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RESEARCH ARTICLE

TREND ANALYSIS OF ANNUAL AVERAGE TEMPERATURE IN JINAN.

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Abstract

The methods of trend analysis for hydrometeorological series include parametric statistical analysis and non-parametric test.In this paper, two methods are used to analyze the trend of annual average temperature data of Jinan in 65 years.It is found that the parametric statistical analysis (Cumulative Departure and Linear Regression), Spearman's rho test and Cox-Staut test can only make simple judgments on the trend of annual average temperature, while Mann-Kendall test can draw the detailed results.As a whole, the annual average temperature in Jinan is on the rise.

Introduction:-

In recent years, climate change and human activities caused heavy environmental problem, which produced lots of worldwide extreme drought and hydrological events.These problems have caused great losses to the human economy, and posed a threat to the safety of human life.Whether it is the change of global temperature, or the possible flood and the low flow in the future, the trend analysis of hydrometeorological series can be used, and it is seen that trend analysis is very important.

Methods of trend analysis:-

The methods of trend analysis for hydrometeorological series include parametric statistical analysis and non-parametric test.

There are three different methods in principle about parameter statistic analysis, that is, Cumulative Departure[1], Linear Regression[1] and Movingt-test[2].If the methods of parametric statistical analysis are used, the original data should obey the normal distribution.There are many non-parametric tests. In this paper, nonparametric rank test (Spearman's rho test[3], Mann-Kendall test[4]) and Cox-Staut test of trend are used.When non-parametric rank test method is used, the time series cannot exist autocorrelation.When time series are autocorrelated, there are usually two ways to solve.One is data preprocessing such as Pre-whitening[5] and Trend-free pre-whitening[6], and the other is modified non-parametric test[7].

Because parametric statistical analysis and non-parametric rank test are introduced in many papers, this paper only introduces Cox-Staut test of trend.

Cox-Staut test of trend:-

In this hypothesis test, the null hypothesis is that series have no trend, and the alternative hypothesis is that the series has the trend of increasing or decreasing.Where[3]

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$$c=\begin{cases} n/2 & if\ n\ is\ even \\ (n+1)/2 & if\ n\ is\ odd \end{cases}$$

x_i and x_{i+c} compose the (x_i, x_{i+c}).If n is even, c pairs can be formed and if n is odd, $c-1$ pairs can be formed. $D_i = x_i - x_{i+c}$ is used to express the difference between the two values.And the sign is used to measure the change of increasing or decreasing. S^+ represents positive number of D_i and S^- represents negative number of D_i ,where $S^+ + S^- = n', n' \le n$ .Besides $K = \min\{S^+, S^-\}$,it can be seen that when S^+ is too large or too small,that is K is so small,hydrometeorological series have trend.

Results about annual average temperature in Jinan:-

The annual average temperature of Jinan in 1951-2015 is analyzed, and the change of average temperature in Jinan in 65 years is shown:

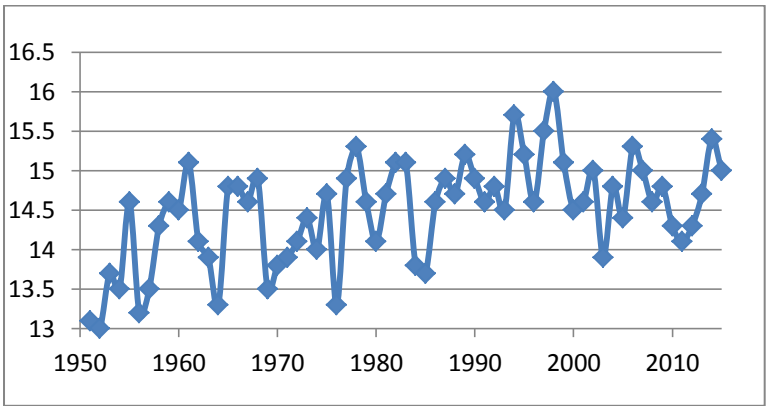

Figure3.1:- annual mean temperature change in 65 years

Parametric statistical analysis:-

Normality test:-

The data must satisfy the prior hypothesis that the distribution obeys normality before using the method of parameter statistic analysis.In this paper, the Kolmogorov-Smirnov is used to test the normality of the original data.The null hypothesis is population distribution of the data obeys a normal distribution.We can get the final result using SPSS:

One-Sample Kolmogorov-Smirnov Test

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N		65
Normal Parameters[a,b]	Mean	14.4846
	Std. Deviation	.65461
Most Extreme Differences	Absolute	.139
	Positive	.057
	Negative	-.139
Kolmogorov-Smirnov Z		1.122
Asymp. Sig. (2-tailed)		.161

a. Test distribution is Normal.

b. Calculated from data.

Figure 3.2:- K-S normality test

As you can see from the diagram, the value of K-S test statistic is 1.122, and the P value of the test is 0.161.For a given significance level $\alpha = 0.05$,the null hypothesis cannot be rejected because $p > \alpha$ and the data is assumed to be normal distribution.Therefore the original data satisfies the prior hypothesis, and the parameter statistics method can be adopted.

Cumulative Departure:-

The variation trend of annual mean temperature in Jinan is analyzed, and the curve of cumulative departure is plotted. The cumulative departure of average temperature in different years is calculated and as shown in the table. From the table, the departure value of each age presents a trend of increasing firstly and then decreasing.In 50s, the departure value is -0.76 and then increasing to -0.13 in 70s.In 80s, the departure value of annual mean temperature becomes positive.According to the value of departure,the annual average temperature has been increasing from 50s. By 90s, the temperature has increased significantly. By twenty-first Century, the decrease of the departure shows that the annual average temperature has decreased slightly.Generally speaking, the average annual temperature in Jinan increases continuously from 1951 to 2015.And the speed of warming gradually slows down in the later stage.

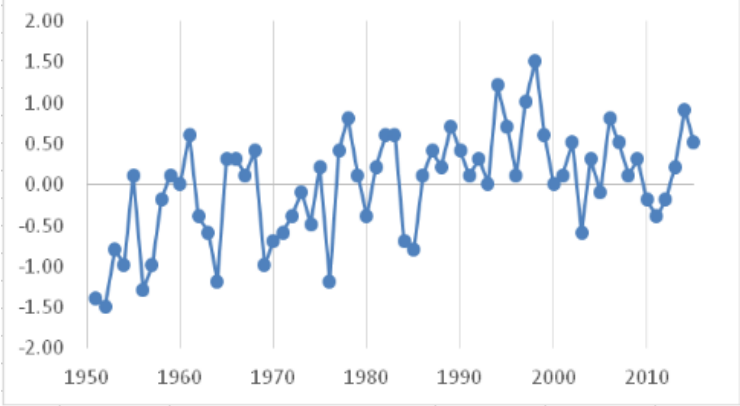

Figure3.3:- cumulative departure curve

Table 3.1:- average temperature departure in different years

Time	Departure value	Time	Departure value
1951-1959	-0.76	1990-1999	0.61
1960-1969	-0.13	2000-2009	0.21
1970-1979	-018	2010-2015	0.15
1980-1999	0.11		

Linear Regression:-

The results of regression analysis are obtained by SPSS, in which the model parameters are estimated to be $a=-20.981$, $b=0.018$.Then the linear regression equation between annual mean temperature and time is obtained,that is $\hat{x}_i=-20.981+0.018t_i$ .The simple correlation coefficient calculated is 0.517.The correlation coefficient is tested by significance test, and P value of the test is approximately 0.Therefore, when the level of significance is $\alpha=0.01$,the null hypothesis should be rejected.It is considered that the annual average temperature and time in Jinan are related and the correlation coefficient is positive. It shows that the annual average temperature in Jinan increases with the increasing of time, that is, there is an upward trend.

Correlations

		time	temperature
time	Pearson Correlation	1	.517**
	Sig. (2-tailed)		.000
	N	65	65
temperature	Pearson Correlation	.517**	1
	Sig. (2-tailed)	.000	
	N	65	65

**. Correlation is significant at the 0.01 level (2-tailed).

Figure 3.4:- correlation test

Non-parametric test:-

Autocorrelation test:-

Non-parametric rank test requires sample data is independent.In order to determine whether the data has first-order autocorrelation, correlation analysis is done by using SPSS and the results are as follows.The null hypothesis of the hypothesis test is that there is no correlation.The correlation coefficient between X_t and X_{t+1} is 0.440.The P value of the test is approximately 0. For the given significance level $\alpha = 0.01$, the null hypothesis is rejected because of $p < \alpha$, and the data has a first-order autocorrelation.

Correlations

		x	t
x	Pearson Correlation	1	.440**
	Sig. (2-tailed)		.000
	N	65	64
t	Pearson Correlation	.440**	1
	Sig. (2-tailed)	.000	
	N	64	64

**. Correlation is significant at the 0.01 level

Figure 3.5:- autocorrelation test

Trend-free pre-whitening:-

Since the annual average temperature in Jinan has a first-order autocorrelation, and also has a linear trend, trend-free pre-whitening is adopted to reduce the influence of correlation.

The data after using trend-free pre-whitening is shown:

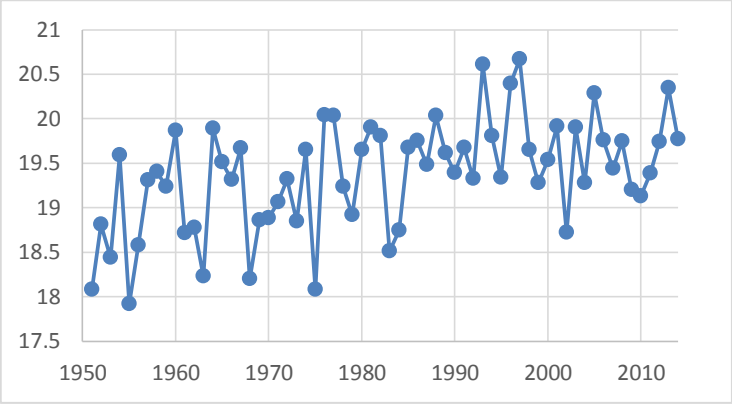

Figure 3.6:- the data after using trend-free pre-whitening

The processed data is also analyzed by correlation analysis.It is found that the correlation coefficient between X_t and X_{t+1} is 0.221.The P value of the test is 0.096. For the given significance level $\alpha = 0.05$, the null hypothesis is not rejected because of $p > \alpha$, and the data is independent.

Correlations

		whitening1	whitening2
whitening1	Pearson Correlation	1	.211
	Sig. (2-tailed)		.096
	N	64	63
whitening2	Pearson Correlation	.211	1
	Sig. (2-tailed)	.096	
	N	63	63

Figure 3.7:- correlation analysis for data after using trend-free pre-whitening

Spearman's rho test:-

The Spearman rank test is carried out by using the R for data after using trend-free pre-whitening.It is found that the value of statistic is $r_s = 0.459$.The P value of the test is approximately 0. For the given significance level $\alpha = 0.05$, the null hypothesis is rejected because of $p < \alpha$, and the data is independent.So there is a correlation between the time and the annual average temperature, that is, there is a increasing trend for the annual average temperature in Jinan.

```
        Spearman's rank correlation rho

data:  TIME and x
S = 23620, p-value = 0.0001595
alternative hypothesis: true rho is not equal to 0
sample estimates:
      rho
0.4592491
```

Figure 3.8:- the results of Spearman rank test

Mann-Kendall test:-

For the data after using trend-free pre-whitening, the curve of UF_k is drawn using the R software.It can be seen $UF_k > 0$,which shows that the annual average temperature in Jinan is on the rise.From 50s to 70s, the fluctuation of UF_k indicates that the temperature increases but appears stable undulating phenomenon;from 70s to 80s, the value of UF_k increases continuously, and the temperature increases rapidly;after 80s, the value of UF_k exceeds the boundary line, indicating a marked upward trend in temperature;after 2000, the value of UF_k fluctuates, indicating the temperature is slowly increasing.

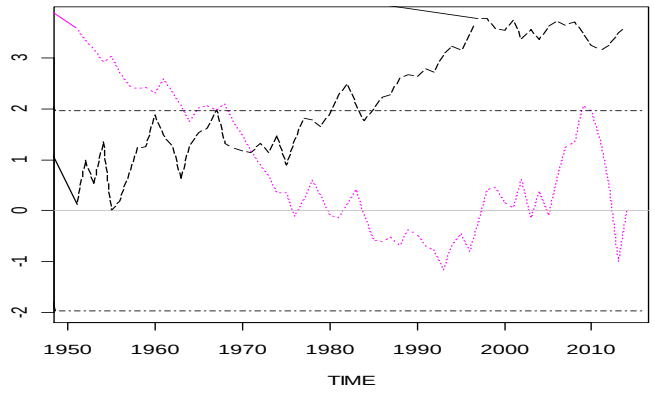

Figure 3.9:- UF_k curve

Cox-Staut test:-

For the raw data,it is analyzed by R and it can be seen that the data produces a total of 32 pairs of logarithms, in which the symbols is 11 positive and 21 negative.The P value of the test is 0.1102. For the given significance level $\alpha = 0.05$, the null hypothesis is not rejected because of $p > \alpha$ .So there is no trend for the annual average temperature in Jinan.

```
        Exact binomial test

data:  sum(x > 0) and length(x)
number of successes = 11, number of trials = 32, p-value = 0.1102
alternative hypothesis: true probability of success is not equal to 0.5
95 percent confidence interval:
 0.1857191 0.5319310
sample estimates:
probability of success
               0.34375
```

Figure 3.10:- the results of Cox-Staut test

Conclusions:-

According to the trend analysis of annual average temperature data in Jinan, the conclusions are as follows:

Parameter statistical method, the Spearman test and the Cox-Staut test can only make simple judgments of the trend for the hydrological series, while Mann-Kendall test can yield more detailed results.When the hydrometeorological series has obvious trend, we can use the method of cumulative departure and linear regression to estimate the possible trend. When the hydrometeorological series has no obvious tend, Mann-Kendall test can be used to judge the change of trend.

For the same hydrological series, the results obtained by various methods may be inconsistent.Because these methods have some assumptions and this is also related to different confidence levels.This phenomenon is more likely to occur when trend changes of series are not apparent.

When Mann-Kendall test is used to study the trend of annual average temperature in Jinan,it is found that the annual average temperature in Jinan is on the rise as a whole.From 50s to 70s, the fluctuation of UF_k indicates that the temperature increases but appears stable undulating phenomenon;from 70s to 80s, the temperature increases rapidly;after80s,the temperature has a marked upward trend;after 2000,the temperature is slow increasing trend.

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