Methods of Predicting Watersheds in Danger of Flood

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Flood disasters frequently occur in Japan, causing losses of life and property. In order to take up effective measures to prevent flood disasters, it is necessary to establish the methods of predicting watersheds which are in danger of flood. The prediction of the risk of flood is needed not only for large watersheds but also for smaller watersheds.

When dangerous watersheds are identified, we can formulate the guidline how to arrange and manage the headwaters conservation forests, flood damage prevention forests, etc. in the watersheds.

Methods of study

The following methods have been developed to predict watersheds in danger of flood.

1) A method based on excessive probable flood flow: The amount of flood flow and probability of flood occurrence expected in the future are calculated based on the record of the past flood flow for each of the watersheds, and the degree of danger is rated by numerical figures.

2) A method based on excessive probable rainfall: The higher the amount of rainfall, the more is the risk of flood occurrence. The degree of the danger is ranked by estimating the amount of heavy rain, its probability of occurrence, and regional distribution based on the past records of rainfall by the same way as in the above 1).

3) A method based on watershed factors: Although the direct cause of flood is the conditions such as amount, intensity, etc. of rainfall, the actual occurrence of flood is strongly influenced by the response of watersheds to rainfall. Therefore, in this method, the danger of flood occurrence is determined by watershed factors such as topographic conditions and ground coverings.

Of the above three methods, 1) and 2) are suitable for watersheds of medium to large area, in view of provision and availability of necessary data, but they are difficult to be applied to watersheds of small area lacking necessary data. The method 3) can be applied to any of watersheds of large, medium and small area; but it would be suitable to medium to small watersheds when the amount of works required for measuring watershed factors (also called watershed variables) is considered.

Thus, the flood occurrence depends on a series of complex factors, as if it is an organic phenomenon. Measurement of many characteristic values such as watershed conditions and rainfall conditions is necessary for explanation, and spatial-temporal variation of the characteristic values is governed by many factors. In addition, the characteristic values measured influence each other in many cases. Therefore, the method of multivariate analysis, i.e., a method of analysis in which mutual relation between characteristic values is taken into consideration, would be better for explanation of the phenomena.

Relation between watershed factors (such as geology, topography, soil, forest, etc. of the watershed) which are regarded as a primary cause, and flow factors of the watershed (such as peak specific flow, increment flow, etc.) has been investigated in Japan and other countries by the multiple watersheds method[2]. Correlations between various watershed factors and peak specific flow and other flow factors were obtained. In this method, a multiple regression equation was introduced for obtaining peak specific flow, by taking various watershed factors as independent variables, and the degree of danger of flood in the watershed was estimated. In other words, the method 3) mentioned above was adopted.

Basic investigation for predicting watersheds in danger of flood

The multiple watersheds method is generally adopted for the study on the method of predicting the danger of flood, and works for collection of various data are required accordingly for basic investigation. One of them is measuring watershed conditions in the number of watersheds to be investigated, such as a topographic factor, a geological and soil factor, a ground cover factor, etc.. The second work is flow observation such as measuring runoff from the watershed caused by rain which constitutes necessary objective variables, such as peak specific flow, increment flow, etc..

As the latter work, investigation was carried out right after the runoff of high water level, referring to the simple method by which flow Q was obtained as the product of cross sectional area A of flow and average velocity V. Namely $Q=A \cdot V$. The water level of flood flow at its peak was obtained by the mark left on the stream bank, the bridge pier, etc.. The cross sectional area of flow was obtained by survey, and calculating hydraulic radius R. On the other hand, the water surface slope was obtained by the survey, on the assumption that it is the same as that of the stream bed. The coefficient of roughness n was decided according to the conditions of the stream, and average velocity was calculated by the Manning's formula;

$$V = 1/n \cdot R^{2/3} \cdot I^{1/2}$$

Thus, the peak flow from a watershed can be obtained from the cross-sectional area multiplied by the average velocity, both at the time of the highest water level indicated by the remaining mark.

As other methods of observing the water level, a simple maximum water level mark meter can be manufactured tentatively, and an inexpensive maximum and minimum water level meter can be purchased and installed. To get higher accuracy in observation, the gauging weir shall be constructed and self-recording must be carried out.

Method of predicting watershed in danger of flood

1) *Example of prediction of watershed in danger of flood in the past*

Here the method of multiple regression analysis will be shown from examples in Japan and other countries.

The method is simple and independent variable as well as criterion variable can be expressed in the interval scale.

Actual examples of the multiple regression equation introduced from the result of observation by the multiple watersheds method are as follows:

(a) Example in the Ogawa River watershed of the Tenryugawa River system in Japan

The 15 forest watersheds were of 1.1–28.0 km^2 area, and the multiple regression equation for a rainfall of 50 mm was[4)]

$$q=3.22\,R_r-0.44\,B-2.44\,L_c-0.07\,F_c+15.8 \qquad (R=0.70)$$

where q : specific flood flow ($m^3/sec/km^2$)
R_r: mean gradient of main stream
B : mean width of watershed (km)
L_c: concentration ratio of watershed
F_c: forest coefficient (product of forest area and square root of growing stock per km^2)

(b) Example in the State of California, U.S.A.

The result of investigation of 38 watersheds of 0.1–201 $mile^2$ area gave[1)]

$$\log Q=3.624+0.928\log A+0.723\log P+0.860\log R_b \cdot R_s/R_l-1.152\log C \qquad (R=0.983)$$

where Q : maximum momentary peak discharge (ft^3/sec)
A : area of watershed ($mile^2$)
P : maximum 24-hr precipitation (in)
R_b: bifurcation ratio
R_s: slope ratio
R_l : length ratio

C : average cover density

(c) Example in Nigeria

A case of 15 watersheds in southwest Nigeria having 2.0–18.8 km^2 watershed area was[5)]

$$\log RO = 19.5 + 1.08 \log S1 + 0.24 \log S6 - 12.91 \log S7 - 2.50 \log S8 + 5.74 \log S9 + 4.18 \log S11 \quad (R=0.95)$$

where RO: total dry-season runoff (mm)
S1: percentage of basin area underlain by quartzites (%)
S6: relief ratio (%)
S7: total annual rainfall (mm)
S8: total dry-season rainfall (mm)
S9: maximum weekly rainfall in October (mm)
S11: percentage of basin area covered by farms and fallow (%)

2) *Trial for determining the degree of danger of flood*

An example in the Nuta River watershed in Japan[3)] was given as follows:

The 24 watersheds were of 0.153–1.838 km^2 area, and a used rainfall was 30 mm or more in this investigation. The watershed factors of the 24 investigated watersheds are shown in Table 1.

The multiple regression equation obtained for estimating peak specific flood flow by selecting watershed factors highly correlated with peak specific flood flow was as follows:

$$q = -4.76A + 31.66S - 29.19L_c + 0.19H_s - 1.16F - 1.59 \quad (R=0.74)$$

where q : peak specific flood flow ($m^3/sec/km^2$)
A : watershed area (km^2)
S : mean slope of main stream
L_c: concentration ratio of watershed
H_s: soil depth (cm)
F : forest area ratio

The equation shows that the peak specific flood flow increases as S increases and that it decreases as A or F increases. This result seems to be applausive by the common sense. However, as shown in several examples of research in the past,

Table 1. Watershed factors

Watershed number	Watershed area (km^2)	Mean slope of main stream	Concentration ratio of watershed	Soil depth (cm)	Forest area ratio
1	1.715	0.13	0.104	51	0.92
2	0.889	0.19	0.136	57	0.97
3	1.810	0.18	0.117	62	0.98
4	0.499	0.32	0.259	76	0.73
5	0.393	0.36	0.286	53	0.52
6	0.892	0.32	0.271	65	0.64
7	0.162	0.39	0.467	58	0.99
8	0.292	0.27	0.290	42	0.99
9	0.975	0.23	0.275	56	0.99
10	0.153	0.57	0.588	81	0.97
11	1.510	0.18	0.203	63	0.96
12	0.299	0.40	0.300	39	1.00
13	0.915	0.22	0.196	72	0.99
14	0.698	0.27	0.195	78	1.00
15	1.838	0.19	0.133	77	0.98
16	0.314	0.33	0.333	85	0.97
17	0.985	0.12	0.144	87	0.99
18	0.329	0.13	0.216	74	0.96
19	0.581	0.14	0.153	63	0.99
20	0.336	0.13	0.278	73	0.97
21	0.371	0.08	0.140	68	0.99
22	1.167	0.18	0.180	68	0.89
23	0.670	0.25	0.217	79	0.97
24	0.208	0.50	0.391	63	0.99

Table 2. Relative rank of danger of flooding in the Nuta River watershed

Watershed No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Danger rank	22	19	17	6	21	13	18	23	20	3	16	24	10	5	7	2	1	8	15	9	11	12	4	14

the constants of the independent variables in the equation can be either positive or negative depending on the experimental watersheds, even if the same independent variables are used. Therefore, it is necessary to be careful of that usage.

The relative importance of the independent variables that is shown by the standard partial regression coefficient in the multiple regression equation in the multiple regression analysis for this investigated watershed was as follows:

$$F:A:S:L_c:H_s = 1.0:17.8:27.8:23.8:16.6$$

It shows that watershed area, the mean slope of the main stream, concentration ratio of the watershed, and soil depth affect the peak specific flood flow about 20 or 30 times as much as forest area ratio among the 5 watershed factors, but what we can change by our effort is the forest area ratio only. Therefore, the difference between forest area ratio and four other factors may not be regarded large.

The degree of danger in the 24 watersheds can be estimated from the values of peak specific flood flow that are calculated by the multiple regression equation, but we adopted the weighted total of the watershed factors, as calculated by multiplication of value of watershed factors by the coefficient of relative importance and summing up the products. The larger the weighted total, the larger is the danger.

The result of calculation ranked these watersheds in the order of danger of flood occurrence as shown in Table 2.

This predicting method is not only concise but also convenient for practical use. In the research cooperation with the Forest Institute of São Paulo, Brazil, this method was employed in selecting priority watersheds in the cooperative project (between Brazil and Japan) to recover soil and water conservation, deteriorated due to extensive farming, by means of reforestation efforts.

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