_i / U \qquad (8)$$

$$SpA = (a * Log\,(p_U) + b)^2 \qquad (9)$$

The same procedure is also used for the randomly generated sub-set of the same data-set used for censoring. 6 sub-sets are generated and the mean calculated. Both results are drawn in Table 1.

Tab. 1: Range of the SpA_{101}-values predicted as the average of Austrian torrents, derived by area-frequency method. Column 2: mean of random samples, column 3 results of censored data (worst case).
Tab. 1: Spannweite der SpA_{101}-Werte berechnet als Durchschnitt über ganz Österreich, abgeleitet mit Hilfe der „Area-Frequency Methode". Spalte 2: Mittelwert aus Zufallsstichproben, Spalte 3 zensorierte Stichprobe (Höchstwerte, entstanden durch Auswahl der jeweils größten Wertes von mehreren).

Return period	SpA_{101}-values (random)	SpA_{101}-values (censored)
1000	28 300	91 800
500	20 800	67 800
250	14 400	47 300
150	10 500	34 600
100	7 800	26 000
50	4 200	14 000
25	1 700	5 700

Torrent Hazard Classes

The geographical distribution of events and their magnitude show some interesting pattern: There are some regions with a higher number of events and some regions with higher SpA-values. Therefor a hazard level is developed on community level - represented by the centroid point of the community area. The number of events as well as the amount of SpA-values are arranged in 5 classes (censored data-set). The Torrent Hazard Classes are the result of adding the classes of number of events and the SpA-classes, dividing by 2 and rounding. The number of events are equal distributed, the SpA-values are approximately logarithmic distributed. With an ordinary point kriging estimator (e.g. Cressie 1991) a grid with a cell size of about 1 km * 1 km and as depended value the hazard class will be developed in the software-package "Surfer 7.0". This grid will be imported into ArcView 3.2 and meshed to a TIN. The result is shown in Fig. 2. For these Torrent Hazard Classes SpA-values are correlated with return periods and are predicted with the area-frequency method.

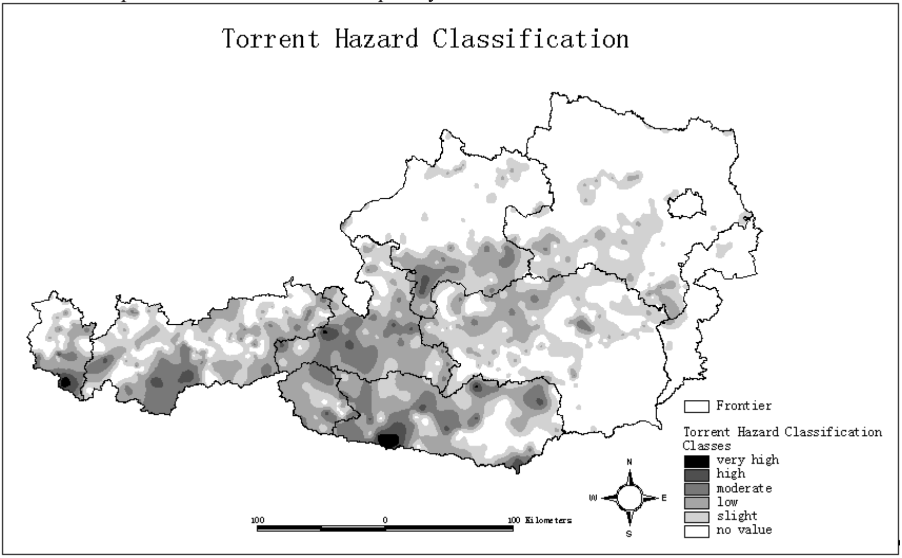

Fig. 2: Provisional Torrent Hazard Classes in Austria.
Abb. 2: Vorläufige Wildbach-Gefährlichkeitsklassen in Österreich.

Tab. 2: SpA_{101}-values for 4 different Torrent Hazard Classes and the three most important return periods in Austria. The SpA-values of class 2 follow a distribution different from the others. Danger class 1 is very low. The return period of 100 show a SpA-value of 40. One value in the record of class 3 is very unlikely and probably wrong and in this table removed. All values developed from censored data: ***worst cases***.
Tab. 2: SpA_{101}-Werte für 4 verschiedene Gefahrenklassen und den 3 wichtigsten Jährlichkeiten in Österreich. Bemerkenswert ist, dass bereits die 2. Gefährlichkeitsklasse in ihrer Verteilung von den höheren abweicht. Die 1. Klasse ist sehr niedrig und erreicht beim 100 jährlichen Ereignis nur mehr 40. Innerhalb der Gefährlichkeitsklasse 3 wurde der höchste Wert eliminiert, da er im Vergleich unwahrscheinlich hoch ist und auf einem Aufzeichnungsfehler beruhen könnte. Alle Werte aus zensorierten Daten und daher ***obere Grenzwerte***.

Return period	Class 5	Class 4	Class 3	Class 2
150	66 600	51 400	30 700	6 400
100	53 600	39 800	23 700	5 900
50	34 600	23 300	13 700	4 700

Because the arrangement of the classes has a big influence on the size of the SpA-values, table 2 should be seen as preliminary results. More investigations are needed in connection with the distribution of rainfall events and the geology.

FURTHER INVESTIGATIONS OF THE FULL DATA SET (2648 EVENTS)

Time series of SpA-values

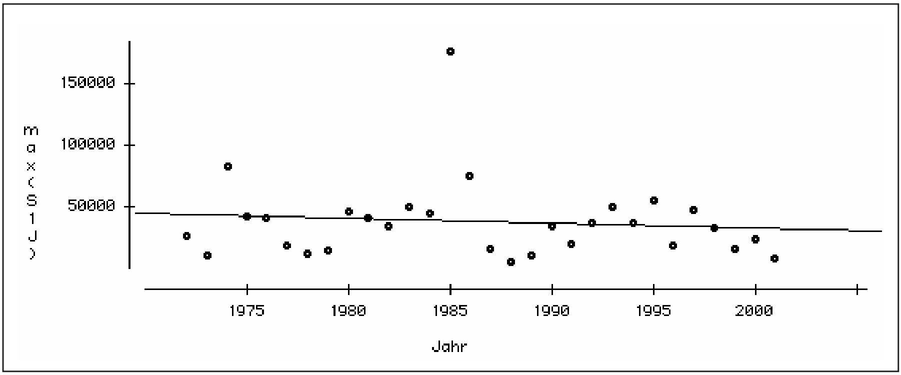

Fig. 3: during the 30 years of the investigation period the SpA-values of the maxima per year is nearly constant. Only a very weak falling tendency can be recognized. Therefore a stationary state of the maxima is stated, because the standard deviation is in the order of the mean.
Abb. 3: Innerhalb der 30 jährigen Beobachtungszeit blieben die Maxima der SpA-Werte fast konstant. Eine nur sehr geringe fallende Tendenz ist zu beobachten. Daher wird eine Stationarität der Daten angenommen, da obendrein die Standardabweichung der Maxima in der selben Größenordnung liegt, wie deren Mittelwert.

Relative frequency of the SpA-values

If the SpA-values are classified by a regular distance of e.g. 3000 SpA dimensions, the logarithms of the counts or the relative frequency and the logarithms of the class values follow a straight line (Tab.3 & 4, Fig. 4). It seems, that ***fractal dimensions*** or ***power law behaviour*** can be interpreted.

Different processes of natural hazards show a power law behaviour (Jensen 2000, Bak 1997, Ito 1995, Schroeder 1991). The Gutenberg-Richter relation of the magnitude of earthquakes show such a power law behaviour with exponents between 1.8 and 2.2. The result of a power law behaviour of the SpA-values is also similar to the relationship between diameter of crater impacted by meteorites or length of faults and their frequency. Fractal dimension 2.0 is almost common in both phenomena. Because the sediment yield is resulting from a destruction phenomena similarity can be thought as satisfied.

The clear differentiation of the sediment transport processes demonstrates the importance of a accuracy distinction of processes in future records. The influence of it on the SpA-value explains the different behaviour of meteorological and geological features of the landscape.

In the Figures (5 to 7) the intercepts and slopes of the different regression lines are shown in the formulas. With this parameters some prediction for different processes or regions is possible. In the Figure (7) a comparison of SpA-values of controlled rivers (partly and full) and uncontrolled rivers is shown. If mitigation measures are efficient the relative frequency of a SpA-class should be smaller than that of uncontrolled rivers. Effective measures reduce the frequency of the same amount of SpA-values; in an other interpretation increase the return period of the same SpA-value.

Tab. 3: Frequency breakdown of SpA_{101}-classes (classes with a distance of 3000 SpA101-values are developed („Group" 0 – 3000 -> 1500, 3000 – 6000 -> 4500, ..) and the number of events falling in this group are counted („count")

Tab. 3: Häufigkeitsanalyse der SpA-Klassen („Group"); Zahl („Count") und relativer Anteil (%) der Ereignisse

Total Cases	2648	
Number of Categories	21	
Expected	126.095	
Chi-square	35458.1	

Group	Count	%
1500	2176	82,175
4500	245	9,252
7500	81	3,059
10500	44	1,662
13500	27	1,020
16500	20	0,755
19500	14	0,529
22500	7	0,264
25500	6	0,227
28500	3	0,113
31500	4	0,151
34500	4	0,151
37500	2	0,076
40500	5	0,189
43500	1	0,038
46500	2	0,076
49500	2	0,076
55500	1	0,038
73500	1	0,038
82500	2	0,076
85500	1	0,038

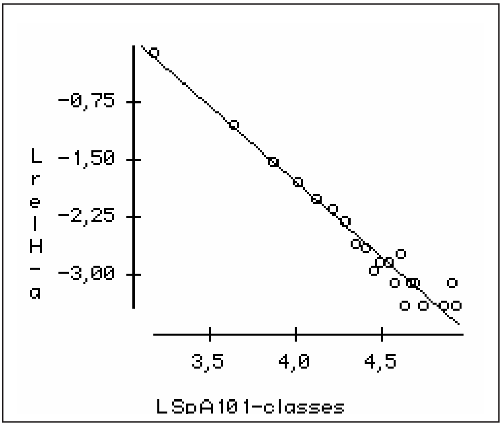

Fig. 4: Scatterplot of the Log-SpA_{101}-classes vrs. log-relative frequency of the SpA-classes

Abb. 4: Streuungsdiagramm der Log-SpA_{101}-Klassen vrs. Log-relative Häufigkeit der SpA-Klassen

Tab. 4: Results of the regression calculation: R^2: regression coefficient, s: standard deviation of regression line, s.e. of coeff. Standard deviation of intercept (constant) and slope of regression line ($LspA_{101}$ classes).

Tab. 4: Bestimmung der Regressionskonstanten: R^2: Regressionskoeffizient, s: Standardabweichung der Regressionsgeraden, s.e. of coeff: Standardabweichung des Achsenabschnittes (Constant) bzw. der Steigung der Regressionsgeraden ($LspA_{101}$ classes).

R squared = 95,7% R squared (adjusted) = 95,4%
s = 0,1867 with 21 - 2 = 19 degrees of freedom

Variable	Coefficient	s.e. of Coeff	t-ratio	prob
Constant	6.07635	0.4228	14.4	0,0001
$LSpA_{101}$ classes	-1.96327	0.09579	-20.5	0,0001

Mitigation measures only could be seen as efficient ones, if, before controlling measures were done, the river had had much higher SpA-values (factor 2). This means for example, that a SpA_{101} = 26 000 of controlled rivers (return period of 100 years) corresponds to a SpA_{101} = 52000 (return period of about 300 years) before control works were done (compare Tab 2).

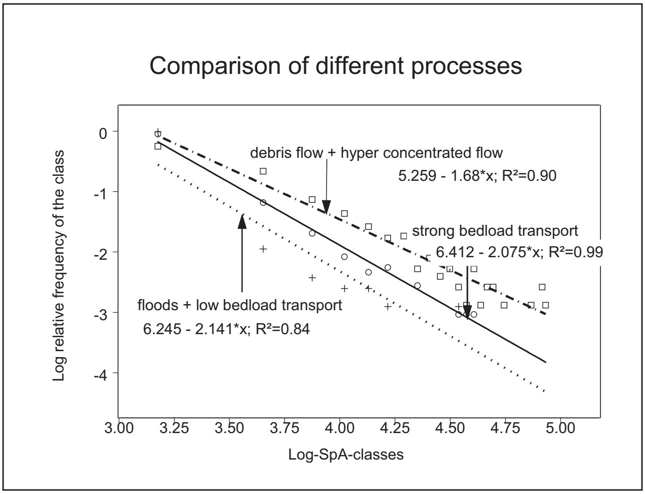

Fig. 5: The comparison of different processes like floods and low bedload transport, strong bedload transport and sediment transport by debris flow + hyper-concentrated flow clearly show separated regression lines. The equations show the intercept and the slope of the regression line.

Abb. 5: Ein Vergleich der verschiedenen Prozesse (Hochwasser + leichter Geschiebetrieb, starker G. und Murgang + hyperkonzentrierter Fluss) zeigt deutliche Unterschiede in den Gefällen und Achsenabschnitten der Regressionsgeraden. Der Achsenabschnitt und die Steigung ist den zugehörigen Formeln zu entnehmen.

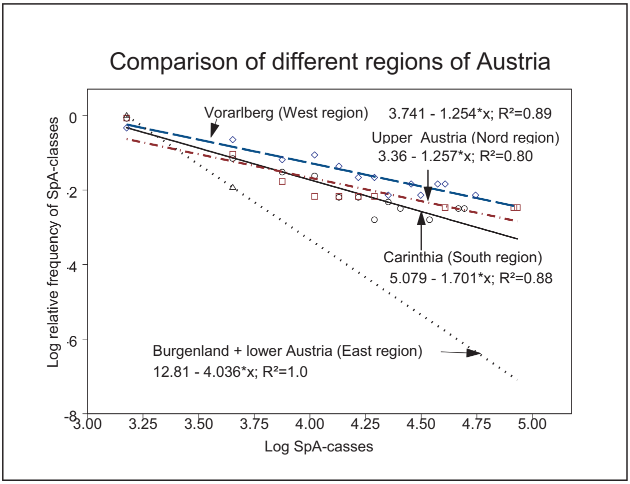

Fig. 6: In different regions of Austria (East: Burgenland + Lower Austria), West (Vorarlberg), North (Upper Austria) and South (Carinthia) the frequency of SpA-classes differ clearly. Carinthia shows a high relative frequency of strong debris flow events. The steep inclination of the regression line of the East region depends only on 2 values and therefore has to be carefully interpreted.

Abb. 6: Verschiedene Regionen in Österreich (B + N.Ö = Ostregion, V = Westregion, O.Ö = Nordregion, K = Südregion) zeigen klar differenzierte Steigungen der Regressionsgeraden. Bei der Ostregion ist für eine Interpretation wegen der geringen Anzahl von Werten Vorsicht geboten.

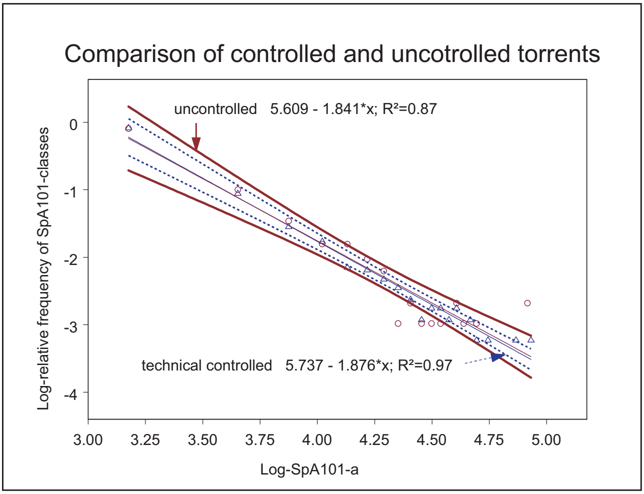

Fig. 7: Comparison of controlled and uncontrolled torrents in Austria at a confidence level of 0,95. The blue data has a smaller confidence region because of much more data = much more torrents are controlled than uncontrolled. The controlled rivers show the same relative frequency as the uncontrolled rivers.

Abb. 7: Vergleich relativer Häufigkeit von verbauten und unverbauten Wildbäche in Österreich. Der Vertrauensbereich (95%) der verbauten Bäche (blau und strichliert) liegt innerhalb von dem der unverbauten (rot, ganze Linien). Er ist enger wegen der viel größeren Zahl verbauter Bäche.

CONCLUSION

With some small restrictions it seems possible to get better values of the sediment yield of torrents in the order of return periods, if records of areas are included in the evaluation. The “area-frequency-method” offers a possibility to solve this problem. By using frequencies of specific sediment yields it is possible to distinguish different processes, areas and to check the efficiency of mitigation measures.

LITERATURE

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