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Hydrological Parameter Analysis Based on Similarity Theory and 3S Technology

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Abstract. Parameter identification is an important step on the hydrological modelling. Nevertheless, some parameters of the hydrological model cannot be determined directly through experimental observation, which are related to watershed characteristics. As a result, the way to analyze effectively the correlation between the parameters and watershed characteristics become the important content of hydrological model development. In this study, we use similarity theory combines with 3S technolog (RS, GIS and GPS) to analyze the hydrological model parameters. The results show that the distances on the parameters of two similar watersheds are mostly small and close in the geometric space. This founding can help us to find some of the laws of runoff response function.

1. Introduction

Watershed characteristics have a great effect on the hydrological model parameters, and with the different space scale, different characteristics, the response of hydrological parameters on watershed characteristics are varied[1]. By the development of computer and 3S technology, the data of watershed characteristics is obtained more easily. Recently, more and more attention has been paid to the relationship between parameters and watershed characteristics, due to solve the problem of predictions in the ungauged basins.

This paper selects 20 typical reservoir basins (Tab.1) in different areas as the research object, covering the humid and semi-humid regions, on behalf of the Chinese most topographic and climatic characteristics.

Tab.1 Reservoir Watershed Summary

Serial number	Reservoir name	Province	Serial number	Reservoir name	Province
1	Duihekou	Zhejiang	11	Mengshan	Shandong
2	Nanjiang	Zhejiang	12	Chengbihe	Guangxi
3	Fushi	Zhejiang	13	Shimen	Shanxi
4	Fushui	Hubei	14	Feijiantan	Jiangxi
5	Longjinshang	Guangdong	15	Baipengzhu	Guangdong

6	Hemianshi	Guangxi	16	Dongzhang	Fujian
7	Dongzhen	Fujian	17	Sandaohe	Hubei
8	Hengjing	Zhejiang	18	Changzhao	Zhejiang
9	Dahesha	Guangdong	19	Houwan	Shanxi
10	Rizhao	Shandong	20	Qingshitan	Guangxi

2.Data and Methods

2.1 Xi'anjiang Model

The hydrological forecasting uses Xin'anjiang Model in this paper. The Xin'anjiang Model is widely used in china, and has achieved good results[2], which is divided into Evapotranspiration, runoff yield, water source separation, flow concentration, and each part has related parameters(Tab.2). Some parameters which has physics meaning, can be directly determined.

Tab.2 Xi'an Jiang Model Parameters

Parameter symbol	The significance of the Xinanjiang Model parameters.
KC	Evapotranspiration coefficient. This Parameter controlling water balance of the whole watershed, is very important for water quantity calculation.
UM	The tension water capacity of upper layer(mm)
LM	The tension water capacity of lower layer(mm)
C	The evapotranspiration coefficient of deeper layer， associated with the coverage area of deep rooted plants.
WM	The areal mean tension water storage, on behalf of watershed drought condition.
B	the exponential of the distribution of tension water capacity，This para value depends on the uneven distribution of tension water conditions, related with watershed area.
IM	The ratio of impervious area to the total area of the watershed
SM	The free water storage capacity(mm)
EX	the exponential of distribution water capacity, reflect the nonuniform distribution of aquifers condition about surface layer of free water.
KG	The out f low coefficient of free water storage to the g round water flow
KI	The out f low coefficient of free water storage to the inter flow
CI	The recession constant of lower interflow storage
CG	The recession constant of g round water storage
CS(UH)	The recession constant of channel network storage
KE	Muskingum parameter, the residence time of water(h)
XE	Muskingum coefficient(h)

2.2 Watershed Characteristics Extraction

Watershed characteristics are the basic physical properties of a basin, including slope, drainage, basin shape, vegetation and so on, which affect the runoff, sediment and pollutant formation, transport and storage process, so the watershed characteristics has great influence on the hydrological parameters. In this paper, the watershed characteristics extraction were statistically analyzed using Arcgis 9.2 and ENVI 4.2, whose data provided from the DEM and TM Database.

2.2.1 Watershed Characteristics Extraction based on DEM Data

①Slope: Slope refers to the angle which exists between the cutting plane of any point that is over the surface and ground level. It makes the great influence on the time of flow concentration. If the slope increases, the time of flow concentration will decrease, otherwise it will increase. ②River length: The extraction of river length is based on the river system. It can be got through the number of grid cells of each river which can be figured out through drainage map generated from DEM data, then multiply it by the length of grid cells[3]. ③Basin shape coefficient Ke: Ke means the ratio between the physical length of basin divide and the circumference of the same basin. If the basin shape has a huge difference with the round shape, the basin shape coefficient Ke is larger. The value of Ke is close to 1, the basin shape is close to circular, so it is easy to cause the big flood. The larger the value is, the narrower basin shape is. And at the same time, the runoff variation is more gently. ④Drainage density: It means the river length in the unit of the basin, which expresses the effectiveness of water drainage. The calculation formula is as follows:

$$D = \frac{\sum_{w=1}^{\delta}\sum_{j=1}^{N_w} L_{wj}}{A}$$

Where D is Drainage density; Lwj is the length of the j river in the w class, j=1,2,…,Nw; Nw is The total of the w River; A is drainage area.

Tab.3 Basin Features Summary Based on DEM Data

Reservoir Name	Slope	River length （km）	Basin shape coefficie-nt Ke	Draina-ge density	Reservoir Name	Slope	River length （km）	Basin shape coeffici-ent Ke	Draina-ge density
Duihekou	15.44	41.13	1.902	0.621	Mengshan	5.64	11.52	1.283	0.828
Nanjiang	12.04	61.83	1.782	0.508	Chengbihe	17.92	562.95	1.792	0.157
Fushi	13.74	118.98	2.681	0.574	Shimen	24.93	95.58	1.271	0.272
Fushui	14.07	929.79	1.563	0.108	Feijiantan	11.18	23.85	1.616	0.735
Longjinsha-ng	2.82	84.51	1.363	0.326	Baipengzhu	12.84	258.84	2.971	0.39
Hemianshi	15.83	19.53	1.380	0.688	Dongzhang	13.36	46.08	1.58	0.477
Dongzhen	10.70	22.59	1.564	0.652	Sandaohe	20.3	272.52	1.74	0.238
Hengjing	17.33	43.20	2.767	0.885	Changzhao	16.23	95.58	1.365	0.296
Dahesha	4.95	25.83	1.459	0.548	Houwan	6.94	495.81	1.476	0.145
Rizhao	6.68	155.61	1.545	0.259	Qingshitan	17.22	56.88	1.69	0.476

2.2.2 Watershed Characteristics Extraction based on TM Data

Vegetation index is a reflection of the density of green vegetation over one region. As vegetation has a great influence on hydrological cycle, this index is an important parameter to the hydrological characteristics of the basin. NDVI (Normalized Difference Vegetation Index) is a commonly used vegetation index, measuring the wavelengths and intensity of visible and near-infrared light reflected by the land surface back up into space(Tab.4). The calculation formula is as follows:

$$NDVI = \frac{\rho_{NIR} - \rho_R}{\rho_{NIR} + \rho_R}$$

Where ρ_{NIR} is the value of band4 from TM data, ρ_R is the value of band3 from TM data. According to TM data from Landsat5, the type of band4 is NESR IR, and the type of band3 is RED.

Tab.4 Reservoir Watershed NDVI

Reservoir name	NDVI				Reservoir name	NDVI			
	Min	Max	Mean	Std dev		Min	Max	Mean	Std dev
Duihekou	-0.179	0.691	0.515	0.107	Duihekou	-0.459	0.755	0.220	0.136
Nanjiang	-0.286	0.589	0.315	0.106	Nanjiang	-0.875	0.810	0.244	0.184
Fushi	-0.128	0.691	0.500	0.112	Fushi	-0.636	0.728	0.552	0.119
Fushui	-0.304	0.621	0.302	0.114	Fushui	-0.366	0.431	0.156	0.136

Longjinshang	-0.600	0.561	0.221	0.154	Longjinshang	-0.375	0.656	0.392	0.161
Hemianshi	0.096	0.558	0.397	0.051	Hemianshi	-0.357	0.734	0.533	0.111
Dongzhen	-0.895	0.716	0.451	0.197	Dongzhen	-0.693	0.758	0.299	0.155
Hengjing	-0.243	0.566	0.335	0.131	Hengjing	-0.220	0.579	0.347	0.108
Dahesha	-0.200	0.575	0.354	0.094	Dahesha	-1.000	1.000	0.130	0.126
Rizhao	-0.811	0.977	0.265	0.121	Rizhao	-0.471	0.750	0.525	0.203

2.3 Meteorological Data

In this paper, the meteorological data is obtained from China Meteorological Data Sharing network (Tab.5).

Tab.5 Climate Values of Different Reservoir Watershed

Reservoir name	Average annual temperature (°C)	Average annual total cloud amount	Average annual rainfall (mm)	Reservoir name	Average annual temperature (°C)	Average annual total cloud amount	Average annual rainfall (mm)
Duihekou	16.8	6.8	1017	Duihekou	12.5	5	858.5
Nanjiang	17.3	6.7	1563	Nanjiang	22	7.3	1320
Fushi	16.5	6.8	1200	Fushi	14.3	7.2	900
Fushui	16.6	6.5	1553	Fushui	17.1	7.1	1720
Longjinshang	22.2	7	1500	Longjinshang	21.5	6.9	1924
Hemianshi	21	7.2	1604	Hemianshi	20.2	7.1	1374
Dongzhen	20.2	7.3	1398	Dongzhen	15.5	6.6	935
Hengjing	16.5	6.7	1454	Hengjing	16.5	6.8	1955
Dahesha	18	7.2	2130	Dahesha	10	5.9	4548

3. Analysis and Results

3.1 Variable Selection

In order to get rid of the inconsistency of principle, Need to variable standardization before similarity analysis[4]. Then, distance or cluster analysis requires the linear relationship between variables isn't strong[5]. Otherwise, it will lead to the same kind of variables will repeat, thus affecting the statistical results. So before the analysis in this paper, the writer carries out the correlation analysis to discover the linear variables, so some variables can be kicked out. Simple Pearson correlation coefficient calculation formula is as follows:

$$r = \frac{\sum_{i=1}^{n}(x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_{i=1}^{n}(x_i - \bar{x})^2 \sum_{i=1}^{n}(y_i - \bar{y})^2}}$$

Where n is the total number of samples, xi or yi is variable value.

Tab.6 Pearson Simple Correlation Coefficients of Watershed Characteristics Variables

Variable	Z (Slope)	Z (River length)	Z(KE)	Z (Draina-ge density)	Z (NDVI)	Z (Average annual tem-perat-ure)	Z (Average annual total cloud amount)	Z (Average annual rain-fall)
Z(Slope)	1.000	0.101	0.195	-0.125	0.522	0.087	0.441	0.019
Z (River length)	0.101	1.000	0.018	-0.712	-0.335	-0.104	-0.138	-0.163
Z (KE)	0.195	0.018	1.000	0.234	0.204	0.200	0.118	0.159
Z (Drainage density)	-0.125	-0.712 *	0.234	1.000	0.167	0.098	0.030	0.141
Z (NDVI)	0.522	-0.335	0.204	0.167	1.000	0.285	0.495	0.244
Z (Average annual tempera-ture))	0.087	-0.104	0.200	0.098	0.285	1.000	0.742	0.673
Z (Average annual total cloud amount)	0.441	-0.138	0.118	0.030	0.495	0.742 *	1.000	0.655

Z (Average annual rainfall)	0.019	-0.163	0.159	0.141	0.244	0.673 *	0.655 *	1.000

From the Tab.6, river length is closely related to drainage density. Taking into account the river length is closely related with the time of concentration, so this paper decides to select river length as a variable. At the same time, there is a strong correlation among the Average annual total cloud amount, temperature and rainfall, but the Pearson of mean annual temperature, cloud amount and rainfall is very high. The average annual temperature can reflect other information. In the end, the writer cut off three variables: drainage density, Average annual cloud amount and rainfall amount.

3.2 Correlation Analysis and Results

he correlation analysis between parameters and characteristic values of the hydrological model were statistically analyzed using Pearson (Tab.7).

Tab.7 Correlation Coefficients of Parameters and Watershed Characteristics Variables

Parameter/ Variable	Slope	River length	KE	NDVI	Average annual temperature
k	-0.019	-0.279	0.034	-0.384	0.105
WM	0.019	-0.035	-0.156	-0.242	-0.360
WUM	0.104	-0.162	-0.183	0.085	0.276
WLM	-0.104	0.162	0.183	-0.085	-0.276
C	0.106	-0.072	0.044	0.012	-0.245
B	-0.506	0.086	0.236	-0.378	0.239
SM	0.256	0.238	0.012	-0.151	0.303
EX	-0.252	-0.156	-0.050	-0.062	-0.175
KI	0.002	-0.017	0.097	0.325	-0.402
KG	0.030	0.304	0.004	-0.475	0.067
CS	0.439	0.272	0.137	0.006	-0.036
CI	-0.009	0.041	-0.162	-0.223	0.227
CG	0.289	0.249	0.135	0.228	0.175
KE	0.559	0.394	0.127	0.173	0.022
XE	-0.141	-0.266	0.086	0.228	-0.473

It can be seen from the table that there is no strong correlation coefficient between the model parameter set and drainage basin characteristics value. The writer analysis the reason that is the model parameter is not decided by a single variable, but it is affected by many other factors such as topography and climate. In other word, model parameter is a whole comprehensive reflection of watershed characteristics. The reason of his information is how to affect the parameters is still unknown, just like the black box model.

3.3 Distance Analysis and Results

his paper refers to the similar basin means the basin which has similar geomorphology and climate. Euclidean distance is treated as judgment standard. The reservoir distance which is taken the variable of watershed characteristics is analyzed in Tab.8. On the basis of this analysis, we find the minimum distance between two reservoirs(bold font indicates). Except for this reservoir, we should also find the most similar reservoir among19 reservoirs. Then, the distance analysis can be gotten using parameters as variables. The detail result can be found in Tab.9. Some inspirations also can be obtained from Tab.9 that is the distances on the parameters of two similar watersheds are mostly small and close in the geometric space.

Tab.8 Distance analysis using watershed characteristics as the variable

	Euclidean Distance																			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	0.0	1.7	1.6	4.0	3.7	1.9	3.6	2.2	2.4	3.6	3.4	3.4	2.2	2.9	2.9	1.3	2.1	1.7	4.4	0.8
2	1.7	0.0	2.3	3.6	2.5	1.7	4.9	2.2	**1.5**	5.4	2.2	2.8	3.2	**1.3**	2.8	1.9	1.8	**1.2**	3.4	1.9
3	1.6	2.3	0.0	4.2	4.2	3.0	4.5	**1.5**	3.1	2.8	4.0	3.7	3.5	3.4	**1.9**	2.5	2.7	2.8	4.6	2.2
4	4.0	3.6	4.2	0.0	4.4	4.0	2.1	4.3	4.1	2.7	4.3	**2.4**	4.4	3.9	4.2	4.1	2.9	3.4	3.3	4.0
5	3.7	2.5	4.2	4.4	0.0	2.7	2.3	4.2	1.7	2.4	3.0	3.4	5.3	2.3	3.9	3.1	3.9	3.1	4.2	3.7
6	1.9	1.7	3.0	4.0	2.7	0.0	5.1	3.1	2.2	3.3	3.5	2.7	2.9	2.4	3.3	**1.2**	2.4	1.5	4.7	**1.4**
7	3.6	4.9	4.5	2.1	2.3	5.1	0.0	2.4	2.0	4.0	5.2	3.2	3.3	3.1	3.2	1.4	3.7	2.6	2.4	3.5
8	2.2	2.2	**1.5**	4.3	4.2	3.1	2.4	0.0	3.4	4.1	3.9	3.4	3.7	2.8	2.0	3.1	2.3	2.7	4.4	2.6
9	2.4	1.5	3.1	4.1	1.7	2.2	2.0	3.4	0.0	4.3	2.0	3.6	4.0	1.9	3.6	2.1	3.1	2.1	3.6	2.6
10	3.6	5.4	2.8	2.7	2.4	3.3	4.0	4.1	4.3	0.0	**1.3**	3.3	2.9	2.5	5.2	2.6	4.3	4.7	4.4	3.2
11	3.4	2.2	4.0	4.3	3.0	3.5	5.2	3.9	2.0	**1.3**	0.0	4.4	4.3	1.9	4.8	3.7	3.1	2.5	**2.3**	3.7
12	3.4	2.8	3.7	**2.4**	3.4	2.7	3.2	3.4	3.6	3.3	4.4	0.0	4.2	3.0	3.0	3.2	2.4	2.8	4.3	3.1
13	2.2	3.2	3.5	4.4	5.3	2.9	3.3	3.7	4.0	2.9	4.3	4.2	0.0	4.0	4.7	2.8	2.4	2.3	5.0	2.1
14	2.9	1.3	3.4	3.9	**2.3**	2.4	3.1	2.8	1.9	2.5	1.9	3.0	4.0	0.0	3.6	3.0	2.3	1.8	3.0	3.1
15	2.9	2.8	1.9	4.2	3.9	3.3	3.2	2.0	3.6	5.2	4.8	3.0	4.7	3.6	0.0	3.1	3.4	3.6	5.2	3.0
16	1.3	1.9	2.5	4.1	3.1	**1.2**	**1.4**	3.1	2.1	2.6	3.7	3.2	2.8	3.0	3.1	0.0	2.8	1.9	4.9	0.8
17	2.1	1.8	2.7	2.9	3.9	2.4	3.7	2.3	3.1	4.3	3.1	2.4	2.4	2.3	3.4	2.8	0.0	1.3	3.3	2.2
18	1.7	**1.2**	2.8	3.4	3.1	1.5	2.6	2.7	2.1	4.7	2.5	2.8	2.3	1.8	3.6	1.9	**1.3**	0.0	3.5	1.7
19	4.4	3.4	4.6	3.3	4.2	4.7	2.4	4.4	3.6	4.4	2.3	4.3	5.0	3.0	5.2	4.9	3.3	3.5	0.0	4.8
20	**0.8**	1.9	2.2	4.0	3.7	1.4	3.5	2.6	2.6	3.2	3.7	3.1	**2.1**	3.1	3.0	0.8	2.2	1.7	4.8	0.0

Tab.9 Distance analysis using model parameters as the variable

	Euclidean Distance																			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	0.0	4.6	4.3	4.4	4.8	8.1	6.1	4.7	4.8	6.0	6.1	9.1	5.0	5.1	2.6	4.7	5.6	4.3	2.6	4.4
2	4.6	0.0	4.9	5.3	3.8	9.6	7.8	4.3	4.3	7.3	5.0	8.5	6.4	4.1	4.8	3.1	5.8	4.4	4.8	4.8
3	4.3	4.9	0.0	1.8	3.4	7.0	3.8	3.7	3.9	4.5	4.8	7.7	6.1	3.7	4.4	4.5	3.9	2.1	4.4	3.7
4	4.4	5.3	1.8	0.0	4.0	7.3	4.6	3.4	3.4	6.2	5.2	8.0	5.8	4.2	4.0	4.1	4.4	3.0	4.0	3.2
5	4.8	3.8	3.4	4.0	0.0	8.0	6.9	5.0	2.1	6.0	4.3	7.6	6.2	4.0	4.6	4.2	4.4	2.2	4.6	4.3
6	8.1	9.6	7.0	7.3	8.0	0.0	9.0	7.3	8.3	6.9	8.5	9.7	9.4	8.2	8.4	9.2	7.9	7.4	8.4	8.1
7	6.1	7.8	3.8	4.6	6.9	9.0	0.0	5.8	6.2	4.0	4.6	7.7	3.8	4.7	4.6	3.7	6.0	6.4	4.1	4.4
8	4.7	4.3	2.7	3.4	2.0	7.3	5.8	0.0	2.9	5.8	3.7	7.0	6.1	3.7	4.4	4.6	3.9	2.1	4.4	3.7
9	4.8	4.3	3.9	3.4	2.1	8.3	6.2	5.9	0.0	3.7	4.7	7.8	5.9	4.4	4.0	3.6	4.8	3.0	4.0	3.7
10	6.0	7.3	4.5	6.2	6.0	6.9	4.0	5.8	3.7	0.0	4.5	7.3	7.4	6.7	5.7	6.6	6.1	5.6	5.1	5.5
11	6.1	5.0	4.8	5.2	4.3	8.5	4.6	3.7	4.7	4.5	0.0	8.4	7.2	4.6	5.8	5.0	3.8	4.7	5.8	5.7
12	9.1	8.5	7.7	8.0	7.6	9.7	7.7	7.0	7.8	7.3	8.4	0.0	9.1	6.3	8.1	8.7	7.6	7.2	8.1	6.0
13	5.0	6.4	6.1	5.8	6.2	9.4	3.8	6.1	5.9	7.4	7.2	9.1	0.0	6.4	4.2	6.4	6.8	5.8	4.2	5.4
14	5.1	4.1	3.7	4.2	4.0	8.2	4.7	3.7	4.4	6.7	4.7	6.3	6.4	0.0	4.8	4.0	4.7	3.4	4.8	3.6
15	2.6	4.8	4.4	4.0	4.6	8.4	4.6	4.4	4.0	5.7	5.8	8.1	4.2	4.8	0.0	4.7	5.3	4.0	0.0	3.4
16	4.7	3.1	4.5	4.1	4.2	9.2	3.7	3.6	3.6	6.6	5.0	8.7	6.4	4.0	4.7	0.0	6.0	4.7	4.7	4.3
17	5.6	5.8	3.9	4.4	4.4	7.9	6.0	3.9	4.8	6.1	3.8	7.6	6.8	4.7	5.3	6.0	0.0	3.6	5.3	4.7
18	4.3	4.4	2.1	3.0	2.2	7.4	6.4	4.1	3.0	5.6	4.7	7.2	5.8	3.4	4.0	4.7	3.6	0.0	4.0	3.6
19	2.6	4.8	4.4	4.0	4.6	8.4	4.1	4.4	4.0	5.1	5.8	8.1	4.2	4.8	0.0	4.7	5.3	4.0	0.0	3.4
20	4.4	4.8	3.7	3.2	4.3	8.1	4.4	3.7	3.7	5.5	5.7	6.0	5.4	3.6	3.4	4.3	4.7	3.6	3.4	0.0
Average distance	4.9	5.2	4.1	4.3	4.4	7.8	5.2	4.5	4.3	5.5	5.1	7.5	5.9	4.6	4.4	4.8	5.0	4.1	4.3	4.3

4. Conclusions

In this paper, 20 reservoirs' watershed characteristics were extracted by the support of GIS/RS technology and hydrological model parameters were analyzed based on similarity theory. The main contents of this paper include: ①20 reservoirs' watershed characteristics were analyzed and extracted, which provides variables for similarity analysis.②Hydrological model parameters for 20 reservoirs were determined, achieved good simulation results. ③Some variables were selected which have useful information, others variables were kicked out with linear correlation. ④Parameters of similar basin were analyzed. Finally, we can find that the distances on the parameters of two similar basins are mostly small and close in the geometric space.

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