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 technology (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\textsuperscript{[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.

| 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|

Tab.1 Reservoir Watershed Summary
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 have physical meaning, can be directly determined.

| 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. |
| \(e^B\)          | the exponential of the distribution of tension water capacity, This parameter 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) |
| \(e^EX\)         | the exponential of distribution water capacity, reflect the nonuniform distribution of aquifers condition about surface layer of free water. |
| KG               | The outlet flow coefficient of free water storage to the groundwater flow |
| KI               | The outlet flow coefficient of free water storage to the interflow storage |
| CI               | The recession constant of lower interflow storage |
| CG               | The recession constant of groundwater 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 have 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
Slope: 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. River 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. Basin 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. Drainage 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:

\[ D = \frac{\sum_{j=1}^{i} L_{wj}}{A} \]

Where \( D \) is Drainage density; \( L_{wj} \) 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.

### 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 \( \rho_{NIR} \) is the value of band4 from TM data, \( \rho_{R} \) 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 |
| Duhekou        | -0.179 | 0.691 | 0.515 | 0.107 | -0.459 | 0.755 | 0.220 | 0.136 |
| Nanjiang       | -0.286 | 0.589 | 0.315 | 0.106 | -0.875 | 0.810 | 0.244 | 0.184 |
| Fushui         | -0.128 | 0.691 | 0.500 | 0.112 | -0.636 | 0.728 | 0.552 | 0.119 |
| Rizhao         | -0.304 | 0.621 | 0.302 | 0.114 | -0.366 | 0.431 | 0.156 | 0.136 |
2.3 Meteorological Data
In this paper, the meteorological data is obtained from China Meteorological Data Sharing network (Tab.5).

| Reservoir name | Average annual temperature (°C) | Average annual total cloud amount | Average annual total rainfall (mm) | Reservoir name | Average annual temperature (°C) | Average annual total cloud amount | Average annual total 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                              |
| Dongzheng      | 20.2                            | 7.3                               | 1398                              | Dongzheng      | 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.

| Variable                              | Z (Slope) | Z (River length) | Z (KE) | Z (Drainage density) | Z (NDVI) | Z (Average annual temperature) | Z (Average annual total cloud amount) | Z (Average annual rainfall) |
|---------------------------------------|-----------|------------------|--------|----------------------|----------|-------------------------------|---------------------------------------|---------------------------|
| 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 temperature)        | 0.087     | -0.104           | 0.200  | 0.098                | 0.285    | 1.000                         | 0.742                                 | 0.655                     |
| Z (Average annual total cloud amount) | 0.441     | -0.138           | 0.118  | 0.030                | 0.495    | 1.000                         | 0.742                                 | 0.655                     |

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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

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

| 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

This 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 among 19 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

|          | 1     | 2     | 3     | 4     | 5     | 6     | 7     | 8     | 9     | 10    | 11    | 12    | 13    | 14    | 15    | 16    | 17    | 18    | 19    | 20    |
|----------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| Euclidean Distance |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |
| 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   | 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   | 2.6   | 3.6   | 2.6   |
| 10 | 3.6  | 5.4   | 2.8   | 2.7   | 2.4   | 3.3   | 4.0   | 4.1   | 3.9   | 0.0   | 1.3   | 3.3   | 2.9   | 2.5   | 2.6   | 2.5   | 4.6   | 4.3   | 4.7   | 4.4   |
| 11 | 3.4  | 2.2   | 4.0   | 4.3   | 3.0   | 3.5   | 5.2   | 3.9   | 2.0   | 4.3   | 0.0   | 1.3   | 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   | 2.1   | 2.6   | 3.7   | 3.2   | 2.8   | 3.2   | 3.0   | 3.1   | 0.0   | 2.8   | 1.9   | 4.9   | 0.8   | 3.2   |
| 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   | 2.4   | 2.8   | 0.0   | 1.3   | 3.2   | 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   | 3.5   | 2.4   | 3.1   | 3.3   | 3.6   | 4.9   | 0.0   |
| 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   |
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: ① 20 reservoirs’ watershed characteristics were analyzed and extracted, which provides variables for similarity analysis. ② Hydrological model parameters for 20 reservoirs were determined, achieved good simulation results. ③ Some variables were selected which have useful information, others variables were kicked out with linear correlation. ④ Parameters 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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