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Morphology of Basin of Debris Flow

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Abstract: Morphology of small drainage basin is in principle the same as general basins, disregarding its scale. Data concerning characteristics of basins of debris flow, from *The DataBase of Debris Flow in China*, are used in this paper to examine their properties in small scale. In fact, distributions of characteristic factors, including area, length, elevation, gradient, and degree of incision, of drainage basins of debris flow, are subject to distributions in the unique form of the generalized Gamma distribution, i. e., in special cases, the Weibull distribution, Gamma distribution and others alike, only distinctive in the value of parameters. The unification of distributions for various factors indicates some invariance of scale in the drainage system, with power laws hidden behind. Some power relations have been actually revealed, i. e., that between length and area, length and gradient, gradient and area, etc.. All the power exponents differ from those supposed theoretically for drainage evolution at some stable states, enhancing our belief in the periodicallity of debris flow that occurs only in some special phase in the evolution history. On the other hand, debris-flow surges of the Jiangjia Gully reveal another power relation between discharge and flow depth, which corresponds to that between discharge and area for usuall flood process, and therefore prove its validity for debris flow as well. The consistency in all respects ensures that appearances of debris flows in regions are also representative for debris flow in individual basins. Then, debris flow in a certain basin finds its origination from the drainage pattern.

Key words: debris flow; drainage basin; probability distribution; power exponent; morphology

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1 Introduction

Drainage patterns are derived from geomorphologic evolution, specifically, from processes of erosion. Therefore, modeling fromation of drainage basin, either dynamically or stochastically, is actually often modeling surface erosion, (e. g., Shreve, 1966, 1967, 1969; Smart, 1968; Willgoose, et al., 1991; Willgoose, 1994; Howard, 1994; Talling, 2000). Most confirmations for those models are the resulted relations that have been generally observed, like the power relation between basin area and stream length (Hack, 1957; Gray, 1961; Leopold, 1964). On the other hand, debris flow is perhaps the most active agent in erosion. Frequently, it changes slopes and gullies in relatively small scale of time and space, and consequentially, it occurs in certain stage of the basin evolution. We know that debris flow forms under special circumstances, hence basins that witnessed the very occurrences in history or at present are necessarily in some special conditions differing from others. In the present paper, these basins will be under considerations specifically, and the data involved are from *The Database of Debris Flows in China*, consisting 6000 basins with characterstic factors determined, established under the special support of Chinese Academy of Sciences (for the details of the data base, see Zhong et al., 1997).

First of all, debris flow always occurs in basin of small area, much smaller than the "small" ones in the sense of hydrology. Then we are faced with tiny basins in the study of debris flow. According to the data, over 60% of the basins are in area of less than $5km^2$, 75% less than $10km^2$, and 95% less than $50km^2$. Even from the several

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figures can one simply find a decaying in power of basin number with increasing area: $N(>A) \sim A^{-m}$, with index $m=0.92$—a fact we've explored in detail for other case (Li et al., 2002)*. In comparison, basins mustered in the classical researches such as those of Hack (1957) and Leopold (1964) expand in a much larger scale range, from magnitude of 1km^2 or less to 10^7km^2, including the greatest rivers all over the world, like the Rio Amazonas, Nile, Yangtze, Yellow, and Mississippi. Intuitively, the large-scale effect would blot out the small one if they were taken into account in the same statistics. Then it is of necessity to expose details in small scale for drainage basins, the de facto units of active erosion, or more specifically, of the geohydrologic processes.

In general, pattern of drainage network is an eloquent and somewhat a synthetic expression of the geohydrologic phenomena for a basin. In particular, debris-flow basins are exclusively of the dendritic pattern, one of the generally identified sorts in nature (Howard, 1967; Gregory and Walling, 1973). And, basins of dendritic pattern, being likely to possess moderate characteristics, hold the utmost probability of appearance. That is to say, most of the basins are assigned averaging values for geometric properties, according to analysis of Ichoku and Chorowicz (1994). One might find in the fact further relation between the drainage structure and the formation of debris flow. Practically, drainage pattern is characterized by essential geomorphologic and geometric factors, i.e., the drainage area, the maximal distance from outlet to the utmost source (or, the maximal length of the channel for proxy), drainage density, magnitude and order of the unbranched segment of stream (Strahler, 1952; Shreve, 1967), bifurcation ratio (Horton, 1945), stream—flow direction (Morisawa, 1963), junction angle (Lubowe, 1964), and special indices for the plane shape of the basin like the form factor (Horton, 1932), basin elongation (Schumn, 1956), and lemniscate (Chorley et al., 1957). Factors like magnitude, order, and density, although crucial to specific individuals, are difficult to determine in regional studies, and hence byeond the scope of our discussion here. Drainage pattern and characteristic parameters find their significance in influencing hydrologic processes in somewhat a deterministic manner, as learned from the empirical relations in practice, say, $Q=k M^a F_1{}^b R^c$, which involeves magnitude and the first order frequency of the basin, F_1, as well as other factors like drainage density (M), relief ratio (R) (Patton and Baker, 1976; Patton, 1988). One may expect the same impact of these factors on the occurrence of debris flow.

What focused on in the present paper are factors concerning the geomorphologic circumstance of the basin: area, elevation, length and gradient (or slope as referred in some literatures) of the channel, which are also dominant in developing debris flow.

2 Morphometric index of debris flow basin

An index has emerged from the statistic of debris flow basins in China (Tang and Li, 1997), which surprisely falls into a concentrated domain, (2.5, 3.5), for the absolute majority of the basins. The index, β, relates area (A) and perimeter (p) of the boundary of the basin in the way that

$$A=p^2\exp(-\beta) \tag{1}$$

And it is as well a pretty indicator for the shape of a basin. One might easily find its equivalence to the basin circularity R, introduced by Miller (1953), $\beta=\ln(4\pi/R)$, and its correspondence to the shape of basins. In fact, this very exponet represents the departure of a basin boundary from the circle. Usually, bigger exponent corresponds to a farther departure, in elongation or irregularity. (By the way, it is also somewhat a planimetric index for it can be used in estimating the drainage area through the shape.) For the tiny basin concerned, elongated basins are almost those of the least order and immature rills on slopes. In other words, this exponent is as well the indicator for evolution of the basin, at least of statistic means. One can see this clearly from comparison with, for example, the low-gradorder basins in the source area of Jinagjiagou, Yunnan. The range of average and variance of the exponent are listed in table 1:

* Li Yong, Hu Kai-heng, and Cui Peng. 2002. Distribution of basin and the probability of debris-flow occurrence. (In press)

Tabel 1 Morphometric index of basins with different order

Basin order	1st	2nd	4th	8th	Average(China)
Average area	0.023	0.059	0.067	0.29	12.83
Range of β	(3.07, 6.14)	(3.26, 5.52)	(3.28 4.95)	(3.11, 4.37)	(2.55, 4.10)
Average of β	4.33	4.00	3.83	3.60	3.11

Interesting is the converging tendency of the index range and average with the ever increasing order of basin. And, of more significance is the way it converges, i.e. the average of the index decreases in manner of a power curve: $\beta \sim n^{-r}$, where n is the order, and the exponent here, r, is expecting an explanation that is possible only in comparison between special individuals. Correspondingly, the average area increases, however, in the manner of exponential curve with the order, appearing to be not in so much coincidence with the order— law of Horton which expressed area as a geometric progression with the bifurcation ratio. Anyhow, relation of the morphometric index to the order is of special significance in the context of evolution of drainage basin.

3 Distribution of characteristics of the basin

Power law is ubiquitous in drainage basins and their hydrologic processes. Among other things possessing the property, well-known are freqency of basin area or discharge (Rodriguz-Iturbe et al., 1992), and of the channel length of given order (Tarboton et al., 1988). On the other hand, one usually finds distributions of other forms, e.g., links in a channel network seem to present distribution approaching Gamma (Abrahams and Miller, 1982). It is the case for most of the characteristics. A skewed distribution is usually found simply by drawing a histogram for factors like the morphometric index, gradient of the main channel, elevation difference (relief), and incision of the basin. Actually, all the factors involved possess distributions near the form of Normal, Gamma, and Weibull. For instance, distribution of the index β is fitted by these forms and plotted for comparison in Fig. la. Similar distributions are also conspicuous for other characteristics, as shown in Fig. 1b ~ f, with parameters listed in table 2.

Tabe 2 Distribution parameters of characteristic values of debris-flow basins

Distribution	Parameter	Area	Length	Gradinet	Elevation	Incision	Morphometry
Weibull	α	0.55	0.68	(4.52)	(7.03)	(4.91)	3.36
	β	3.00	2.74	(4.06)	(99.17)	(2.27	0.38
Gamma	α	0.26	0.45	2.22	2.50	3.37	44.96
	β	0.02	0.08	0.01	0.002	0.03	140.20
Power	Exponent	1.47	1.78	(* values in brackets are those of logarithmic distr.)			

To incorporate all the distributions, including the power form, it is reasonable to presume a generalized exponential distribution, i.e. the genaralized Gamma distribution (e.g. Kalbfleisch and Prentice, 1980)

$$g(x, \lambda, \rho, \kappa) = \lambda\rho(\lambda x)^{(\rho\kappa-1)}\exp(-(\lambda x)^{\rho}) / \Gamma(\kappa) \tag{2}$$

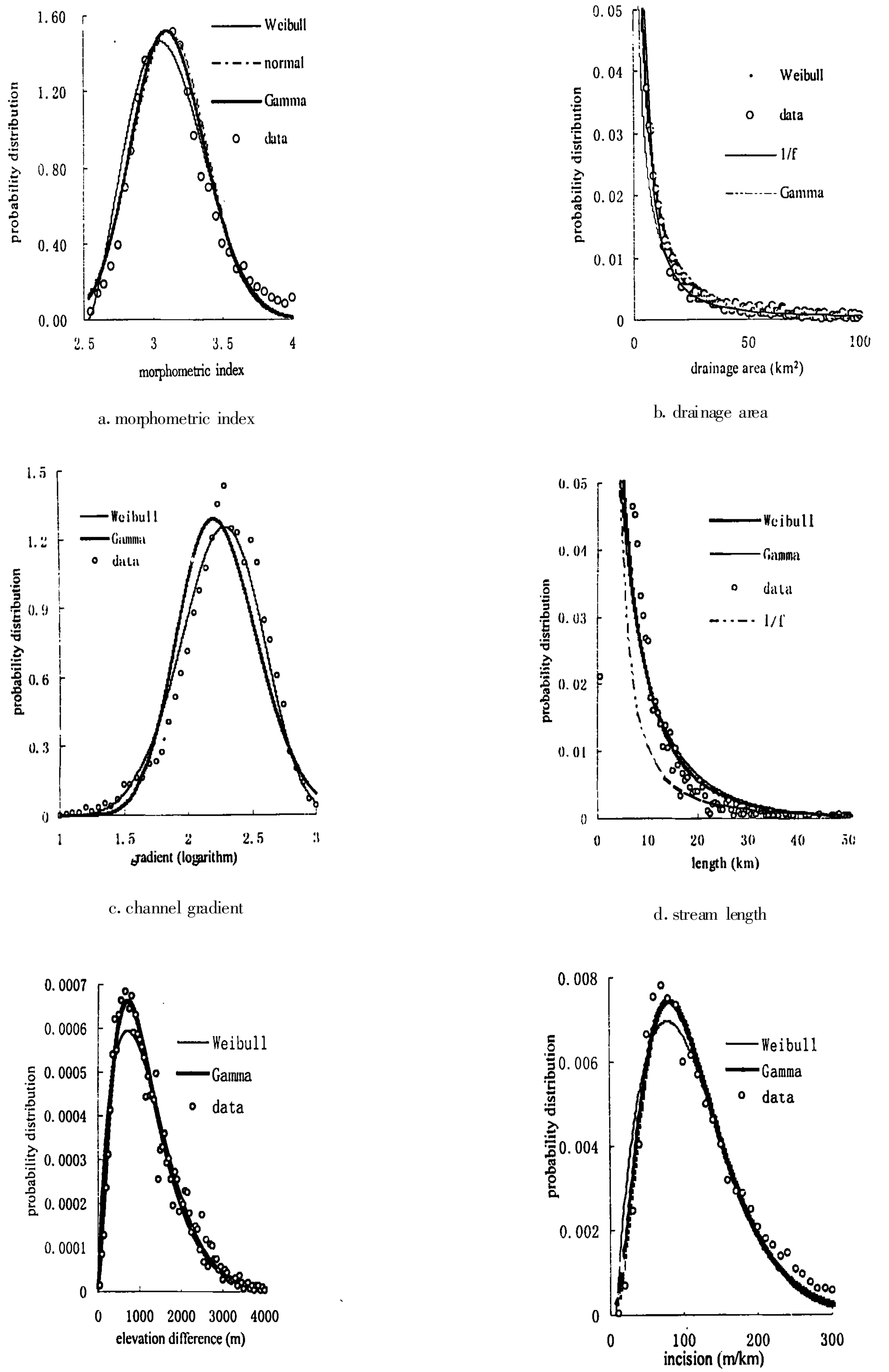
which approaches those special distributions as the parameters change. For example, Gamma and Weibull is respectively the case $\rho=1$ and $\kappa=1$. For convenience, we denote the parameter by α and β in the table and thereinafter, either for the case of Gamma or Weibull.

Of the most importance, however, is to notice the invariance form of (2) while the variable is under the transformation: $y = ax^n$, i.e.,

$$g(y) = g(y, \lambda^n/a, \rho/n, \kappa) \tag{3}$$

From this point of view, λ is the parameter for scale, and ρ, for from of the distribution. It is in some general sense the very feature that borne conspicuously by power law, the so-called invariance of scale, and a property that underlies the evolution of drainage basin (Rodriguz — Iturbe and Rinaldo, 1996; Talling, 2000).

Similarity of the distribution for various factors, scale invariance of the form, compounded by the relation of the morphometric index to the order of drainage basin, strongly



a. morphometric index

b. drainage area

c. channel gradient

d. stream length

e. relief

f. incision

Fig. 1 Distribution of characteristics of drainage basin propose that further interrelations exist among those characteristic factors, since they are mutually locked through the order, and, especially in manner of power law, as we learned from the classical lessons mentioned above.

4 Relations between various characteristics

The unified form of the distribution and the property of the generalized Gamma distribution imply some power relations for various characteristics. As we have learned, power relations arise frequently in drainage basin geomorphology, especially out of basins ranging in a large scale. Consideration here is then focused on the statistics of the debris-flow basins, and the statistics for tiny scale is expected to reveal some distinction from that of the large, and hence the identification of basins for debris-flow occurrences.

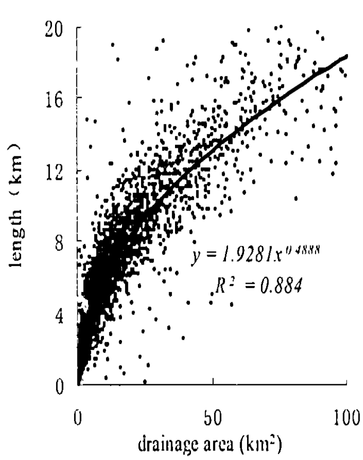
4.1 Results of statistics

(1) *A-L relation*

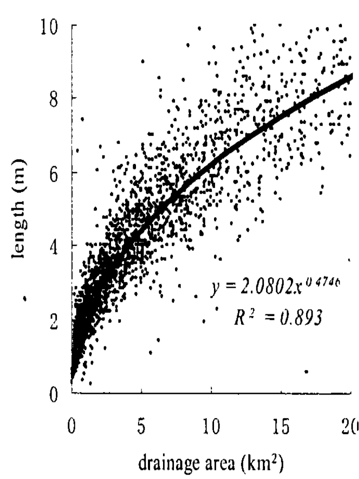
Among other things, the most popular relation in basin is perhaps that between basin area and the maximal length of channel developing in the basin, the Hack Law (e. g. Horton, 1945; Hack, 1957; Gregory and Walling, 1973; Rodriguez-Iturbe et al., 1992). It was originally expressed as $L = 1.4A^{0.6}$, in unit of mile. Of interest is the exponent, which is properly to be examined in the rough relation, $L \sim A^{\alpha}$.

In our statistics, $\alpha = 0.49$ for debris-flow basins over China, obviously less than the average value of the world, which roughly falls into the range of 0.6 ~ 0.7 (Hack, 1957; Gray, 1961; Leopold et at., 1964). Particularly, it is of more dispersion for the case concerned, say, $\alpha = 0.4 \sim 0.8$, which represents more uncertainty of basins in smaller scale; and, in some sense, suggests that this scattering effect be averaged in large scale in the study of those predecessors.

More interesing is the case for individual regions, like Sichuan, Yunnan, Tibet, and Liaoning, where arises almost the same value, $\alpha = 0.48$. This makes sense in two aspects: power law like the Hack is of generality without regional distinction, and, the exponent for tiny basin of debris flow is less than that for the ecumenical basins in the world. On the other hand, experiences might tell that exponent for different region should present different value (e. g. Leopold et al., 1964), then curious coincidence should have been the case here if not otherwise. In additoin, Muller (1973) and Shreve (1974) observed that the exponent decreases from 0.6, for the basin of small and moderate scale ($1 \sim 10^3 km^2$), to 0.5, for the large scale (up to $10^7 km^2$). We know that a large-scale basin, when under close measuring, usually presents a stream line with fractal dimension (Mandelbrot, 1982), and hence must bears exponet bigger than 0.5. One might then conclude from these findings that exponent in Hack law is near 0.5 for the basins of debris flow, since these basins are not so well developed as to show fractal features. Anyhow, distinction of basin of debris flow is to a certain extent presented by the exponent.



a. the whole country



b. sampling region: Sichuan

Fig. 2 Relation between area and length of debris-flow basin

(2) *Other relations*

The area-length relation expressed as Hack law is perhaps the most fundamental in drainage basin, through which all other factors and relations can be linked. Now let's turn to those characteristics, their interrelations, as well as their respective relations to area.

Intuitively, of the most irrelevance is the elevation difference of the basin. In other words, this difference makes no difference regarding other characteristics. After all, one always sees basins of different scales and shapes develop under the same summit of a mountain. In deed, factor in domination is the slope other than elevation, which is usually expressed as the ratio of evelvation difference to the length the basin extends, i.e. $S = H/L$. Willgoose (1994) derived a general area-slope-elevation relation in context of fluvial sediment transport, which involving as premises some power relations like the constitutive equations in term of discharge as power function of area and slope. His result, in simple form, can be rewritten as

$$S \sim kA^{-\gamma} \tag{4}$$

where the coefficient k, as well as the exponet γ are determined by various parameters, especially that concerns elevation, depending on the catchment evolution processes. In special conditions, the author estimated that $\gamma \sim 0.29$ and 0.32, depending on the cycle of tectonic uplift and the response of the basin relief. At this point, elevation (or more strictly, the relief) is somewhat a dynamic factor that influences basin in evolution phase, and finally shows itself through the slope-area relation. So it is irrelevant for a special phase in evolution, which is just the case we are for debris flow.

In fact, the very slope-area relation presents itself in rather a special manner in the case of debris-flow basin, where the slope is properly replaced by the gradient of the channel, J, being determined by

$$J = 2A_s/L^2 \tag{5}$$

where A_s is area of the curved triangle bounded by the channel-profile curve, the horizontal and the vertical axis originating from outlet of the basin that is presumed to be at elevation of zero (Li, 1999). For debris-flow basins, such gradient is generally less than the slope. In the area-gradient diagram, points of the basins are scattering randomly, however, with a conspicuous envelope curve in power form (Fig. 3):

$$J \sim A^{-\gamma} \tag{6}$$

where the exponent γ for che overwheming majority of the opints is about 0.45, and varies between 0.5 ~ 0.7 in different regions. Relation (6) is indeed a rule for the upper limit of the gradient for basins of given area, in other words, $J < A^{-\gamma}$ in general. Obviously, exponent here is bigger than the average value for individual basins in erosion equilibrium as supposed by Willgoose (1994). Then, the exponent excess is of more importance in revealing two facts regarding tiny basins of debris flow: (1) they are of great randomness in different stages of evolution characterized by different exponents; (2) most of these basins are of immaturity as to reach the equilibrium exponent. Roughly and more intuitively, one can expect all basins to be present on the limit curve (6), providing they are well developed.

Therefore, besides the exponent of area-length, α, debris-flow basins are as well distinctive from general basins in the exponent of the gradient-area, γ.

Similar to the area-gradient relation is the relation between gradient and length of channel, also of randomness under a control curve (Fig. 4):

$$J \sim L^{-\delta} \tag{7}$$

where exponetnt is 0.84. Furthermore, this length exponent is a little bigger for the case of ever-smaller basins (e.g. below area of 2km^2), 0.9 or so on average; and varies with region: 0.95 in Sichuan, 0.89 in Liaoning, etc. —a fact in the similar sense as the exponent γ. It is should be smaller for basins of maturity, perhaps approaching 0.7 or less inferred from the envelope. Hence the third exponent arises to identify debris-flow basin.

Combining (6) and (7), one may join these three exponents all together:

$$\alpha = -\gamma/\delta \tag{8}$$

which shows $\alpha = 0.54$ for the upper limit, near to the result from statistics discussed previously. Interesting is the scattering plots of the three exponents, as shown in Fig. 5, where the center in each diagram is just the origin of the coordingate system with scale up to ± 50. What the $\alpha - \delta$ and $\gamma - \delta$ cross mean is still up in the air. As far as one might see, only two are independent among the three

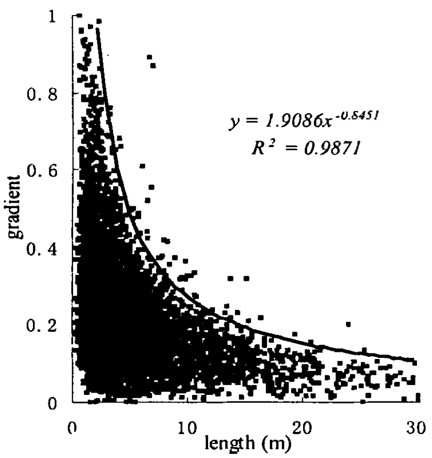


Fig. 3 Relationship between area and gradient of debris-flow basin

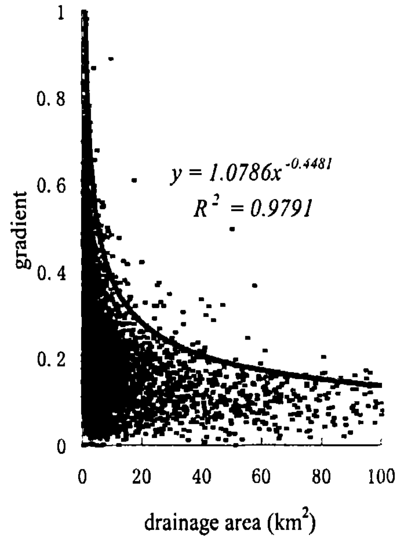


Fig. 4 Relationship between length and gradient of debris-flow basin

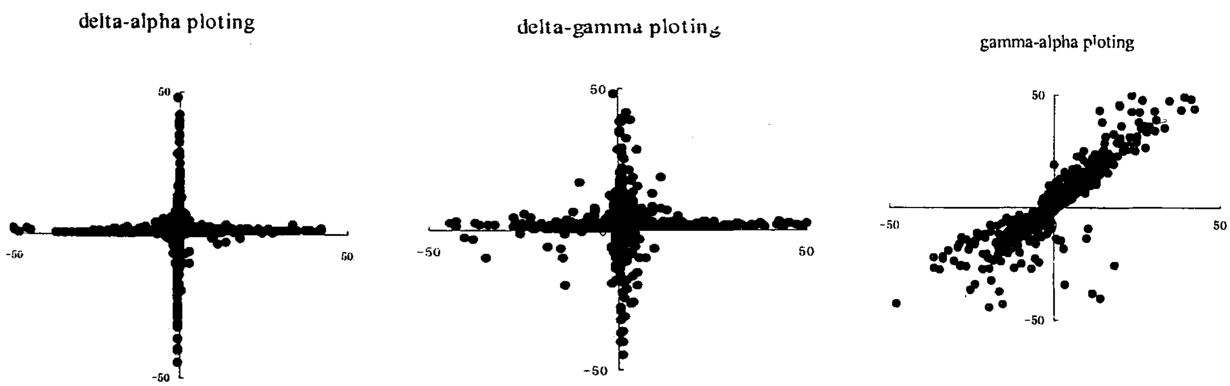


Fig. 5 Relations between exponent α, γ, and δ

exponents.

4.2 Physical implication

Power laws presented above, especially the values of the exponents invloved, are undoubtedly manifestations of evolution of the basin, i. e. representation of the evolutional stage. The fact that all these exponents are more or less apart from the values of other basins of various scales in the world implies that debris flow is a phenomen on only for a certain phase of the evolving basin. Now we turn to the physical implication important to the activity of debris flow as a special erosive process.

In fact, it has been long observed that gully/slope profile is of great responsibility for the erosive processes, which vary in manner as the profile turns from convex slope into concave valley (e.g. Gilbert, 1909; Kirbby, 1971; Ahnert, 1976). Since it is defined in such a way that concerns the profile, the gradient is necessarily in domination as regarding to the slope-gully erosion, and especially to debris flow. Actually, the J-A relation is consistent with the condition necessary for landslide to occur (Tucker and Bras, 1998). Particularly, for the case of erosion in gully, similar condition must be satisfied concerning the gradient (Rigon et al., 1994):

$$\tau \sim Jd \sim JA^{\gamma} \quad (6)$$

where τ is the shear stress, d is the flow depth, and another characteristic relation is involved here: $d \sim A^{n}$, exponent of which will be discussed lately. Debris flow occurs only at stress exceeding some critical value, that is, when $JA^{\gamma} < \tau_c$ is satisfied, which is equivalent to the controlling relation

$$J < A^{-\gamma} \quad (10)$$

just the same as discussed above.

Inaddition, since majority of debris-flow basins are under gradient less than the corresponding relief, $J < S$, inference can be drawn that

$$H \sim A^{\alpha-\gamma} \quad (11)$$

which means $\alpha > \gamma$, roughly in consistence with the values appeared in our study.

5 Discharge of debris flow

Considerations so far conecrn the characteristics of the drainge basins only, to which characters of debris flow must show its inherence. As found in other place, discharge of debris flow, or for surrogate, discharge of surges of the occurrences appeared in Jiangjiagou, is subject to distribution in analogy to the drainage area (Li, 2002)*, this implies that a relation must exist between discharge and area, in analogy to that in the usual flood event, $Q \sim A^f$ (e. g. Leopold et al., 1964; Alexander, 1972; Patton, 1998). As each occurrence or surge initiates in different sources in the basin, discharge for an event is necessarily hard to find the corresponding subbasin it originated from, thus the Q-A relation is hard to confirm for debris flow. But it can be well understood indirectly by noticing another power relation that combines discharge and the flow depth, i. e. $Q \sim d^b$, as shown in Fig. 6. Compounded by the generic relation $d \sim A^n$ mentioned above, the implied $Q \sim A^f$ is then exactly established, with the exponent determined by the empirical and relatively easy exponents n and b, $f = bn$, where $n \sim 1/2$ in general (Rigon et al., 1994; Talling, 2000), and $b = 1.8$ on average for debris-flow surges in Jiangjiagou. The resulted exponent f is thus near 0.9 or more, obviously bigger than that for the flood, which varies between 0.65 and 0.8 (e. g. Leopold et al., 1964; Gupta and Waymire, 1989). This is reasonable since debris flow is always more "powerful" and "stronger" than flood.

Significance for this coincidence lies in that one can draw inference from debris flows in regions for those in individual basins. In other words, various basins in different regions in some sense can be considered as various subbasins in different sources of a certain basin—as if the basin considered were magnified to large region, anyhow, with debris flows unchanged in scale.

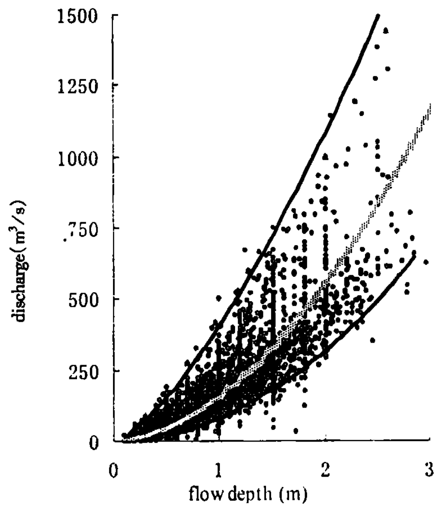


Fig. 6 Relationship between discharge and depth of debris-flow surge

6 Conclusion and discussion

In conclusion, characteristic factors of basins of debris flow possess of distributions and power relations analogue to those of the general basins of various scale, only distinct in value of distribution parameters and power exponents. This approves that debris-flow activity is a special epoch in the evolution history of a basin, and therefore combines long-term growth of debris flow with the geomorphologic tendency of the basin.

More importtantly, debris flow in individual basins might find its oringin from the drainage pattern, as revealed in the case of Jiangjiagou. It is of special significance because that almost all occurrences of debris flow were observed occasionally without any quantitative reference to their origins.

In addition, quantitative infommation for regional studies of debris flow arises from the statisitcs. For example, probability distribution assigns directly a weight to the factor involved, which must be of more reasons than the empirical score, when we are treating with regionalization of a region of large area. Furthermore, power relations among these factors imply that they are not all independent variables, and hence cannot be selected out all together in identifying and classifying a special

* ibid.

region. Nevertheless, beyond those discussed above, there are more other factors concerning the description of drainage patterm, such as the bifurcation ratio (Horton, 1932; Schumm, 1956), density of the basin (Tucker and Bras, 1998), which are of special significance for a certain climatic process, and reletively less impotrant in statistics.

Among other things, dynamic parameters of debris flow are as well interrelated by power laws, like the average flowing velocity and the hydraulic slope and flow depth (the so-called Manning fomula, for example). However, they are more due to the dynamic context, and distinctive from the present discussions.

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泥石流流域的形态特征

(摘要)

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泥石流是特殊的流域侵蚀作用, 同其他流域过程一样, 密切联系着流域的形态特征。一般说来, 泥石流都发生在小流域($10^2 km^2$ 以下), 而经典的流域形态研究所涉及的流域范围却达到 $10^7 km^2$ 的尺度。我们想知道泥石流小流域是否具有特殊的数量特征。通过流域特征量的统计, 我们看到, 与一般流域相比, 泥石流小流域的特征参数之间的关系形式上相同, 而在数值上不同, 这从一个方面肯定了流域演化存在着普遍规律(如自组织临界性), 同时也证明泥石流是流域演化历史的"特殊一幕"。这样, 泥石流的区域演化问题就真正同一般的流域系统演化问题联系起来了: 流域系统演化的一系列方法将有助于我们进一步建立泥石流的系统动力学。

具体说来, 本文根据中国泥石流编目数据库的资料, 对近 6000 个泥石流流域的特征参量进行了统计, 结果显示, 各参量分布都服从广义的 Gamma 分布:

$$g(x, \lambda, \rho, \kappa) = \lambda\rho(\lambda x)^{\rho\kappa-1}\exp(-(\lambda x)^{\rho}) / \Gamma(\kappa)$$

当 $\rho=1$ 或 $\kappa=1$ 时, 即分别为其特例 Gamma 分布和 Weibull 分布。这种分布的一个重要性质是, 在形如 $y=ax^n$ 的幂函数变换下, 分布形式保持不变, 只是分布参数以一定方式改变:

$$g(y) = g(y, \lambda^n/a, \rho/n, \kappa)$$

这实际上就是更一般形式的标度不变性。特征参量分布的一致性同时也就意味着参数间可能存在那样的幂函数关系。具体说, 作为流域基本特征关系的 Hack 定律, $L \sim A^{\alpha}$, 具有较小的指数, 接近 0.5, 小于世界范围的均值 0.56, 说明流域产面形态的分形特征还没形成。另外, 面积－比降关系和沟长－比降关系说明泥石流小流域都在幂函数关系的控制下演化:

$$J \sim A^{-\gamma} \qquad J \sim L^{-\delta}$$

这实际上是更一般演化规律 $S \sim kA^{-\gamma}$ 在小流域的随机表现, 指数 r 大于理论估计的平衡态数值, 说明泥石流小流域远未达到演化的稳定状态。三个指数 α、γ、δ 表现出奇特的随机行为(图 5), 而指数 α 与 γ 则有很好的一致性。这种随机下的规律, 说明两点: 流域演化在大尺度上受一定原理的控制; 小流域没有达到那种成熟的演化阶段。

泥石流流量(以蒋家沟泥石流的阵流流量为代表)与流深表现出幂函数关系 $Q \sim d^b$, 考虑到面积－流深规律 $d \sim A^n$, 这意味着流量以同样的函数关联着流域面积。蒋家沟阵流之所以表现出这种关系, 是因为每个阵流来自不同面积的源区小流域。这为我们研究泥石流在特定流域的源区活动提供了量的参考, 那些活动一般是不可能在野外观测到的。

流域特征的分布也为泥石流区域研究提供了一些定量的线索。例如一个因子的概率分布可以直接给出它的一个"权重", 这比一般的经验赋值更有根据。另一方面, 流域诸因子的相互关系说明这些因子不是独立的, 这为我们在区域研究中的因子选择提出了新问题——对流域形态来说, 同时选择所有的因子并不能使系统的考虑更完备; 我们应该选择那些区域差别显著的因子来作为特征指标。

关键词: 泥石流; 流域特征; 概率分布; 特征指数; 流域演化