APPLICATION OF RIVER BASIN CHARACTERISTICS IN HYDROLOGICAL MODEL ON THE BASIS OF GIS

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ABSTRACT

The drainage network was extracted on the base of DEM in the Three Gorge interbasin by use of the special analysis function of GIS. The runoff concentration routing can be determined in the drainage network. And then the topographic characteristics, such as routing length and grade, were calculated. The distribu tion characteristics of vegetation, soil, geology, physiognomy of the basin were extracted in GIS. The interrelationships between the characteristics and the parameters of Xinanjiang model were studied. These interrelationships were used to the space transplanting of the model parameters in the non-data areas of the interbasin. The scheme of rainfall runoff forecasting in the interbasin has been established in this way.

1. INTRODUCTION

Remote Sensing Data, GIS, DEM (Digit Elevation Model) and so on have all been well known and widely used in many domains. A basin can be divided into a set of rectangular element areas, called pixels or cells. Pixel elevation extracted by DEM is the inherent information of remote sensing data. It is a universal theorem that water flows always from high point to lower point. Therefore, by use of the one direction model (Aurousseau and Squividant, 1995), runoff flow direction in the pixel, shortly pixel direction, can be determined according to the elevation. Connecting pixels in their directions, the drainage network of a basin is created (Beven and Kirkby, 1979; Depraetere, 1991). The topography of a catchment has a major impact on the hydrological, geomorphologic, and biological processes active in the landscape (Moore et al.,1991). A drainage network is the detail depiction of the topography. The pixels can be divided into two parts according to their drainage area. One part is that their drainage areas are larger than a threshold and another one is that their drainage areas are smaller than the threshold. When the pixels of the first part are connected, a hydrologic network is created. According to the drainage network, the distances and mean slops from each pixel to the river or the outlet of the basin can be calculated.

In one direction model, most of the pixel directions can be determined directly on the basis of the pixel elevations except two cases. One case is that the elevation of the lowest neighbor pixel of a processing pixel is equal to the elevation of this processing pixel or the lowest neighbor pixels are more than one, which means that there is a plain area, no matter how large it is. In this paper, the Modified Direction Weight Method (MDWM) is introduced, and the directions of this kind of pixel were determined by this method. Another case is that the neighbor pixels of a processing pixel or a set of processing pixels are all higher than itself or themselves. They are called sinks. A sink is a shallow pit and is not deep enough to stop the flowing of runoff. It is created by micro-geomorphy or due to the insufficient accuracy of the elevation data. These sinks should be eliminated. Otherwise, the drainage network will be broken unreasonably. However, nature lakes and some big pools are not defined as the sinks and should be identified before the elimination.

For eliminating the sinks, a "ditch" is "dug" to lead runoff to go out of its control region in this paper.

According to the drainage network, the basin divide lines can be derived. The basin was segmented into sub-basins (call elements) on the basis of the divide lines. By use of the GIS, the mean distances and mean slops form each pixel to the outlet of the elements, the index of vegetation, soil, geology, physiognomy of the basin were extracted . The relationships between the basin characteristics and the parameters of Xinanjiang model (Zhao, 1992) were established. These relationships were adopted as a method to determined the model parameters in no-data basins.

All the methods addressed in this paper were tested in the interbasin of Three Gauge. The relationships have been used to determine the model parameters for the real time flood forecasting of the interbasin.

2. DRAINAGE NETWORK

2.1. Determining Pixel Direction According to Pixel Elevation Directly

Dividing a basin into a set of rectangular pixels represented by (i,j) pairs in Cartesian coordinate, there will be eight neighbour pixels for every pixel. So, there will be eight possible pixel directions in one direction model. If there is a studied region as shown in Fig. 1, the pixel directions will be like that in Fig. 2.

In order to explain easily, P(i,j) is used to express a pixel, E(i,j) the elevation of P(i,j), D(i,j) the direction of P(i,j) and A(i,j) all the neighbour pixels of P(i,j). In Fig.1, D(3,3) points to P(2,2) because E(2,2) is the lowest one among A(3,3). E(6,10) and E(6,11) are both the lowest one among A(7,10). But, the distance between P(6,10) and P(7,10) is shorter than that between P(6,11) and P(7,10). So, D(7,10) points to P(6,10). P(5,11) and P(7,13) are both the lowest one among A(6,12) and have the same distance to P(6,12). Therefore, D(6,12) is left as a zero pixel represented by Z(i,j). P(7,11), P(8,2), P(9,5) and P(9,6) are some other zero pixels. As far as P(3,7), P(9,4) and the area of [P(11,2), P(11,3), P(12,2), P(12,3)], they are sinks expressed by S(i,j) and will be dealt with in next section.

(i) \ (j)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	12	15	27	45	55	55	58	83	160	305	475	625	750	873	900
2	20	33	48	55	55	48	50	68	112	215	360	495	625	750	873
3	50	68	75	75	65	48	45	65	100	162	277	392	495	625	750
4	90	112	125	125	118	87	70	87	123	152	200	300	398	485	583
5	250	262	273	260	225	168	133	130	145	160	170	215	290	352	418
6	540	525	523	485	418	360	283	210	185	175	175	180	200	242	300
7	710	685	670	635	602	585	502	392	298	215	185	175	170	183	215
8	737	710	680	660	660	670	660	608	480	312	215	175	158	160	183
9	768	705	670	660	670	698	730	730	660	495	312	208	162	150	170
10	755	665	640	660	698	735	777	800	785	687	485	300	202	170	180
11	695	625	620	650	715	780	837	870	860	810	670	465	320	248	248
12	650	620	620	640	730	845	927	983	965	915	827	660	523	415	383
13	635	627	625	655	780	960	988	995	990	985	970	827	698	598	545

Fig. 1 The pixel elevations E(i,j) in a studied region.

(i) \ (j)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	↑	↖	↖	↖	↖	↓	↙	↙	↙	↙	↙	↙	↙	↙	↙
2	↖	↖	↖	↖	↖	↘	↓	↙	↙	↙	↙	↙	↙	↙	↙
3	↖	↖	↖	↖	→	→	○	←	←	←	↙	↙	↙	↙	↙
4	↖	↖	↖	↗	↗	↗	↑	↖	↖	↖	←	↙	↙	↙	↙
5	↖	↖	↖	↗	↗	↗	↑	↖	↖	↖	↖	←	↙	↙	↙
6	↖	↖	↗	↗	↗	↗	↗	↑	↖	↖	↖	○	↓	↙	↙
7	↗	↗	↗	↗	↗	↗	↗	↗	↗	↑	○	↘	↓	↙	↙
8	↗	○	↗	↗	↗	↗	↗	↗	↗	↗	→	→	↘	↓	↙
9	↘	↘	↓	↙	○	○	↗	↗	↗	↗	↗	↗	→	○	←
10	↘	↘	↓	↙	↙	↖	↖	↗	↗	↗	↗	↗	↗	↑	↖
11	↘	○	○	←	↙	↖	↖	↖	↗	↗	↗	↗	↗	↑	↖
12	→	○	○	←	←	↖	↖	↖	↗	↗	↗	↗	↗	↑	↑
13	↗	↑	↑	↖	↖	↖	↖	↖	↗	↗	↗	↗	↗	↗	↑

Fig. 2 The pixel directions D(i,j) derived according to the elevations directly in the region corresponding to Fig. 1. The zeros means zero pixels or sinks.

2.2. Determining the Direction of Zero Pixel

For easy expression, we give a name to each possible direction. If D(i,j) points to P(i-1,j), i.e. ↑, we call it d-1. Similarly, we call ↖ d-2, ← d-3, ↙ d-4, ↓ d-5, ↘ d-6, → d-7, and ↗ d-8. If we draw eight normal lines from a P(i,j) to A(i,j), there will be eight angles between normal lines and the directions of A(i,j)). The angle between normal line and D(7,11) is defined as infinity because P(7,11) is a zero pixel too. According to the angles, A(6,12) can be divided into two sets. If an angle is larger than 90°, the corresponding pixel is called input neighbour pixel (*inp*). They are P(5,13) and P(7,11). The others are called output neighbour pixels (*onp*). The principle determining the direction of a Z(i,j) is that there is useful information in *onp* only, which means the direction of a Z(i,j) is one of the directions of its *onp*. In Fig. 3, D(6,12) should be one of d-2, d-3, d-5 or d-6.

For selecting a reasonable one among d -2, d -3, d-5 and d -6, we give a weight for each angle, 1.5 for angle 0°, 0.7 for 45° and 0.4 for 90°. These weights have been carefully refined in varied cases. And then we calculate a value *V* for each possible direction. Among A(6,12), P(5,11) and P(6,11) have the same output direction d-2 and the angles are 0° and 45° correspondingly. So, we have V_{d-2} = 1.5[P(5,11)] + .7[P(6,11)] = 2.2. For d-2, similarly, V_{d-3} = .4[P(5,12)], V_{d-5} = .7[P(7,13)] + .4[P6,13]] = 1.1 , V_{d-6} = .7[P(7,12)].

In this case, d-2 is selected as D(6,12) because V_{d-2} is the biggest one among all *V* values.

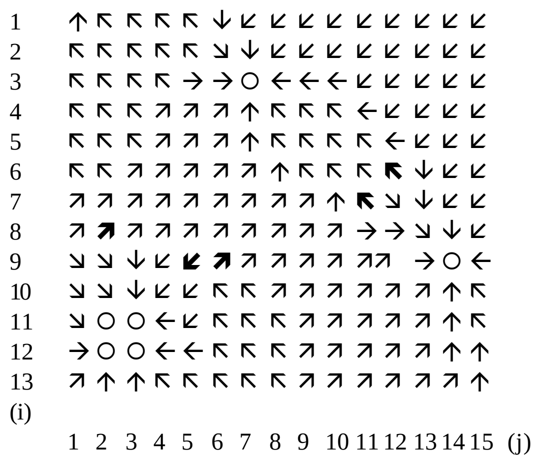

Fig. 3 The directions determined by DWM are highlighted in the region corresponding to Fig. 1. The zeros mean the sinks.

The determination is processed in three steps. First, when the biggest *V* for all zero pixels have been calculated, the directions of Z(i,j) are determined if its biggest *V* is larger than 1.1. Secondly, the biggest *V* of the remainder zero pixels are re-calculated. Meanwhile, the directions determined in first step are taken into account. Those that its biggest *V* is larger than 0.8 are determined. Finally, the directions of all the still remainder zero pixels are determined. Of course, the directions determined in above two steps should be taken into account in final step. For a large area, the determination process will be pixel-by-pixel and from the edge to the center of the area. This method is called Direction Weight Method (DWM). In Fig. 3, it is evident that the directions determined by DWM are reasonable.

2.3. Eliminating the Sink

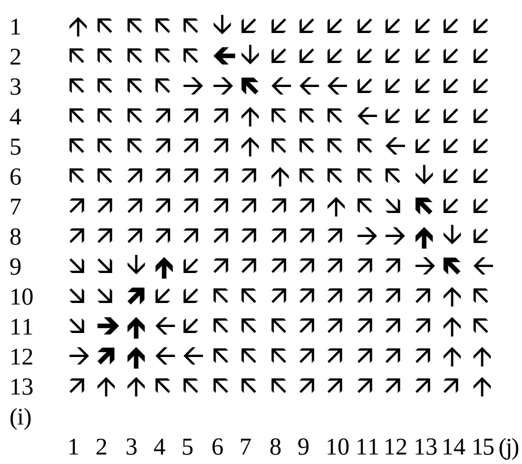

Fig. 4 The directions determined by DM are highlighted in the region corresponding to Fig. 1.

Finding out all the possible ditches is the first step. An edge pixel of the sink region and a sink pixel are the two terminals of a possible ditch. The whole ditch is limited into a rectangular area. The two terminals are the two diagonal corners of the area. This limitation could avoid that a ditch passes an unreasonable long way. We start searching at an edge pixel P(i,j), and find out a lowest $P(i_1,j_1)$ among A(i,j) in the limited area. When $P(i_1,j_1)$ is found, the limited area will be reduced by substituting $P(i_1,j_1)$ for P(i,j) as a corner. The lowest $P(i_2,j_2)$ among $A(i_1,j_1)$ can be found out and the limited area can be further reduced similarly. Finally, the searching will arrive at another terminal, the sink pixel. Connecting all of these pixels, P(i,j)-$P(i_1,j_1)$-$P(i_2,j_2)$-...... , a possible ditch is found. The ditch direction is, of course, from sink to edge. In the same way, we can find out all the possible ditches.

There is a highest elevation in each possible ditch. Clearly, there is a lowest one among all of these highest elevations. The ditch corresponding to this lowest one, shortly called ditch, is then adopted as the solution. The directions of the pixels on this ditch, shortly called ditch pixel, are all modified to follow the ditch direction. If there is a big sink (i.e. there are several sink pixels in the sink) and S(i,j) is a terminal of the ditch, the directions of A(i,j) in the sink point to S(i,j) and that of other sink pixels are determined by MDWM. This method is called Ditch Method (DM). The solutions of DM are highlighted in Fig. 4.

In Fig. 4 we can find that some D(i,j) located on the both sides of the ditch are not harmonious with the ditch direction, such as D(8,14), D(9,13), D(9, 3), D(10,4), etc. At these pixels, there will be acute angles in drainage network. So, they should be modified to follow the tendency of the ditch direction as shown in Fig.5. After these modifications, DM is called Modified Ditch Method (MDM).

3. TEST OF THE METHODS IN THE INTERBASIN OF THREE GAUGE

3.1. The Test Catchments

ChangJiang River is the longest river in China. The interbasin of Three Gauge is from CunTan to YiChang. The area is 14970 km^2, and the length of main river is 658 km. The flood concentration timeis about 55-63 hours in this reach. The mean precipitation is 1100 mm annually. The runoff value yield in the interbasin is about 7.8% of that of YiChang Station. The peak flood of the interbasin is usually about 7000-8000 m^3/s. It was 20500 m^3/s in 1987 and the water stage was raised 3.0 m at YiChang Station. The interbasin is an alp area. Fig. 6 is a drainage network derived by use of the above method in a small basin, called XiangXi. Fig. 7 is the distribution of the elements segmented by the divide lines in the interbasin. The points are the locations of the precipitation stations. Totally there are 162 elements in the interbasin.

There are about 100 precipitation stations in the interbasin. But there are only a several hydrologic stations. That means a lot of area can not be controlled by the hydrologic sta tion. So, it is difficult to determine the model parameters in this kind of area.

(i) \ (j)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	↑	↖	↖	↖	↖	**↓**	↙	↙	↙	↙	↙	↙	↙	↙	↙
2	↖	↖	↖	↖	↖	**←**	**←**	↙	↙	↙	↙	↙	↙	↙	↙
3	↖	↖	↖	↖	**↑**	**↖**	**↖**	←	←	←	↙	↙	↙	↙	↙
4	↖	↖	↖	↗	↗	↗	↑	↖	↖	↖	←	↙	↙	↙	↙
5	↖	↖	↖	↗	↗	↗	↑	↖	↖	↖	↖	←	↙	↙	↙
6	↖	↖	↗	↗	↗	↗	↗	↑	↖	↖	↖	↖	**←**	↙	↙
7	↗	↗	↗	↗	↗	↗	↗	↗	↗	↑	↖	**↑**	**↖**	**←**	↙
8	↗	↗	↗	↗	↗	↗	↗	↗	↗	↗	→	**↗**	**↑**	**↖**	↙
9	↘	↘	**↗**	**↑**	**↖**	↗	↗	↗	↗	↗	↗	↗	**↑**	**↖**	←
10	↘	**→**	**↗**	**↑**	**↖**	↖	↖	↗	↗	↗	↗	↗	↗	↑	↖
11	↘	**↗**	**↑**	**↖**	↙	↖	↖	↖	↗	↗	↗	↗	↗	↑	↖
12	→	**↗**	**↑**	**↖**	←	↖	↖	↖	↗	↗	↗	↗	↗	↑	↑
13	↗	↑	↑	↖	↖	↖	↖	↖	↗	↗	↗	↗	↗	↗	↑

Fig. 5 The directions modified by MDM are highlighted in the region corresponding to Fig. 1.

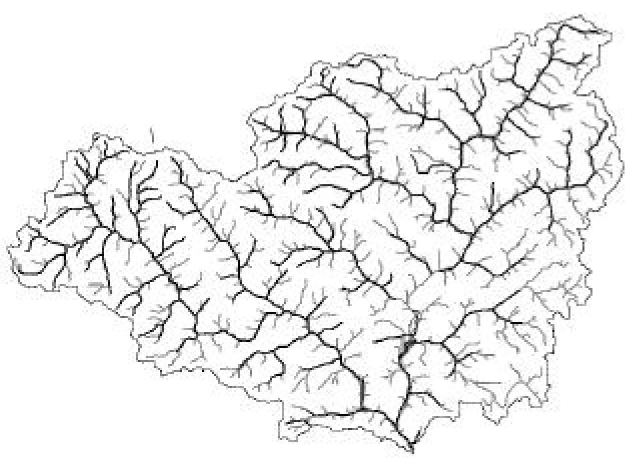

Fig.6 The drainage network of XiangXi basin

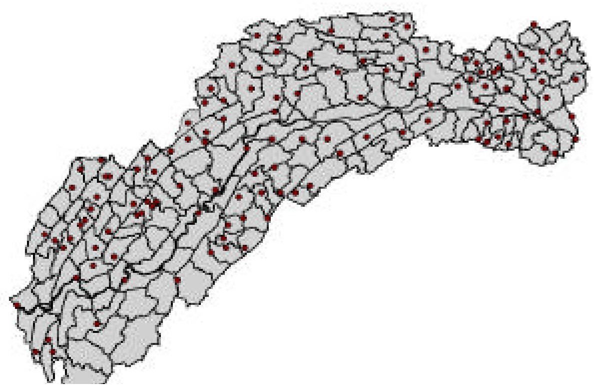

Fig. 7 the distribution of the elements segmented by the divide lines in the interbasin of Three Gauge

In this paper, six small basins were selected in order to calibrate the parameters of Xinanjiang model. The data are full available for the calibration. The parameters of these six basins are listed in Table 1.

3.2. The Relationship Between the Basin Characteristics and the Model Parameters

Totally four parameters, SM, KI, KG and XE, were studied in this paper.

3.2.1 SM: The parameter SM is closely related to the forest index (P). The forest index is the percentage of the forest area to the basin area. Their values in the above small basins are listed in the Table 2. By use of the regression analysis, they have the relationship SM=37.344P-2.8633.

3.2.2 KG, KI: Similarly, the parameter KG and KI are closely related to the index (M) of rock characteristic (Fengbing, 1991). The M is a combination of the areas of different kinds of rocks. Their values are listed in the Table 2 too. By use of the regression analysis, their relationships are KG=0.1389M+0.407 and KI=-0.1786M+0.3271.

3.2.3 XE: Similarly, the parameter XE is closely related to the index (J). (Fengbing, 1991). The J is a mean slop of flow routing from each pixel to the outlet of the element. Their values are listed in the Table 2 too. By use of the regression analysis, the relationship is $XE=0.3917*J^{0.0485}$.

3.3. The Application of the Relationship in the Non-data Area

As mentioned above, the interbasin was segmented into 162 elements by the divide lines. The basin characteristics (P, M, J) of the elements were derived by GIS and the methods addressed in this paper. According to the above relationships, we can get the model parameters (SM, KG, KI, XE) for each element.

Table 1 The parameters of Xinanjiang model

Name	DH	LH	MDX	QGH	DNH	XX
K1	0.99	0.68	0.97	0.76	0.4	0.72
K2	0.97	0.66	0.93	0.7	0.37	0.68
WM	120	120	120	120	130	120
WUM	20	20	20	20	15	18
WLM	65	80	75	60	60	60
B	0.2	0.25	0.32	0.3	0.3	0.35
C	0.16	0.16	0.16	0.16	0.2	0.12
SM	10	6	6	22	17	31
EX	1.5	1.5	1.5	1.5	1.5	1.5
KE	1.5	1.5	1.5	1.5	1.5	1.5
KI	0.49	0.54	0.57	0.5	0.47	0.41
KG	0.21	0.21	0.13	0.2	0.26	0.33
IM	0.02	0.01	0.01	0.02	0.01	0.01
CI	0.22	0.55	0.6	0.7	0.9	0.7
CG	0.99	0.99	0.992	0.992	0.99	0.99
CS	0.41	0.41	0.37	0.41	0.41	0.55
XE	0.37	0.42	0.45	0.4	0.41	0.44

4. MODELING CONPARE OF TWO SETS OF ARAMETER

Two sets parameters are adopted in both six small basins and the interbasin. One set is that in Table 1. Another set is that the SM, KG, KI and EX are substituted by that derived on the basis of the relationships. According to the modeling hydrographs and their statistics analysis, nearly the same modeling results can be obtained by these two sets of parameters.

5. CONCLUSIONS AND DISCUSSIONS

The methods addressed in this paper are powerful for deriving drainage network when they were tested in the interbasin of Three Gauge, especially MDWM for zero pixel. The basin characteristics are suitable to establish the relationship with the parameters of Xinanjiang Model. The relationships can be used in the non-data area spatially.

Table 2 The Relationship Between Model Parameters and the Basin Characteristics

Name	DH	LH	MDX	QGH	DNH	XX
P	20	20	20	20	15	18
SM	10	6	6	22	17	31
M		0.8792	0.9177	0.6177	0.1651	0.2498
KI		0.54	0.57	0.5	0.47	0.41
KG		0.21	0.13	0.2	0.26	0.33
J	0.26	5.99	6.23	4.28	2.80	8.55
XE	0.37	0.42	0.45	0.4	0.41	0.44

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