Analysis and Study on Space Variation Laws of Rainfall of Yuanyang Hani Terrace

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Abstract

In order to analyze and research the space variation laws of rainfall of Yuanyang Hani terrace, monthly average rainfall in this area which was actually measured from 2001 to 2010 of the four typical meteorological sites, Kakou, Xiaoshuijing, Xinjie and 073, was spatial interpolated and its space mutation law was analyzed by using inverse distance weighted method, ordinary Kriging method, the most neighboring method, radial basis function method, and analyzed results of different interpolation methods through cross validation, drawn rainfall isoline maps by utilizing surfer software, spatial distribution of all kinds of interpolation and the actual observation data were compared. The results show that among several interpolation methods, results of Kriging interpolation method was close to variation laws of actual measured data mostly, and its interpolation effect was the best. Meanwhile, through the interpolation analysis, it showed that rainfall of Hani terrace took on strong spatial variability.

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Keywords: space mutation; spatial interpolation; interpolation methods; Hani terrace; rainfall

1. Introduction

Rainfall is the main source of water supply, and the time and space distribution characteristics of it is one of the main reasons that composed of the temporal and spatial distribution characteristics[1]. The actual situation shows that in the same climate zone, the same river basin, rainfall is obviously variable in different time and space [2], especially in the mountain plateau, rainfall is significantly different in the factors as longitude and latitude, water system (reservoir, rivers, lakes), the run of the mountains, slope aspect and altitude change, it is the space variability of rainfall. The rainfall spatial distribution of some

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basin exists the obvious differences, especially in the dry regions[3]. The preliminary analysis of space variance is to understand the change rule of the natural factors in the changeable environment, so that it is good to the related research. The analysis research of the space variation law of rainfall is based on the actual observation rainfall data in a period, and to analyze the space mutation characteristics of the characteristic parameters, its own parameters and the relationship of all the parameters in the space. The rainfall distribution and the distribution of the vegetation have a lot of correlation, it is usually like that the area of higher plant coverage will have a corresponding rainfall, and the area with more rainfall, plant growth power and coverage rate in the ground is higher than that the less rainfall region[4]. In the mountains district, human activities attach more influence to the ground runoff, soil and water loss and landslide. Therefore, only if the spatial distribution law of rainfall fully understood in this area, that can be reasonable allocation and use of water, and give full play to the ecological and economic benefits of water resources, and do service for the human production and life.

At present, the research to rainfall mainly set up remote rainfall station and weather stations on the ground. Because China's meteorological research has a late starting, automation level and equipment is backward, many meteorological factors can't be accurately determined, especially in the relatively poor mountainous area. Because of the limitation of labor power and financial resources, hydrological station distribution is limited, and they are still not reasonable in space layout[5], so that the precipitation data observed can only represent the rainfall situation within the scope of this area, it is difficult to observe the continuity of rainfall spatial variability. As a result, it can't analyze and study the space variation rules of the rainfall. Thus, in order to receive more information on rainfall within the limited data, it is necessary to do space interpolation processing to rainfall, and supply the data within the area[6].

Presently, there is a lot of research on the spatial distribution characteristics of rainfall at home and abroad, the process is from multiple regression analysis, classical statistical analysis to the ground analysis, and all kinds of methods are used in the different research fields[7]. To sum up, the main are statistical interpolation and spatial interpolation method. The statistical interpolation method should establish the statistical relationship between independent variable and the dependent variable, is mainly based on actual site information, it is chiefly to establish the relationship between rainfall factor and the position, terrain and other meteorological factors, according to the information of on-the-spot station to imitate the spatial variation rules of rainfall. And spatial interpolation method uses several kinds of mathematical models, fits the rainfall information which is not observed, and the common interpolation method includes the Kringing interpolation method, inverse weighting, the most neighboring interpolation method, sample groups, etc.

In order to study the accuracy of results with different interpolation method, this thesis used the 10 years’ average rainfall data per month in three weather stations and eleven rainfall observation sites in the area, respectively with inverse weighting method, ordinary Kriging interpolation method, the most neighboring interpolation method and radial basis function interpolation method to do data interpolation to rainfall, and with verified and analysis to the different interpolation results, to obtain the interpolation precision and interpolation equivalence value maps of different interpolation methods, and consequently get the space variability of rainfall in the research area.

2. Research data and methods

2.1 General situations of study region

Yuanyang Hani terraced is located in south of Yunnan province, southern part of Ailaoshan mountains of the southern of Red River. The geographical position is east longitude 102°27' ~ 103°13', northern latitude 22°49' ~ 23°19', where is belong to subtropical monsoon climate region, its annual mean air
temperature is 16.4 °C, the highest temperature is 32.4 °C, the lowest temperature is -2.6 °C, annual frost free period is 363.5 days, annual average rainfall is 1405 mm. Because of the influence of geography environment and topography condition, three-dimensional climate is significantly obvious. Valley area where rainfall is below 1200mm has no frost perennially, abundant precipitation, evaporation is large, and the climate is hot. Rainfall which is from 1200 to 1700 mm is low and middle mountainous area, precipitation is abundant, and the climate is mild.

Time distribution of precipitation of Hani terrace is extremely uneven, it has obvious seasonal difference. Rainfall mainly concentrated in 5 ~ 10 months, accounting for 76.50% of the annual precipitation, the most monthly average precipitation accounts for 16.19% of the annual precipitation; while the smallest precipitation of the four months (12 ~ 3 months) accounts for only 11.35% of the annual rainfall, the least monthly average precipitation accounts for 2.68% of the annual precipitation. Ratio of the most monthly average precipitation to the least monthly average precipitation is 6.04[8-9].

Precipitation of spatial distribution of Hani terrace is more stable than its time distribution, not only has the obvious seasonal difference, but also obvious spatial variation with change of longitude and latitude, altitude, water system, hillside slope, slope, ground vegetation condition.

2.2 Rainfall data source

Basic materials were based on monthly average rainfall which actually measured from 2001 to 2010 of the four meteorological sites of Kakou, Xiaoshuijing, Xinjie and 073 in survey region as well as 11 rainfall observatories around. Due to Bada mixed forests is close to Bada pine forest area, treat the two as a site in data processing, take average rainfall of the two as the interpolation original data.

2.3 Interpolation method

Our country research spatial variation of rainfall by applying geostatistics began in the mid 1990s [10]. At present the research of this aspect is very active, common interpolation methods are many, precision of different interpolation method is different, even the results are very different [11]. Therefore, according to the actual condition of research area to select appropriate interpolation method is the key link which impacts interpolation results, through comparative analysis, select inverse distance weighted method, ordinary Kriging interpolation method, the most neighboring interpolation method and radial basis function interpolation method as basic method of spatial interpolation analysis research.

2.3.1 Inverse distance weighted interpolation method

Inverse distance weighted interpolation method is a kind of spatial interpolation geometry method[12], which belongs to distance weight coefficient method series, the principle is to grant closer point greater weight than distant point.

\[ u_e = \sum_{j=1}^{n} \omega_j u_j \]

Among them, \( u_j \) \((= 1, 2 \ldots n)\) is the variable value of point \( j \) \((x_j, y_j)\), \( \omega_j \) is corresponding weight coefficient. Weight coefficient \( \omega_j \) is calculated:

\[ \omega_j = \frac{f(d_{ej})}{\sum_{j=1}^{n} f(d_{ej})} \]

Among them, \( n \) is known point, \( f(d_{ej}) \) is weight coefficient of distance \( d_{ej} \) between interpolation
points \((x_e, y_e)\) and known points \((x_j, y_j)\), one kind of the most commonly used form is \(f(d_{ej}) = \frac{1}{d_{ej}^b}\).

Among them, \(b\) is an appropriate constant, when \(b = 1\) or \(2\), corresponding to distance reciprocal interpolation and distance reciprocal square interpolation. The method is simple and easy to operate, and it can provide rational interpolation results for data when its variable value varies widely, meaningless interpolation results won’t appear as well. Shortcomings are: first of all, this method is very sensitive to the choice of weight function; Second, this method is greatly influenced by inhomogeneous distributed data points, when two or more sample points are adjacent, there is no processing to existing redundant information; Finally, inverse distance square has few forecast characteristics, global maximum and minimum variable values are scattered in the data.

### 2.3.2 Ordinary Kriging interpolation method

Ordinary kriging interpolation method is also called as spatial autocovariance best interpolation, this method is based on variation functions theory and structure analysis, use original data of regionalized variables and structure characteristics of variation functions, adopt weighted average of variable values of observation points around to ascertain average value of test points. Basic ideas: variables of closer points should be more adjacent than variable value of distant points, so the closer the distance from observation points to estimated points, the greater the weight of the observations [13]. The more detailed speak, Kriging method is according to mutual space position relation in unknown sample points of measured value of some known points within limited field of unknown points, and after structure information is offered by variation functions, conduct a linear unbiased optimal estimation for value of unknown points, general formula is:

\[
Z_v(x_0) = \sum_{i=1}^{n} \lambda_i Z(x_i)
\]

Among the formula:
- \(Z_v(x_0)\) is predicted value of unknown point \(x\);
- \(Z(x_i)\) is measured value of test point \(x_i\);
- \(\lambda_i\) is weighting efficient of Kriging method, \(n\) is sum of known predicted points.

Kriging method confirms weighting efficient \(\lambda_i\) according to unbiased estimation and variance minimality, that is

\[
\sum_{i=1}^{n} \lambda_i = 1
\]

Combine the two formulas above, can get to the value \(Z_v(x_0)\) of measuring points \(x_0\). The method makes full use of data spatial field nature, it can reflect anisotropy of spatial field in the process of interpolation, and makes full use of space correlation between data points.

### 2.3.3 The most neighboring interpolation method

The nearest point interpolation method is also called tyson polygon analysis method, it’s an analysis method proposed by A. H. Thiessen, a Dutch meteorologist. Core ideology: variable value of interpolation points are the same as the closest points to them. In the specific interpolation process, variable value of point that is nearest to test point is given to it, and then take the variable value as estimated points’, \(v_e\) means variable value of test points, there

\[v_e = v_i\]
Among them, $U_i$ is variable value of $i$, point $i$ meet the conditions $d_{ei} = \min(d_{e1}, d_{e2}, \ldots d_en)$,
\[ d_{ij} = \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2} \]
means Euclidean distance between point $(x_i, y_i)$ and point $(x_j, y_j)$.

The most neighboring interpolation method need to know coordinates of known measuring points or distance between test points and estimated points, these are the main characteristics of space statistics, of course is also one of the very important factors that spatial interpolation must consider, and coordinates of known variable value of test points must also be given in advance[14]. The basic approach is to compare distance between interpolation points and known points, and then find out the nearest points to interpolation points, and finally obtain estimated variable value of interpolating point.

The method is one of the common interpolation methods, especially in smaller areas, spatial variation of variable is not obvious, the effect of the interpolation can accept, the method is simple and easy to implement, this kind of method accord with people's thinking habit, the closer point is more similar to the farther point, the influence to interpolation is more obvious.

2.3.4 The radial basis function interpolation method

The radial basis function interpolation (RBF) interpolates according to nonlinear conversion of observation variable values within points, variable relationship of each interpolation points single point reduce as distance ($r$) to central point (have variable values) increase is the notable features. In order to estimate behavior of a variable value, radial symmetry function conversion is often a linear combination of low order polynomial. The coefficients used in linear combination are calculated according to relationship of known variable value and other conditions. Usually, a function $\Phi(\cdot)$ that taking maximum value when distance is zero will be seen as approximate function, choice of $\Phi(\cdot)$ depends on dimension of solving problems, interpolation condition and interpolation property of expected interpolation formula, basically has the following kinds:

1. Linear:
   \[ \Phi (r) = r \]
2. Plane spline:
   \[ \Phi (r) = r^2 \log r \]
3. Gaussian:
   \[ \Phi (r) = \exp (ar^2) \]
4. Higher secondary surface
   \[ \Phi (r) = (r^2 + c^2)^{0.5} \]

Among them, $a, c$ is constant parameters. The radial basis function interpolation method as a precise interpolation method, its calculation is complex, and the calculated results can be below or above value of forecasted points of sample points.

3. Comparison of interpolation results

3.1 Comparison of interpolation methods

In order to evaluate the pros and cons of interpolation of various interpolation methods, select the four sites of Kakou, Xiaoshuijing, Xinjie and 073 in study region, and their simulation conditions are evaluated and analysed, the results are shown in Table 1. The results show that ordinary Kriging interpolation method is the best, its estimation on rainfall of examining sites is close to actual conditions, followed by inverse distance interpolation, next is radial basis function interpolation and the nearest neighboring interpolation. The main reason is under the conditions of rainfall impacted by terrain, latitude and longitude, altitude, aspect and slope etc, ordinary Kriging considers impacting factors more comprehensively, uses the structural characteristics of data to conduct linear unbiased optimal estimation on not sampling value, therefore its interpolation effect is best.
Table 1 Results of cross validation

| weather station | the inverse distance interpolation method | the ordinary Kriging interpolation method | the nearest neighboring interpolation method | the radial basis function interpolation method |
|-----------------|------------------------------------------|------------------------------------------|---------------------------------------------|-----------------------------------------------|
| Kakou           | 104.095                                  | 92.446                                   | 120.249                                     | 109.859                                       |
| Xiaoshuajing    | 143.428                                  | 129.217                                  | 119.733                                     | 97.184                                        |
| 073             | 128.717                                  | 109.083                                  | 153.463                                     | 103.580                                       |
| Xinjie town     | 10.369                                   | 10.228                                   | 11.486                                      | 10.440                                        |

3.2 Cross validation and analysis of the results

In course of the study, forecast results of the four interpolation methods in 15 sites were compared and analyzed by using full cross validation, that is, in every place where there are observations, set this value is unknown, observations with the rest of the sites was estimated by four kinds of interpolation methods, use this method to estimate the value of all observations, then all the estimates were compared with observations. Take the mean relative error MRE, mean absolute error MAE and root mean square error RMSIE as standard for assessing interpolation effect of several interpolation methods. Of which: ME reflects the size of estimation error, MAE can estimate the possible range of error estimates, RMSIE can reflect sensitivity and extremum of estimates by using data of sampling points. Assume measured rainfall is P(x₁), P(x₂), ...P(xₙ) in rainfall point x₀, x₁, ...xₙ, and value after spatial interpolation is P’(x₁), P’(x₂), ...P’(xₙ), then the ME, MAE, RMSIE expressions separately are:

\[
ME = \frac{1}{n} \sum_{i=1}^{n} \left| P'(x_i) - P(x_i) \right|
\]

\[
MAE = \frac{1}{n} \sum_{i=1}^{n} \left| P'(x_i) - P(x_i) \right|
\]

\[
RMSIE = \sqrt{\frac{1}{n} \sum_{i=1}^{n} \left( P'(x_i) - P(x_i) \right)^2}
\]

Tab.2 Results of cross validation of different interpolation methods

| methods                        | maximum  | average  | minimum | relative errors | average absolute error | root mean square errors |
|--------------------------------|----------|----------|---------|-----------------|------------------------|------------------------|
| measured value                 | 149.217  | 116.083  | 57.446  |                 |                        |                        |
| the inverse distance weighted interpolation method | 129.946  | 134.217  | 77.421  | -0.139          | 2.343                  | 5.812                  |
| the ordinary Kriging interpolation method | 157.428  | 127.097  | 96.862  | 0.105           | 1.423                  | 5.436                  |
| the nearest neighboring interpolation method | 173.315  | 154.435  | 104.353 | 0.242           | 5.956                  | 7.057                  |
| the radial basis function method | 188.427  | 162.476  | 113.324 | 0.163           | 3.995                  | 6.384                  |

The results of the cross validation is in table 2, from average relative error, mean absolute error and root mean square error of all kinds of interpolation methods taken together, interpolation effect of ordinary Kriging method is the best of the four interpolation methods, second is inverse distance weighted method through index optimization and radial basis function interpolation method, and the most neighboring distance interpolation method is relatively poor, but simulation results’ gap of the four interpolation methods are not very big, in this research area, interpolation results of the four kinds of
interpolation methods can all basically satisfy preliminary analysis of spatial variability of rainfall in study area.

3.3 Results analysis of spatial interpolation

Drawn isoline maps of interpolation results according to the above four interpolation methods[15].

![Isoline maps of inverse distance weighted interpolation](image1)

![Isoline maps of ordinary Kriging interpolation](image2)

![Isoline maps of the nearest neighboring interpolation](image3)

![Isoline maps of radial basis function interpolation](image4)

Fig.1 Isoline maps of precipitation of different interpolation methods

Figure 1 show that results of ordinary Kriging method and inverse distance weighted method are closest to variation laws of actual measured data, overall effect is well, especially effect of ordinary Kriging interpolation method is the best. Meanwhile, it can be seen band of longitude and latitude of monthly average rainfall in the whole study area is obvious, it is roughly south is more than the north, the east is more than the west, mountains is more than valley.

4. Discussion

For the purposes of the study area, several interpolation methods can basically reflect the spatial variability law of actual rainfall in the region. Among them, interpolation effect of ordinary Kriging method is the best, second is radial basis function interpolation method. Because interpolation effect of ordinary Kriging interpolation method is the best, this paper mainly based on ordinary Kriging interpolation results to analyze the spatial variability law of rainfall in the study area.

Rainfall of general distribution characteristics of Yuanyang Hani terraced is that southeastern is more than the northwest, mountain more than valley, its space change rule exists obvious spatial variation not only with the change of longitude and latitude of area, altitude, vegetation, slope and the slopes, but also impacted by wind speed, trend of mountain chain, field microclimate of ground and human activities etc.
This paper only from longitude and latitude, altitude, vegetation coverage, slope and the slopes to research and analysis rainfall preliminarily, specific change amplitude and other factors impacting spatial variability of rainfall are not further researched, recommending for further study and explore next.

5. Conclusion

Rainfall possesses significant spatial variability within study area, layout of rainfall observation site should be based on the spatial variability law. Under normal circumstances, the rainfall is increasing with rising altitude; it is gradually decreasing to a certain height. Change law with altitude of rainfall in the region is increasing with altitude rises. General elevation for each additional 100 meters, increasing precipitation is about 0.42 millimeters. Rainfall and the ratio of ground vegetation coverage is positively correlativity, the rainfall in the region is increasing with the increasing ratio of ground vegetation coverage increases. The greater the longitude and latitude, the more the rainfall. Rainfall changes with difference of hillside slope size and slopes as well.

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