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Application of SCS Model to Simulate Rainfall-Runoff Relationship in Lack of Data Area

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Abstract: According to the actual situation of the basin and underlying surface conditions to optimize SCS model parameters and using GIUH model instead of original dimensionless unit hydrograph. We use the analysis tool of GIS to automatic extraction river system, basin, slope and other related geomorphic parameters. The constructed model is used to simulate the rainfall-runoff process at the small basin of Luanchuan Tanyu River, and compared it with the actual measurement process. The simulation results show that the simulation of runoff process is consistent with the actual measurement, and the simulation accuracy is more than 85%, which indicates that the model can be applied to the actual rainfall-runoff relationship.

Keywords: *SCS model; GIUH; GIS*

1. Introduction

In recent years, the research for hydrology in lack of data area has become the hot topic in the study of water resource and water environment [1]. In order to solve the problems, hydrologists dedicated to the development of hydrological models. As SHE Model, SWAT Model, TOP - MODEL, Xin'anjiang Model, etc. These models involve many parameters, which need a large number of measured data to rate them [2-4]. Therefore, these models have been greatly limitedin the study of Hydrology in lack of data area [5-9]. SCS Model is developed by the US Department of Agriculture Soil Conservation Service in 1954, which is characterized by simple structure, few parameters, and it is a good method to calculate runoff of small basin [10].

2. Model structure

2.1. Introduction of the SCS model

SCS Model is a model for storm runoff estimation in small basin, which is developed by the US Department of Agriculture Soil Conservation Service. The model can objectively reflect the influence of soil type, land use pattern and antecedent soil moisture content on rainfall runoff, and can be used in the estimation of runoff in lack of data area [11-12]. The US Soil Conservation Service obtained SCS Model rainfall - runoff basic relation through analysis of large amounts of data

$$\begin{cases} Q = \frac{(P-I_a)^2}{P+S-I_a} & P \geq 0.2S \\ Q = 0 & P < 0.2S \end{cases} \quad (1)$$

among $$S = \frac{25400}{CN} - 254 \quad (2)$$

$$I_a = \lambda S \quad (3)$$

Where, Q is actual runoff, mm; P istotal rainfall, mm; I_a is early loss value, mm; F is actual amount of infiltration, mm; S was the maximum retention amount, mm; $\lambda$is coefficient, USDA Soil Conservation Service has analyzed a large number of long-term experimental results, then they proposed λ= 0.2[13]; *CN* is the runoff curve number, it is a comprehensive parameter that reflects the characteristics of the basin before rainfall, and it is related to the antecedent soil moisture status, slope, vegetation, soil type and land use[14-15].

SCS-confluence Model adopts dimensionless unit line to calculate the flow process of basin.

2.2. Parameters optimization of SCS-runoff Model

As can be seen from the principle of SCS-runoff Model, its simulation accuracy depends on the parameter CN. Since the basin underlying surface (including soil characteristics, land use and antecedent soil moisture content) of the inhomogeneity, the runoff in the basin becomes extremely uneven in space. In the SCS Model, in order to quantitatively distinguish basin underlying surface non-uniformity of space, and then reflect those information to the CN, this article based on the GIS hydrological analysis tool to divided the study area into multiple sub-basin, respectively calculated the CN value of each sub-basin, and then the CN value of the whole basin is obtained by the weighted average method.

According to the actual condition of the basin to correct the grade of the antecedent soil moisture status (AMC). The AMC (I, II, III) grade of the plant growth season in Tanyu basin was adjusted to <20mm, 20mm to 70mm and >70mm.

In the earlier drought conditions, Tanyu basin runoff when a rainfall more than 5mm, thus select $I_a = \lambda S = 0.05S$.

2.3 GIUH confluence model

The original confluence model of SCS is the dimensionless unit hydrograph confluence model, which is established based on experience. Its calculation formula did not consider spatial variables, which will inevitably result in a significant impact for the simulation accuracy. GIUH is a kind of basin confluence random model with physical basis, it use landform characteristic reflect basin effect on the unit line, and it overcomes some weaknesses of using black-box method to compute unit line, which is closer to the actual situation. Especially with the development of GIS and DEM, which provide a strong technical support to obtain the precise parameters of GIUH.

For the three-level rivers, GIUH expression can be simplified to:

$$u(t) = \theta_1(0)\left[\frac{\lambda_1\lambda_2(\lambda_2-\lambda_1P_{12})}{(\lambda_2-\lambda_1)(\lambda_3-\lambda_1)}e^{-\lambda_1 t}+\frac{\lambda_1\lambda_2\lambda_3P_{12}}{(\lambda_1-\lambda_2)(\lambda_3-\lambda_2)}e^{-\lambda_2 t}+\frac{\lambda_1\lambda_3(\lambda_2-\lambda_3P_{13})}{(\lambda_1-\lambda_3)(\lambda_2-\lambda_3)}e^{-\lambda_3 t}\right] + \theta_2(0)\left[\frac{\lambda_2\lambda_3}{\lambda_3-\lambda_2}e^{-\lambda_2 t}+\frac{\lambda_2\lambda_3}{\lambda_2-\lambda_3}e^{-\lambda_3 t}\right]+\theta_3(0)\lambda_3 e^{-\lambda_3 t} \quad (4)$$

Where: $\theta_i(0)$ is the ratio of the i-th stage river basin area and the whole basin area; P_{12}, P_{13} is the transition probability; λ_i is the ratio of the average velocity of the river(v) and the average length of the i-th stage river.

In this paper, the flow rate calculated by Eagleson-Bras formula. It considers some natural and geographical factors (like width of the river, the river gradient and other) and can reflect the nonlinear change of flow rate through the net rainfall intensity changes:

$$v_\Omega = 0.655\alpha_\Omega^{0.6}(i_r A_\Omega)^{0.4} \quad (5)$$

$$\alpha_\Omega = S_0^{0.5}/(nB^{\frac{2}{3}}) \quad (6)$$

Where: i_r is the net intensity rain; A_Ω is the basin area, km^2; B is the width of the river, m; n is the roughness coefficient, according to the situation of the basin underlying surface it is taken as 0.025.

3. Examples of applications

3.1. Overview of research object

Tanyu basin is located in the northeast of Luanchuan County of Luoyang City, belongs to the hot temperate climate, where the altitude is about 460 meters ,the average annual temperature is 13.7℃, sunshine is 2292 hours, frost-free period is about 210 days. The basin area is 87.8km^2, the main channel length is 7.2 km. The annual average precipitation of the basin is 737.9 mm, while the rainfall from June to September accounted for 62.2% throughout the year, and heavy rain often appear in late July and early August. Basin land use types were classified as grassland, woodland, unused land, soil type is mainly in brown and brown soil, leaching cinnamon soil, cinnamon soil.

3.2 Get model parameters

Firstly, using 30m resolution DEM model of Tanyu basin to obtain hydrographic net and their characteristics (such as river length, slope), based on which the basin will be divided into 23 mutually not nested and closed sub-basin(Figure 1).Then handle the unit map, land use map and soil classification map superimposed (Figure 2). Secondly, refer to CN table, calculating for the CN value of each sub-basin under different soil moisture levels by area weighted method, and then calculating the CN value of the entire basin (Table 1).

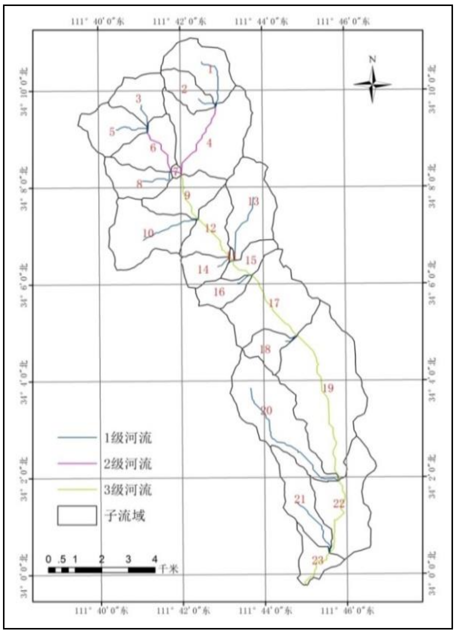

Figure 1: *Diagram of extracted sub-basin in Tanyu basin*

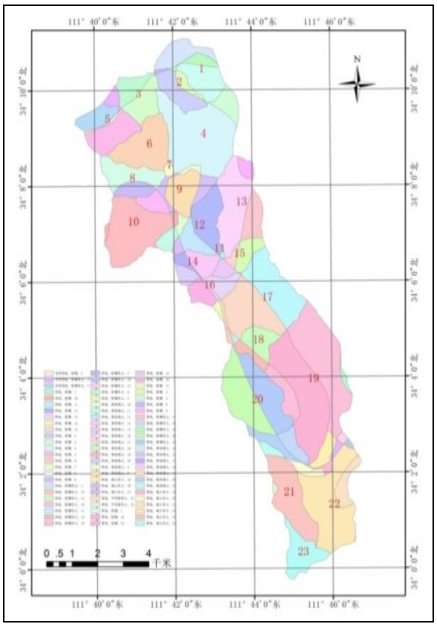

Figure 2: *Sub-basin, land use, soil classification superposition map*

Table 1: *CN values of each sub-basin in Tanyu basin*

The number of sub-basin	AMC Ⅰ	AMC Ⅱ	AMCⅢ
1	39	60	78
2	38	59	77
3	37	58	76
4	37	58	76
5	41	62	79
6	37	58	76
7	37	58	76
8	38	59	77

9	49	70	84
10	46	67	82
11	40	61	78
12	44	65	81
13	35	56	75
14	54	74	87
15	41	62	79
16	51	71	85
17	45	66	82
18	51	71	85
19	45	66	82
20	45	66	82
21	64	81	91
22	60	78	89
23	64	81	91
average value	66	45	81

Using GIS hydrologic analysis module to obtain the topography parameters of the confluence model. Geomorphic parameters, $\theta_i(0)$ and P_{ij} are listed in Table 2.

3.3. Application of the model

To make the units line calculation time consistent with the net rainfall period, this paper uses 2h as the unit line calculation time. The relevant parameter values of Tanyu basin into the formula (4), and transformed into geomorphologic unit line ($\Delta t = 2h$), as shown in Table 3.

In order to test the accuracy of the model, this paper selected 18 floods from 2003 to 2015 to calculate and then the results were compared with the measured data. The calculation results of the flood are listed in Table 4, in which the results of two floods as Figure 3.

Table 2: *Geomorphic parameters,$\theta_i(0)$ and P_{ij} of Tanyu basin*

Level of the river	N_i (strip)	$\bar{L}_i$ (km)	$\bar{F}_i$ (km^2)	R_B	R_L	R_F	$\theta_1(0)$	$\theta_2(0)$	$\theta_3(0)$	P_{12}	P_{13}
1	12	1.82	3.38								
2	3	1.83	3.68	3.5	5.803	5.432	0.415	0.303	0.282	0.821	0.179
3	1	19.4	35.97								

Table 3: *Geomorphologic unit line of Tanyu basin ($\Delta t = 2h$)*

The number of time interval	0	1	2	3	4	5	6	7	8	9	10	11
Geomorphologic unit line	0	0.0482	0.0728	0.0647	0.0535	0.0436	0.0355	0.0289	0.0235	0.0192	0.0156	0.0127
The number of time interval	12	13	14	15	16	17	18	19	20	21	22	23
Geomorphologic unit line	0.0103	0.0084	0.0068	0.0056	0.0045	0.0037	0.0030	0.0024	0.0020	0.0016	0.0013	0.0011

Table 4: *Comparison of simulated and measured flood characteristic for Tanyubasin*

Flood number	Measured peak flow (m^3/s)	Calculated peak flow (m^3/s)	Peak relative error (%)	Error of peak time (h)	Coefficient of certainty
030829	700	692	-1.143	-1	0.939
031001	180	179	-0.556	+1	0.922
040716	252	278	10.317	-3	0.827
040930	150	140	-6.667	-1	0.978
050717	413	394	-4.600	-1	0.899
051001	315	316	0.317	0	0.813
080721	236	241	2.119	+1	0.914
090829	180	193	7.222	0	0.974
100724	490	503	2.653	-2	0.900
100819	465	458	-1.505	+2	0.960
100906	396	389	-1.768	+2	0.776
110705	114	110	-3.509	+1	0.838
110725	146	166	13.699	+3	.796
110905	155	168	8.387	0	0.966
110913	506	502	-0.791	-2	0.947
120707	130	128	-1.538	0	0.9530
120805	152	155	1.974	1	0.912
140914	359	362	0.836	-1	0.971

4. Conclusion

In this article, by using GIS and RS methods to determine the parameters and take them into the model to simulate the runoff, so you do not need a large amount of measured data to identify the model parameters. Not only that, according basin hydrologic characteristics and underlying surface conditions of the basin to optimize the SCS model parameters, and using GIUH instead of the original no dimensionless unit hydrograph to compute sink flow, which is closer to the actual situation. The practical application in the Tanyubasin shows that the model constructed in this paper with high accuracy, it provides a feasible method to simulation the rainfall-runoff relationship in areas lacking data.

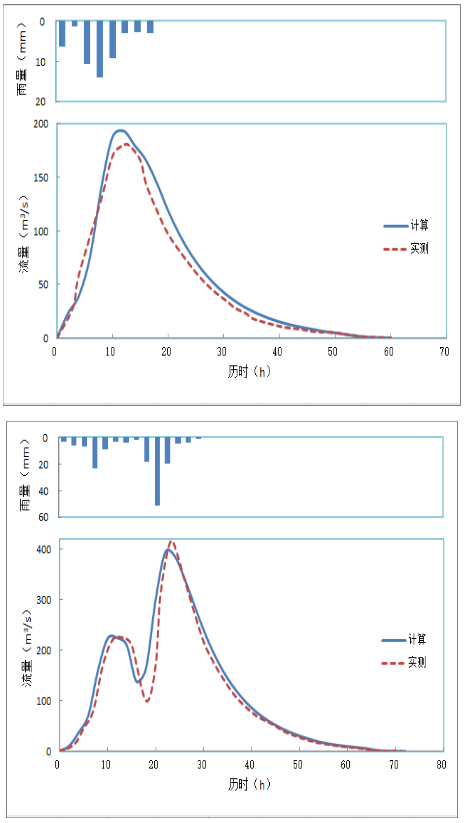

Figure 3: *Comparison of the measured and calculated results of Tanyu basin*

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