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Application of ArcGIS in the Calculation of Basins Rainfall-Runoff

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Abstract

It is key issue to predict the rainfall-runoff process on the Kuronagi River before the joint sediment flushing and sluicing of Dashidaira and Unazuki dams at the downstream of the Kurobe River. In this paper, the ArcGIS system is used to produce the digital basin of the Kuronagi River, the distributed Kinematic Wave hydrological model is used to calculate the rainfall-runoff process on the Kuronagi River, and the results are in good agreement with the observations. The results show that with the progress of rainfall observation techniques and computational methods, the development of digital land information and the effective application of GIS technology, a relatively simple rainfall-runoff model can get higher precision results.

Keywords: Kuronagi River, Digital Basin, Rainfall-Runoff, ArcGIS

Ⅰ. Fabrication of the digital basins in Kuronagi River

Kuronagi River is the largest first-class tributary of Kurobe River in Japan, and the basin in Kuronagi River covers an area of 117km^2, belonging to a special area in middle mountainous district National Park. The basin finds rare human activities and has high vegetation coverage and good natural environment. In this paper, ESRI's ArcViwe8.3 and its Spatial Analyst extension module was used to carry out Fill Sinks, Flow Direction, Flow Accumulation, Stream Network as Feature and other processing of the 50mDEM data issued by Japan Geographical Survey Institute in 1996 and produce the digital basin in Kuronagi River. Refer to Fig. 1 (a). On this basis, the basin in Kuronagi River was extracted and many Arc Hydro Tools for ArcGIS were used to divide the basin into 27 sub-basins to calculate the slope area, the average slope gradient and the length and slope of river section in each sub-basin. Refer to Fig. 1 (b) and Table 1.

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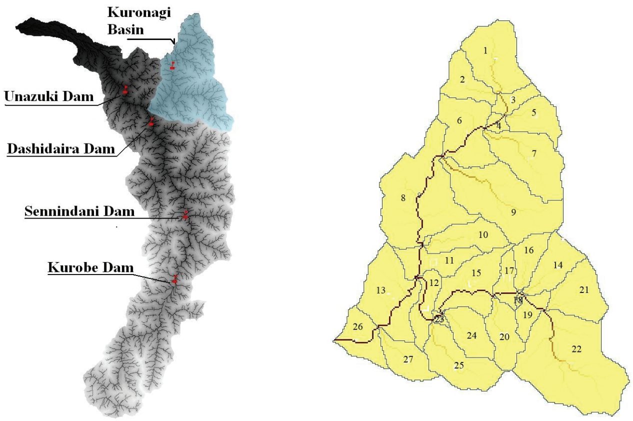


(a) Kurobe River Basin (b) Kuronagi River Basin

Fig. 1 Digitalization of Kuronagi River Basin

Table 1 Slope and river course parameters of Kuronagi River Basin

No. of sub-basin	Left slope		Right slope		River course	
	Area (km^2)	Gradient (%)	Area (km^2)	Gradient (%)	Length (m)	Gradient (%)
1	3.87	15.72	2.04	15.50	4773	13.03
2	1.1	16.16	1.69	16.11	3407	17.23
3	1.02	15.92	0.36	16.53	1159	10.19
4	1.83	14.47	1.09	12.64	3935	24.14
5	0.36	18.20	0.28	18.21	1124	16.14
6	2.75	16.10	3.61	14.48	5292	26.36
7	2.06	15.52	3.53	16.85	2607	17.04
8	5.99	15.71	4.16	15.65	7130	23.34
9	4.26	16.57	7.72	16.40	5161	16.89
10	1.58	17.93	1.84	16.97	4640	31.74
11	2.08	17.06	1.18	18.64	1674	27.74
12	1.35	19.49	1.25	20.24	2663	21.06
13	1.9	20.05	4.89	19.92	3387	17.08
14	1.46	20.06	1.49	20.92	3951	35.23
15	1.54	20.12	1.62	21.05	2316	10.58
16	7.44	17.38	6.9	15.78	6819	23.99
17	3.21	16.04	1.01	11.85	3347	31.28
18	1.18	17.09	0.55	13.48	1209	13.98
19	1.49	11.68	1.92	14.46	3653	32.38
20	0.14	17.63	0.03	11.60	290	9.61
21	0.99	16.29	1.31	16.63	3397	36.86
22	0.41	21.20	1.28	17.48	1144	24.14
23	1.24	16.81	2	16.32	3771	35.66
24	1.57	18.54	3.69	16.85	3296	18.23
25	1.17	19.61	1.93	18.65	3076	47.92
26	0.21	19.89	0.1	20.71	555	17.11
27	2.87	18.42	2.26	18.23	5286	31.14

Calculation of rainfall runoff

The calculation of rainfall process is a process to calculate the runoff via the rainfall process and the basins conditions. The calculation methods can be roughly divided into two major categories: linear methods and nonlinear methods[1,2]. The linear models carry out linear processing of the relation between rainfall intensity and runoff, and the typical models include rationality model and unit graph method. The nonlinear methods are divided into distributed constant model and concentrated constant model, and the typical models include Kinematic Wave method and storage function method. This paper uses the Kinematic Wave method of the GIS System. Since the basin under study has a relatively small area and the calculation time is relatively short, the method only taken into the surface runoff in the calculation of runoff but ignored infiltration and river recharge from underground runoff caused by infiltration. The flood calculation based on the Kinematic Wave method includes two parts: slope calculation and river course calculation [3].

Slope calculation

(1) Continuity equation

$$\frac{\partial h}{\partial t}+\frac{\partial q}{\partial x}=r_e \qquad (0 \le x \le L) \tag{1}$$

(2) Motion equation

$$q=\alpha h^m \tag{2}$$

In the formula, t: time, x: distance to the top of slope, h: water depth, q: discharge per unit width, r_e: effective rainfall, L: length of slope, α and m: a constant determined by flow pattern, in which α is calculated by formula (3) and $m=\frac{5}{3}$.

$$\alpha=\frac{\sqrt{i}}{N} \tag{3}$$

In the formula, i: slope gradient, N: slope equivalent roughness. The basin under calculation is a mountainous area. $N=1.5$ ($m^{-1/3}s$).

River course calculation

(1) Continuity equation

$$\frac{\partial W}{\partial t}+\frac{\partial Q}{\partial x}=q \qquad (0 \le x \le L_c) \tag{4}$$

(2) Motion equation

$$Q=GW^M \tag{5}$$

In the equation, W: cross sectional area, Q: discharge of river course, L_c: length of river course, G, M: a constant determined by flow pattern, which is calculated based on Q during flood period and the observed data of W. However, as no observed data about Kuronagi River are available, it is calculated after calculating the flow of river course via the Manning formula (6).

$$Q = \frac{1}{n} W R^{\frac{2}{3}} I^{\frac{1}{2}} \tag{6}$$

In the equation, n : roughness coefficient, I : slope of river course, R : hydraulic radius(m), which is calculated by formula (7).

$$R = K_1 W^Z \tag{7}$$

In the equation, K_1 and Z are constants. Substitute equation (7) into equation (6) and then calculate the constants of river course G and M according to formula (8)

$$G = \frac{K_1^{\frac{2}{3}} I^{\frac{1}{2}}}{n} \tag{8}$$

$$M = 1 + \frac{2}{3} Z \tag{9}$$

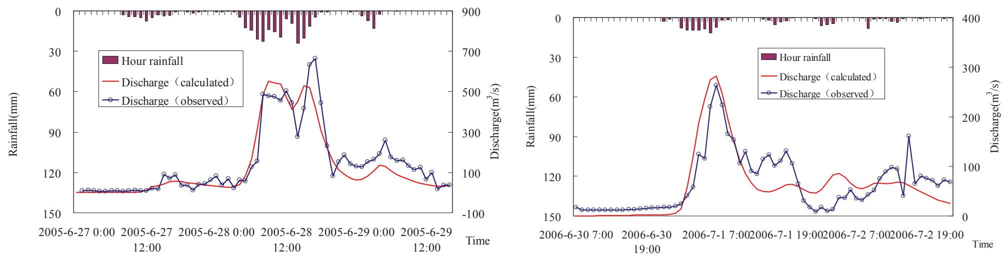
In addition, assuming that the width of river course is 2 times of water depth, and thus we can conclude that $K_1 = \frac{4}{\sqrt{2}}$ and $Z = 0.5$. Substitute K_1 and Z in the equation (8) and (9) to get the river constants G and M.

Rainfall data processing

There are two rainfall stations in Kuronagi River Basin, and the number of rainfall stations is relatively less compared with the entire area of the basin. Therefore, in this study, we have carried out interpolation of rainfall data at 84 rainfall stations in the basin and its surrounding areas using the Inverse Distance Weighted tool of the Spatial Analyst extension module and then calculate the average rainfall in each sub-basin to obtain average rainfall per hour in each sub-basin of Kuronagi River. In addition, in this study, we assumed that 3mm of hourly rainfall amount within 8 hours after rainfall is a loss (totally 24mm), and the rainfall amount except the loss is effective rainfall.

Calculation results of rainfall runoff process

According to the rainfall data processing method, the hourly rainfall observation data on the two rainfalls on June 27~ June 30, 2005 and June 30 ~ July 2, 2006 were processed, and the Kinematic Wave method was used to calculate the rainfall runoff process. The calculation results of flood discharge at the cross section of the estuary are shown in Fig. 2. As shown in the figure, except the calculation result of the peak flow discharge in 2005 which is slightly smaller than the observed value, the other calculation results are basically in agreement with the observed values. The calculation result of the peak flow discharge process in 2006 is basically in agreement with the observed value, but there are errors in later stage because the model has only taken into consideration the surface runoff but ignored infiltration and river recharge from underground runoff caused by infiltration.



(a) June 27 ~ 30, 2005 (b) June 30 ~ July 2, 2006

Fig. 2 The discharge process at estuary of Kuronagi River

Conclusion

In this paper, the ArcGIS system was used to create the digital basins in Kuronagi River and calculate the rainfall runoff process in the river basin. The conclusions are as follows:

(1) ESRI's ArcViwe8.3 and its Spatial Analyst extension module was used to carry out processing of the 50mDEM data issued by Japan Geographical Survey Institute in 1996 and produce the digital basin in Kuronagi River. On this basis, the basin was divided into 27 sub-basins to calculate the slope area, the average slope gradient and the length and slope of river section in each sub-basin.

(2) The Kinematic Wave method suitable for the GIS system was used to calculate the two rainfall runoff processes in 2005 and 2006, and the calculation results are basically in agreement with the observed values.

(3) With progress of rainfall observation techniques and computational methods, development of digital land resources information and application of GIS technology, the accuracy of calculation of rainfall runoff in basins has been greatly improved.

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