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Rain Score and Debris Flow Occurrence Criterion in Case of Mizunashi River, Shimabara

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Abstract

Debris flow occurrence at Mizunashi river of Mt. Unzen, Shimabara, Nagasaki prefecture, is discussed with the various factors obtained from the parameters a,b of rainfall intensity maxima curve. The maximum instantaneous intensity (R0) and the space liquid water content (M10) of the maximum 10 minute rainfall intensity (R10) are recognized important factors as well as the maximum 3 hour rainfall (R180). In case of R0>21.4 mm, M10>0.8 g/m^3, and R180>38 mm, the debris occurrence probability is 90.9%. This paper proposes the rain score P as a new factor representing the rain strength. 8 significant debris occurrences including 5 flooded cases occur without exception in case of P≧5. The criteria are useful for the voluntary disaster prevention activity with the aid of 1-3 hour rainfall amount forecast.

1. Introduction

Fugen-dake of Mt. Unzen has become active since November, 1990. Lava spores up and forms the giant lava dome at summit. The overhanging part of dome falls down the slope, breaking into fragments and generating the pyroclastic flows. The broken lava stones deposit in the valley. The lava stones and ashes easily begin to move with the flow water of streams. The houses, traffic roads and farmlands have been destroyed by the flooding debris flows out of river course. The debris flow within river occurs even in a weak rainfall of which maximum 10 minute rainfall amount (R10) is only 3.5mm.

It is frequently experienced that the rainfall type and amount are quite different within two stations 2-3 km apart. The locality of rainfall strongly appears in the case of convective rainfall type. Most of rainfall disasters are caused by the convective rainfalls which have high rainfall intensity. The local voluntary observation, understanding and forecast of rainfall are recommended. If we have the Mizunashi-river debris flow occurrence criteria written by the rainfall informations, it is useful for the voluntary disaster prevention activity.

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2. Rainfall parameter

Various maximum rainfall amounts can be read in a continuous record paper of raingage. Japan Meteorological Agency uses the maximum 60 minute (1 hour) rainfall amount (R60, mm) and the maximum 180 minute (3 hour) amount (R180, mm) for classification of the strength of heavy rainfall as shown in Table 1.

The class A includes the heavy rainfall Nagasaki event (R60=187 mm, R180=330 mm), which caused the 299 deads on July 29, 1982. Even the class F heavy rainfall causes the human deads by the slope failure.

In a rainfall record we can look for the location of time duration in which each of 10 min., 30 min., 60 min....., T min. maximum rainfall amount appears. Talbot[1] first proposed the relation between the rainfall durations (T min.) in a rainfall and their maximum rainfall intensity (R_T mm/hr) as follows,

$$R_T = a/(T+b)$$

This is called Talbot equation. Shiotsuki[2] found that the raindrop size distribution in a rainfall is reconstructed by the a, b parameter set. The raindrop size distribution determines all of physical rain parameters. The a, b set is utilized for the 1-3 hour rainfall amount forecast (Shiotsuki[3]). The parameter a, b set thus provides not only the statistical, but the phyisical information of rainfall.

3. R60-R180 Diagram

Fig. 1 shows the distribution of R60 and R180 of the significant heavy rainfalls observed in Kyushu during last 40 years. The small circles[4] are those of cases when the disaster with more than 10 deads occurs. The squares are of Taketa City (Oita Prefecture) heavy rainfall (July 24 ,1982) that caused 7 deads damage by landslide.

Table 1 Heavy raifall class by Japan Meteorological Agency.

CLASS	R60 mm	R180 mm
A	110	250
B	90	200
C	70	150
D	50	100
E	30	70
F	20	50

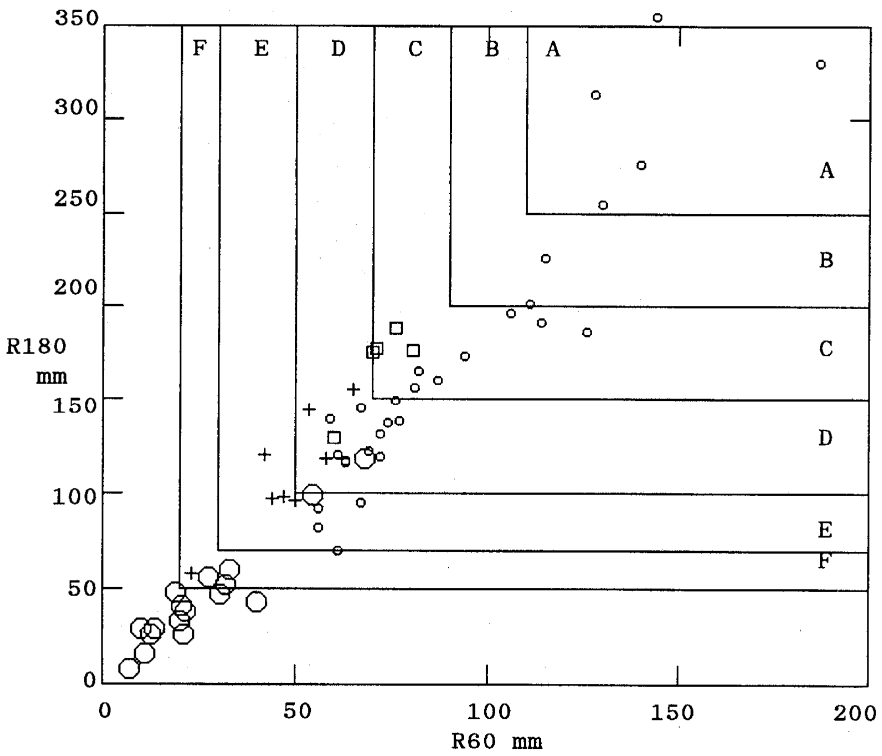

Fig. 1 Classes of the significant heavy rainfalls observed in Kyushu during last 40 years.

The crosses are of Houhi heavy rainfall (July 2, 1990) that caused 11 deads damage in Aso-Ichinomiya Town, Kumamoto Prefecture by the mud flow with the flooding logs. All cases are included in classes higher than F heavy rainfall class.

The 17 large circles indicate the R60-R180 relation observed at Mt. Unzen Meteorological observatory when the debris flow is observed in Mizunashi river for years of 1991-1992. 5 cases are in the region higher than F class. 12 cases are out of heavy rainfall class. It is seen the debris flow of Mizunashi river is caused even by the weak rain. The figure shows that 11 cases with the R60 rainfall amount more than 20 mm (F class level in R60) caused the debris flow.

4. a-b Diagram

When T=0 is given in Talbot equation, the instantaneous rainfall intensity $R0=a/b$ (mm/hr) is obtained. Characteristics of a/b parameter is discussed as a key of slope failure (Shiotsuki et al.[5)]). Similarly when T=180 is given, the maximum 180 min. rainfall amount $R180=a/(180+b)\times 3$, mm, is obtained. The liquid water content M10 (g/m^3) within rainclouds when their rainfall intensity attains the maximum 10 min. rainfall intensity can be calculated by $M10=(a/(8+b)/26)^{0.9616}$ (Shiotsuki[6)]).

Fig. 2 shows the a-b diagram where 3 lines of a/b=171/8=20 mm/hr, 171/3=49 mm/hr, 171 mm/hr, 3 curves of R180=27 mm, 38 mm, 50 mm, and 10 curves of M10=. 5, 1,..., 5 g/m^3 are drawn. The instantaneouvs rainfall intensity 171 mm/hr was introduced as the severe heavy rainfall criterion (Shiotsuki[2)]). When 0.1 mm depth

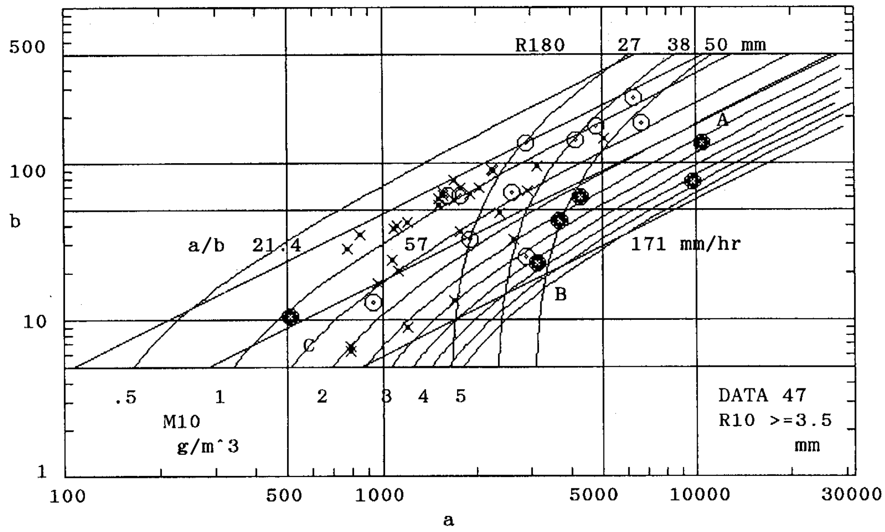

Fig. 2 (a, b) distribution of 47 rainfalls (R10≧3.5mm) observed at Mt. Unzen Observatory during years of 1991-1992. Cases of 17 rainfalls which caused the debris flow in Mizunashi river are shown by circles. Black circles are for the cases of flood debris flow.

filter paper is used for raindrop sampling in 1 second exposure, it is too many raindrop flecks in a paper to read the individual fleck size any longer in case the instantaneous rainfall intensity is more than 171 mm/hr. Similarly, the filter paper is full of raindrop flecks in 3 second exposure at a/b=171/3, and in 8 second exposure at a/b=171/8, respectively. Most of the values of a/b for 100 year probable rain at each observatory in Japan are more than 171 mm/hr[2].

a-b plots of 47 rainfall cases at Mt. Unzen observatory for years of 1991-1992 of which the muximum 10 min. rainfall amount R10 is more than 3.5 mm are shown in the figure. The smallest value of R10 was 3.5 mm in cases of the debris flow occurrence. The occurrences of debris flow in Mizunashi river were recognized according to the daily paper news and TV news. The 17 circles and the 30 multiplies indicate the debris flow occurrence cases and the non-occurrence cases, respectively. The 6 black circles are for the cases when the debris flow flooded out of Mizunashi river to destroy many houses, Route 251, and the Shimabara railroad line.

The cases B, C of black circles occurred within a week just after the occurrence of main flood case A on August 8, 1992. It is considered the B, C cases were caused in a secondary effect of the main flood A.

As seen in the figure, the significant debris flow flood is occurred in case that the rain is in the region of a/b>57 mm and R180≧50 mm in which the heavy rainfall class is higher than F. In the region of a/b≧21.4 mm and Rl80≧38 mm where 10 debris occurrence cases and 1 non-occurrence case are included, the debris flow occurrence probability is 90.9%. In the region of a/b≧21.4 mm/hr and R180≧27 mm where 13 occurrence cases and 5 non-occurrence cases are included, the debris flow occurrence probability is 72.2%.

5. Rain Score

As discussed above, the various factors such as R0, R10, M10. R60, R180 are tested for finding of debris flow occurrence level. Those factors are obtained from a parameter set of a, b. If we have a comprehensive term defining the rain strength using those factors collectively, it is convenient to write a debris flow occurrence criterion. For this purpose the principal component analysis (PCA) is made using 2157 (a, b) parameter sets obtained in case of Nagasaki heavy rainfall event. Every 2157 (a, b) set is determined by the last 6 ten minute rainfall amounts within an hour. 10 rain factors calculated by a parameter set of a, b are selected for analysis, as follows.

X1. maximum 10 min. rainfall amount. $R10=a/(10+b)/6$, mm
X2. maximum 30 min. rainfall amount. $R30=a/(30+b)/2$, mm
X3. maximum 60 min. rainfall amount. $R60=a/(60+b)$, mm
X4. maximum 180 min. rainfall amount. $R180=a/(180+b)\times 3$, mm
X5. value of a
X6. value of b
X7. maximum instantaneous raifall intensity. $R0=a/b$, mm/hr
X8. liquid water content bringing R10. $M10=(a/(8+b)/26)^{0.9616}$, g/m^3
X9. rainfall duration time. $DR=\sqrt{a\times b/10}-b$, min. (Shiotsuki[3])
X10. value of $a\times b$. Generally speaking, the value of $a\times b$ becomes large as the rain strength is increasing. (Shiotsuki[2])

Table 2 shows the result of PCA. The eigenvalue of the 1st component is 7.353. This means that the 1st component explains 73.5% of implication of all data, because the total of eigenvalues of all factors is 10. The eigenvector values of R60 and R180 are larger than other factors. Those of b and a/b are smaller than others. The former group plays main role in strengthening the rain. Thus we can adopt the score of lst component as the rain score which expresses the rain strength.

The rain .score is calculated by following equation.

$$P=2.894\times \sum_{n=1}^{10} (X_n-\langle X_n\rangle)\ /\ \mathrm{Var}\ \langle X_n\rangle\times\langle EV\rangle_n$$

X_n ; value of each factor X1, X2,..., X10 in a rainfall
$\langle X_n\rangle$; mean value of X_n obtained in Nagasaki Heavy Rainfall as shown in Table 2
Var$\langle X_n\rangle$; variance of each $\langle X_n\rangle$ as shown in Table 2
$\langle EV\rangle_n$; value of eigenvector of each X_n as shown in Table 2

The figures 3a-3d show the relation between each rain factor R60(X3), R180(X4), b(X6), a/b(X7) and the rain score P calculated by the parameters a, b for 700 data observed at 16 stations in Nagasaki Prefecture under Nagasaki event. As expected from the values of eigenvector, correlation is most significant in R180-P. The circles show the heavy rainfall classes according to R60 and R180, from F (smallest circle) to A (largest). The rains out of class are dotted.

Table 2 Result of Principal Component Analysis for 2157 sets of 10 rain factors (X1, X2,...., X10) calculated by their own prameter (a, b).

Component	1	2		
Eigenvalue	7.353	1.832		
Factor X_n	Eigenvector $\langle EV \rangle_n$		Mean $\langle X_n \rangle$	Variance $Var\langle X_n \rangle$
X1 (R10, mm)	0.906	-0.536	7.76	32.31
X2 (R30, mm)	0.968	-0.322	17.22	185.6
X3 (R60, mm)	0.992	-0.160	25.54	473.2
X4 (R180, mm)	1.000	0.071	39.32	1442
X5 (a)	0.971	0.322	3442	1.578×10^{7}
X6 (b)	0.513	1.000	59.10	2162
X7 (a/b)	0.566	-0.726	60.78	3719
X8 (M10, g/m^3)	0.892	-0.568	1.805	1.571
X9 (DR, min)	0.939	0.433	75.92	6633
X10($a\times b$)	0.770	0.724	322505	4.589×10^{11}

Fig. 4 shows the debris flow occurrences in Mizunashi river in case of $P\geqq5$ in the same figure as Fig. 2. The 1 non-occurrence case as seen in the region $R180\geqq38$ mm in Fig. 2 vanishes in this figure. There are not seen any non-occurrence cases with $P\geqq5$ criterion. The prediction of heavy debris flow occurrence including the flood case may be made without error by use of the rain score criterion of $P\geqq5$.

Figs. 5a and 5b show the debris flow occurrences with $P\geqq0$ and $P\geqq-5$. The occurrence probability is 75% in case of $P\geqq0$ and 62.5% in $P\geqq-5$ respectively.

6. Concluding Remarks

The debris flow occurrence criteria written by the rainfall parameter are useful for local community or inhabitants to keep themselves safe from the debris flow hazards with the aid of information of rain-forecast. Shiotsuki[3] proposed the method of 1-3 hour rainfall amount forecast by use of only 10 minute rainfall data. This method is

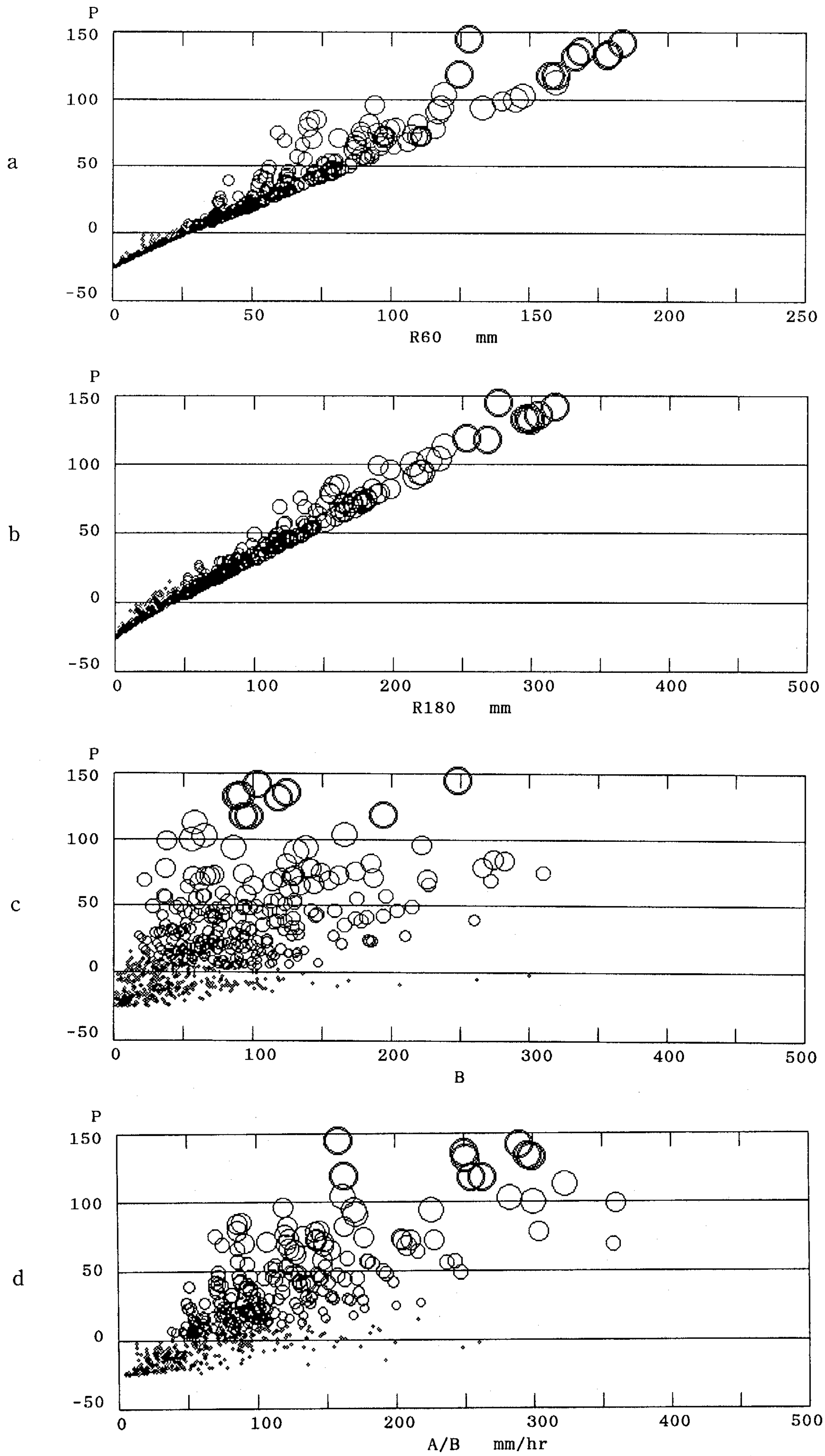

Fig. 3 Relation between the representative rainfactors and the rain score P for 700 data of 16 stations in Nagasaki event.

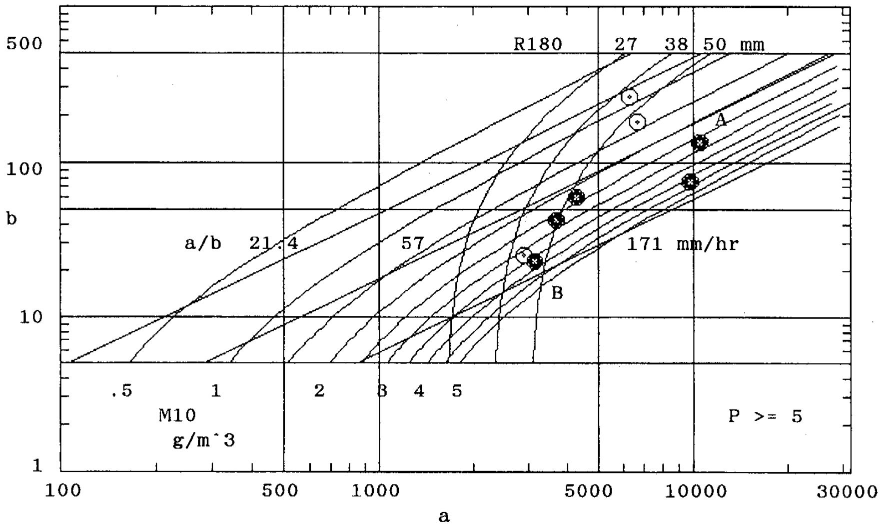

Fig. 4 (a, b) distribution in cases of the rain score P≧5.

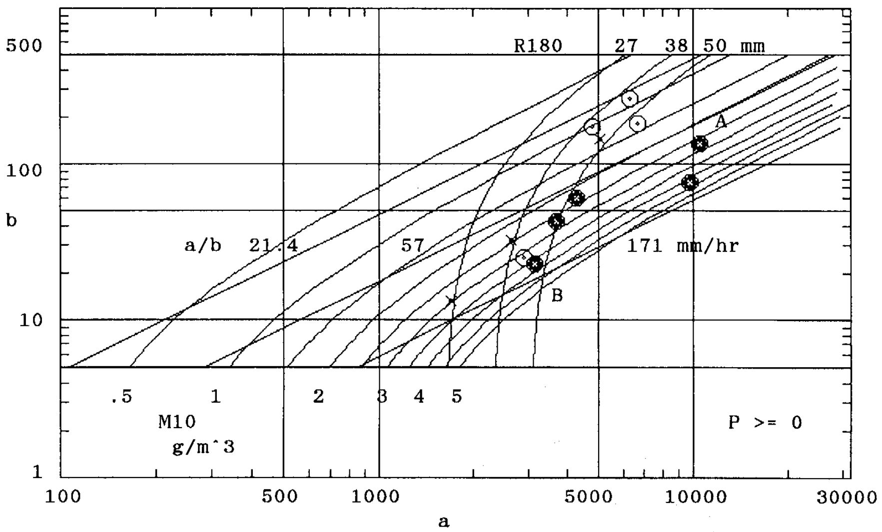

Fig. 5 a (a, b) distribution in cases of the rain score P≧0.

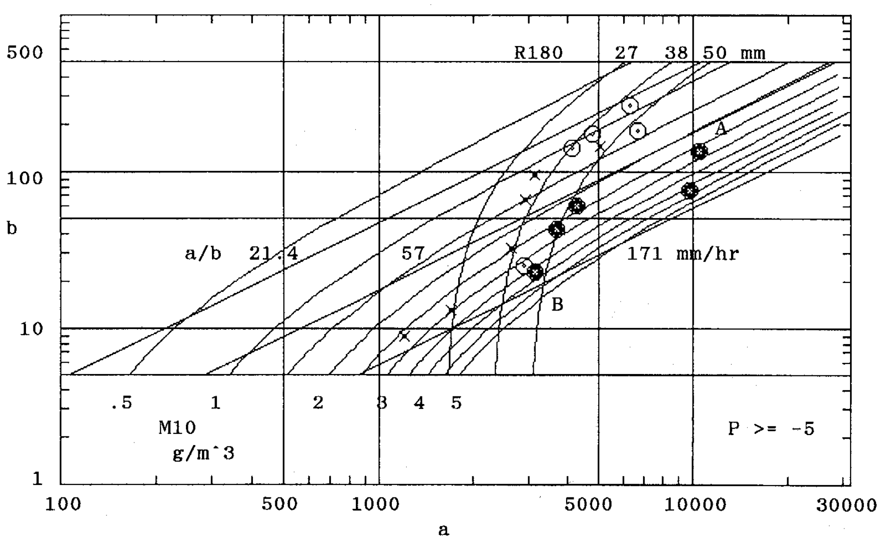

Fig. 5 b (a, b) distribution in cases of the rain score P≧−5.

based on the concept of hyetograph estimated by the rainfall parameter a, b set. If they have the raingage and observe the rainfall amount for themselves, they can predict the coming 1-3 hour rainfall amounts and a/b values by use of the personal computer. If the estimated R180, a/b, M10 and P are crossing the criteria, they can prepare to retire to a safe place.

Acknowledgement

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