Quantitative Analysis of Impact of Climate Variability and Human Activities on Water Resources Change in Suzhou City

Zhang Xiangyu\textsuperscript{1,2}, Zhao Chao\textsuperscript{1,2,*} and Yang Jinyan\textsuperscript{3}

\textsuperscript{1}School of environmental science and engineering, Xiamen University of Technology, Xiamen 361005, China
\textsuperscript{2}Fujian Engineering and Research Center of Rural Sewage Treatment and Water Safety, Xiamen 361005, China
\textsuperscript{3}Suzhou branch of hydrology and water resources investigation bureau of Jiangsu Province, Suzhou, 215000

*Email: zhaochao@xmut.edu.cn

Abstract: Assessing the contribution of climate variability and human activities to Suzhou's water resources change is important to the design of water resources and provide technical support for the overall planning of Suzhou sponge city. Based on Suzhou hydrology history data, Mann-Kendall method and linear regression method is used to study the change trend of more than 50 years of Suzhou rainfall runoff evaporation, coupled with Mann-Kendall method to validate the abrupt change point of the annual runoff series. The elasticity method is used to analysis the contribution of climate variability and human activities, to explore the main cause of the change of the runoff. The results show that the overall trend of rainfall over the years is increasing, the overall trend of runoff over the years is significantly increasing, and the overall trend of evaporation over the years is decreasing, and a sudden change occurred in 1991. climate variability in Suzhou is the main factor of runoff change, contributing 58.52% and contributing 41.48% to human activities.

1. Introduction

As the source of life, water resource acts an indispensable role in the process of human survival and is an important material. IPCCAR5 clearly points out that since the middle of the 20th century, global climate has been warming continuously, precipitation pattern has been redistributed, and extreme weather events have been occurring continuously, which have seriously affected regional water circulation and ecosystem stability. In recent years, the rapid urbanization process in Suzhou has affected the water cycle in this region. As the foundation of Suzhou's survival and development, water resources should correctly evaluate the impact of climate variability and human activities on the change of water resources in Suzhou, so as to provide scientific basis for scientific and reasonable utilization and protection of water resources and technical support for the overall planning of Suzhou sponge city construction.

There are four main methods at home and abroad to analyze the impact of Climate variability and human activities on water resources change:(1) paired catchment approach\textsuperscript{[1]}; (2) empirically statistical methods\textsuperscript{[2]}; (3) physically-based hydrological models\textsuperscript{[3]}; (4) elasticity or sensitivity based method\textsuperscript{[4]-[8]}. The influence of different underlying surfaces on water resources was analyzed by the paired catchment approach method. But this approach usually involves small watersheds and is expensive to
run. Empirically statistical methods such as linear regression, time trend analysis methods usually need a long-term historical data to establish the relationship between rainfall and runoff, to detect the effects of climate change. However, this kind of method is based on the statistical characteristics of the data and seldom considers the physical meaning. The method of physically-based hydrological model is to simulate the impact of climate and land use change on hydrological performance in different scenarios by adjusting the parameter variables in the model. This kind of hydrological model has complex structure, many input data, long calibration and verification time, and great uncertainty. Based on water balance, based on the assumption Budyko elastic coefficient method, the use of simple and have physical meaning elastic coefficient to assess the effect of Climate variability and human activities, and gradually used in the study of this field in recent years.

In view of the limitations of Suzhou's regional area, data, models and other aspects, this paper adopts a variety of elasticity coefficient formulas under the assumption of Budyko to comprehensively evaluate the contribution rates of climate variability and human activities to the change of water resources in Suzhou, which can provide a decision basis for the overall planning of Suzhou's sponge city construction.

2. Watershed profile
Suzhou is located in the middle of the Yangtze river delta, east of Shanghai, south of Jiaxing and Huzhou, Zhejiang province, west of Taihu lake, and Wuxi city, north of the Yangtze river. The total area of the whole city is 8488.42km², among which the water area is 3609.40km², accounting for 42.5% of the total area. The average annual precipitation is 1086.3mm.

3. Data and research methods

3.1 Choose the data
In this paper, annual rainfall and evaporation data of Suzhou city from 1956 to 2017 were selected for data analysis. The average annual rainfall is obtained by weighting the data of rain measuring stations according to the Thiessen polygon method.

3.2 The research methods

3.2.1 Trend test and break point analysis. When analyzing the variation trend of annual rainfall, annual evaporation and annual runoff, two methods, linear regression [9] and Mann-Kendall [10]-[12], were used to judge:

1) linear regression: establish the linear regression relationship between observation data and time, and judge the trend of variables.

2) Mann-Kendall: Mann-Kendall trend test is a non-parametric test method, which has the advantages of not needing Gaussian distribution of samples and not being disturbed by outliers. It can analyze and test the changing trend of precipitation, runoff, evaporation and other non-normal distribution series.

3.2.2 Quantitative analysis of contribution. The change of runoff is the result of regional climate variability and human activities. Namely

\[ \Delta Q = \Delta Q_c + \Delta Q_H \]  \hspace{1cm} (1)

where, \( \Delta Q \) as the total runoff change, \( \Delta Q_c \) runoff variation caused by climate variability; \( \Delta Q_H \) total for the variability of runoff caused by human activities. Quantitative assessment of the result variability and human activities on runoff, by quantifying the \( \Delta Q_c \) can obtain human activities cause the variability of total \( \Delta Q_H \).

Climate change caused by runoff changes can be made of the calculation:

\[ \Delta Q_c = \left( e_p \frac{\Delta p}{p} + e_{E_0} \frac{\Delta E_0}{E_0} \right) Q; \]  \hspace{1cm} (2)

where \( Q, p, E_0 \) are the average runoff, average rainfall and average evaporation of long series respectively. \( \Delta p \) for rainfall average difference before and after the mutation, \( \Delta E_0 \) for the mean difference of potential
evaporation ability before and after the mutation. \( \varepsilon_P \) and \( \varepsilon_{E_0} \) respectively, runoff of the elastic coefficient of rainfall and evaporation potential. Long time due to the basin water balance equation\( (Q = P - E_a) \), as well as Budyko[13] hypothesis, river basin\( (E_a) \) as the actual evaporation drying index of\( (\lambda = E_0 / P) \) function. The elasticity coefficient can be calculated according to the following formula:

\[
\varepsilon_p = 1 + \lambda \frac{F'(\lambda)}{1 - F(\lambda)} \varepsilon_p + \varepsilon_{E_0} = 1, \lambda = E_0 / P
\]

Among them, \( F(\lambda) \) and \( F'(\lambda) \) can be presented with some specific function forms through the following published results [14]-[17] in the form of Budyko, summarized in Table 1.

### Table 1. \( F(\lambda) \) and \( F'(\lambda) \) of the four mathematical expression

|        | \( F(\lambda) \)                                                                 | \( F'(\lambda) \)                                                                 |
|--------|---------------------------------------------------------------------------------|---------------------------------------------------------------------------------|
| Schreiber | \( 1 - e^{-\lambda} \)                                                          | \( e^{-\lambda} \)                                                            |
| Ol’dekop  | \( \lambda \tanh(1/\lambda) \)                                                  | \( \tanh\left(\frac{1}{\lambda}\right) - 4/\left[\lambda\left(e^{-1/\lambda} + e^{1/\lambda}\right)^2\right] \) |
| Budyko   | \( \lambda \tanh(1/\lambda)(1 - e^{-\lambda})^{\alpha} \)                    | \( 0.5 \left[\tanh\left(\frac{1}{\lambda}\right) - (1 - e^{-\lambda})\right]^{0.5} \times \left[\tanh\left(\frac{1}{\lambda}\right) - \sec h\left(\frac{1}{\lambda}\right)\right]\left(1 - e^{-\lambda}\right) + \lambda \tanh\left(\frac{1}{\lambda}\right) e^{-\lambda} \) |
| Turc-Pike| \( (1 + \lambda^{-2})^{-0.5} \)                                                  | \( 1/[\lambda^2(1 + (1/\lambda)^2)^{1.5}] \)                                    |

### 4. The results

#### 4.1 Analysis of variation trend of rainfall, runoff and evaporation

(1) The statistical values of annual rainfall, runoff and evaporation calculated by M-K method are shown in Table 2. The rainfall and runoff series \( Z \) in Suzhou were both greater than 0, indicating that the annual rainfall and runoff had an increasing trend. The \( Z \) of runoff series is 1.67, indicating that the annual runoff increases significantly. The increasing trend of annual rainfall is not significant. The \( Z \) value of evaporation is less than 0, indicating that the evaporation sequence in Suzhou shows a decreasing trend, but the trend is not significant.

### Table 2. \( Z \) value table of rainfall runoff evaporation

|         | \( Z \) value |
|---------|---------------|
| rainfall| 0.76          |
| runoff  | 1.67          |
| evaporation | -0.12       |

(2) according to the linear regression method, it can also be seen from Figure 1 that rainfall and runoff in Suzhou have a general trend of rising, while evaporation has a general trend of declining.

![Figure 1. Linear regression of rainfall(A), runoff(B), evaporation(C)](image-url)

#### 4.2 Mutation analysis
4.2.1 *Abrupt analysis of rainfall.* (1) According to the M–K curve of rainfall, the intersection point of the two curves in the confidence interval may be a sudden change point. As shown in Figure 2 we find that there are many intersection points in the figures, respectively at the sudden change point of rainfall in 1991, 1996, 1998, 2002 and 2006.

(2) According to the M–K curve of runoff, the intersection point of the two curves in the confidence interval may be a sudden change point. As shown in Figure 3, we find that there are many intersection points in the figures, respectively at the sudden change point of runoff in 1991, 1993, 1997, 2003, 2006, 2011, 2012 and 2014.

4.3 *Analysis of contribution of rainfall and human activities to runoff*

From the base period to the abrupt transition period, the average annual runoff increased by 36mm and rainfall increased by 30mm, as shown in Table 3. Four function forms are used to calculate the contribution rate of climate variability and human activities to runoff change by elastic coefficient method. The calculation results are shown in Table 4. Climate variability increased runoff by about 17.19mm–26.98mm, and contributed between 47.10% and 73.89% to runoff. Human activities increased runoff by 9.53mm–19.30mm, and contributed 26.11%–52.90% to runoff change. Climate variability and human activities on runoff change the average contribution rate of 58.52% and 41.48%, respectively, show that in the Suzhou area the influence of climate variability on runoff increase than the impact of human activities.

![Figure 2. MK mutation analysis of rainfall](image)

![Figure 3. MK mutation analysis of runoff](image)

See rainfall and runoff from the Figures 2 and 3 M–K curve no intersection point before 1991, but after 1991, there are a lot of intersection, it can be seen as two different before and after 1991 times, so the year in 1956-1991 as a base period, 1992-2014 years as a abrupt transition period, based on the runoff and rainfall MK mutation analysis diagram 1991 as the year of mutation points are obtained.

| Table 3. Mean values of runoff and rainfall base period and abrupt change period |
|----------------------------------|------------------|------------------|--------|
|                                   | Mean of base period | Mean of mutation period | difference |
| runoff(mm)                        | 297               | 333               | 36      |
| rainfall(mm)                      | 1079              | 1109              | 30      |

| Table 4. Impacts of climate variability and human activities on runoff based on elastic coefficient method |
|--------------------------------------------------|--------|--------|--------|--------|
|                                                   | Schreiber | Ol’dekop | Budyko | Turc-Pike |
| $\varepsilon_P$                                  | 1.84   | 2.28   | 2.78   | 2.06   | 2.24   |
| $\varepsilon_E$                                  | -0.84  | -1.28  | -1.78  | -1.06  | -1.24  |
| $\Delta Q_c$                                     | 17.20  | 21.83  | 26.98  | 19.46  | 21.37  |
| $\Delta Q_H$                                     | 19.31  | 14.68  | 9.53   | 17.05  | 15.14  |
| $\Delta Q_c(\%)$                                 | 47.10% | 59.79% | 73.89% | 53.30% | 58.52% |
| $\Delta Q_H(\%)$                                 | 52.90% | 40.21% | 26.11% | 46.70% | 41.48% |
5. Conclusion
In order to explore the influence of rainfall and human activities on runoff in Suzhou, Mann-Kendall test method and linear regression method were adopted to detect the trend change of rainfall, runoff and evaporation in Suzhou from 1956 to 2014, and it was found that the overall trend of rainfall and runoff was rising, while the overall trend of evaporation was decreasing. By using MK test, it was concluded that 1991 was the year of mutation.

According to the method of elasticity coefficient, climate variability is the main reason that affects runoff change in Suzhou. The following is the outlook and some shortcomings of this paper. rainfall and runoff are directly included in climate variability in this paper. However, as long as enough detailed information is obtained, it will be able to estimate the impact of rainfall and evaporation on runoff change respectively. How to further refine the response of runoff change to rainfall evaporation and different human activities needs to be further discussed.

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References
[1] Brown, A., Zhang, L., McMahon, T., Western, A., Vertessy, R., 2005. A review of paired catchment studies with reference to the seasonal flows. J. Hydrol. 310, 28–61.
[2] Wei, X., Zhang, M., 2010. Quantifying streamflow change caused by forest disturbance at a large spatial scale: a single watershed study. Water Resour. Res. 46, W12525. http://dx.doi.org/10.1029/2010WR009250.
[3] López-Moreno, J.I., Zabalza, J., Vicente-Serrano, S.M., Revuelto, J., Gilaberte, M., Azorin-Molina, C., Morán-Tejeda, E., García-Ruiz, J.M., Tague, C., 2014. Impact of climate and land use change on water availability and reservoir management: scenarios in the Upper Aragón River. Spanish Pyrenees. Sci. Total Environ. 493, 1222–1231.
[4] Schaaake, J.C., 1990. In: Waggoner, P.E. (Ed.), From Climate to Flow, in: Climate variability and U.S. Water Resources. John Wiley, New York, pp. 177–206.
[5] Arora, V.K., 2002. The use of the aridity index to assess climate variability effect on annual runoff. J. Hydrol. 265 (1–4), 164–177.
[6] Roderick, M.L., Farquhar, G.D., 2011. A simple framework for relating variations in runoff to variations in climatic conditions and catchment properties. Water Resour. Res. 47, W00G07. http://dx.doi.org/10.1029/2010WR009826.
[7] Berghuijs, W.R., Woods, R.A., Hrachowitz, M., 2014a. A precipitation shift from snow to-wards rain leads to a decrease in streamflow. Nat. Clim. Chang. 4 (7), 583–586.
[8] Wang, D., Hejazi, M., 2011. Quantifying the relative contribution of the climate and direct human impacts on mean annual streamflow in the contiguous United States. Water Resour. Res. 47, W00J12. http://dx.doi.org/10.1029/2010WR010283
[9] SU Xuerui, GAO Xiyong, GUO Yajun. Analysis on variation characteristics on the runoff series of the upper Hanjiang River[J]. Water Conservancy Science and Technology and Economy, 2010, 16(10): 1148-1151. (in Chinese)
[10] Mann, H.B., 1945. Nonparametric tests against trend. Econometrica 13 (3), 245–259.
[11] Kendall, M.G., 1975. Rank Correlation Measures. Charles Griffifin, London, UK.
[12] YE X C, ZHANG Q, LIU J, et al. Distinguishing the relative impacts of climate variability and human activities on variation of stream- flow in the Poyang Lake catchment, China[J]. Journal of hydrology, 2013, 494: 83-95.
[13] Budyko, M.I., 1974. Climate and Life. Academic, San Diego, CA
[14] SCHIREIBER P. Uber die Beziehungen zwischen dem Niederschlag und der Wasserführung der Flüsse in Mitteleuropa[J]. Zeitachrift fur Meteorologie, 1904, 21(10): 441-452.

[15] OL’DEKOP E M. On evaporation from the surface of river basins[J]. Transaction on the Meteorological Observations, 1911, 4, 200.

[16] BUDYKO M I. Evaporation under natural conditions[M]. Leningrad: Gidrometeorizdat, 1948.

[17] PIKE J G. The estimation of annual runoff from meteorological data in tropical climate[J]. Journal of Hydrology, 1964, 2: 116-123.