# Spatial and Temporal Evolution of Precipitation and Runoff in Mississippi River Basin in Recent 40 Years

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Abstract: As the fourth largest river in the world, the spatial and temporal evolution characteristics of precipitation and runoff of the Mississippi River can provide basic support for the global water cycle. Different from the analysis of single factor characteristics, this paper comprehensively analysed the spatial distribution characteristics of annual precipitation, runoff into the sea, runoff of each typical station and runoff coefficient in the Mississippi River Basin. Long-series precipitation and runoff data were analysed by statistical methods from three aspects of trend, mutation and periodicity. The results indicated that the annual precipitation increased from northwest to Southeast, with great spatial differences. The annual precipitation trend increased from the eastern and western edge areas to the middle. The annual precipitation mutation time generally delayed from high and low longitude areas to middle longitude areas. The annual precipitation periodicity was characterized by a longer period in the eastern and western edge areas and a shorter period in the central area. The runoff of the Missouri River, Kansas river and Illinois River showed a decreasing trend, which was inconsistent with the trend of precipitation. Overall, the spatial distribution of runoff variation amplitude showed the characteristics of increasing from the east and west to the middle. The amount of discharge into the sea generally showed a decreasing trend. From 1970 to 2013, the sudden change fluctuation was large, the main period was 5a and the secondary period was 10a. The runoff coefficient increased from the west to the East. The Ohio basin was severely affected by human activities. This study can provide a reference for the study of large-scale watershed water cycle and even global water cycle.

## 1 INTRODUCTION

According to the AR5 report of IPCC, the global average land surface temperature increased from 0. 65 ℃ to 1. 06 ℃ between 1880 and 2012 (IPCC, 2013). It may change the temporal and spatial distribution of hydrological cycle in the world (Stonevičius et al., 2017; Teklesadik et al., 2018; Zhuang et al., 2017). In this regard, the evolution of precipitation and runoff due to the decline of changing environment has become a hot issue in the field of hydrology, water resources and climate change (Onyutha et al., 2016; Arnell, 1992; Ren et al., 2015). The Mississippi River is the largest river across the north and south of the United States. It not only has an important impact on the regional economy of the United States, but also is of great significance to the study of the global water cycle under the changing environment.

To explore the evolution law and trend change of hydrological cycle, we mainly focus on the change of hydrological cycle elements and other related research (Wang et al., 2016). At present, many scholars at home and abroad have used a variety of methods to discuss and study the evolution law and attribution analysis of water cycle elements (Milly & Dunne, 2001; Nair et al., 2014, Raj et al., 2012). The most widely used method is statistical analysis, which aims to reflect the evolution of hydrological cycle elements in time and space. Generally, it is analysed from three aspects: trend, mutation and periodicity. At present, the trend analysis method is used to

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analyse the trend change characteristics of historical data of hydrological cycle elements, such as cumulative anomaly and climate tendency rate method. Shi et al (2017) analysed and studied the temporal and spatial variation characteristics of temperature and precipitation in Henan Province in recent 50 years by using the method of climate tendency rate. mutation analysis method is used to identify the catastrophe characteristics of historical data of hydrological cycle elements, and Mann Kendall order detection and sliding t-test methods are often used. Fan et al used Mann Kendall order detection method to analyse the climate change trend in Shiyang River Basin, which provides a decision-making basis for water resources allocation (Liu et al., 2017). The periodic analysis method is used to reveal the periodic characteristics of the historical data of hydrological cycle elements. Maximum entropy spectrum method and wavelet analysis method are often used. Zhao et al (2009) carried out periodic identification of annual runoff series of 12 stations in Northern Shaanxi based on the analysis principles of power spectrum and maximum entropy spectrum. (Shao et al (2006) revealed the complex multi-time scale structure of precipitation change in the Yellow River Basin by using wavelet analysis method, and determined the main periods of each series.

Under the background of climate change, there are great differences in the temporal and spatial distribution of precipitation and runoff in the Mississippi River Basin. From the perspective of the whole basin, taking 2016 as the benchmark, compared with the precipitation and runoff in the past 100 years, the runoff of the Mississippi River Basin decreased, but the precipitation showed an increasing trend, and the precipitation and runoff in the East and west of the basin were quite different (Simon et al., 2016). For the upper reaches of the Mississippi River, the upper Mississippi River and Missouri River are the main agricultural production areas in the United States (Lund et al., 2012). They were affected by human activities, the changes of precipitation and runoff were very related to the agricultural planting area in this area (Schilling et al., 2015). From 1939 to 2008, the runoff in this area generally increased, while the runoff in the western Missouri River decreased (Anderson & Norton, 2007; Hubbart, 2010; Anderson et al, 2008). Compared with the upper reaches of the Mississippi River, the precipitation and runoff in the middle and lower reaches were larger. Among them, compared with the last century, the annual maximum precipitation in most areas of the Ohio River Basin in the middle reaches had increased significantly, and the range of extreme precipitation was wider (Munoz & Dee, 2017). In the lower reaches of the Mississippi River, the river runoff of the Arkansas River Basin increased, and the lower reaches were vulnerable to flood (Elgaali & Garcia, 2006).

Most of the studies on precipitation and runoff factors in the Mississippi River Basin are single sequence analysis on its sub basin and time scale. However, there are relatively few comprehensive studies on the temporal and spatial evolution of precipitation and runoff in the whole basin. Therefore, this paper is based on the precipitation and runoff data of the Mississippi River Basin, builded spatial analysis platform, combined with the analysis methods of trend, mutation and periodicity, analysed precipitation evolution characteristics of 0.5 ° grid, which can more intuitively reflect the precipitation evolution law of the basin. On this basis, 13 hydrological stations are selected to analyse their runoff evolution characteristics and the time distribution characteristics of runoff coefficient. Therefore, the spatial evolution of precipitation and runoff in Mississippi River Basin is summarized, which provides a reference for the study of hydrological cycle and rational allocation of water resources in large-scale watershed.

## 2 MATERIALS AND METHODS

### 2.1 Study Area

The Mississippi River Basin is located in the central United States. The drainage area is 3.2 million km$^2$, accounting for 41% of the land area of the United States. The drainage area is 112 ° - 80 ° W and 29 ° - 49 ° N with a total length of 6021km. The main tributaries are Missouri River, Ohio River, Arkansas River and Red River, and the whole basin is in the shape of "branches", Figure 1. The basin starts from the watershed of the Rocky Mountains in the west to the Appalachian Mountains in the East, and the central great plain is in the middle. Generally, the terrain is characterized by "high on both sides and low in the middle". The basin is divided into two climatic zones, namely subtropical monsoon climate and temperate continental climate. The southeast of the basin is subtropical monsoon climate zone. The annual precipitation is more than 800mm, and the highest annual precipitation is about 1710mm. The rest areas are temperate continental climate areas, and their annual precipitation is less than 800mm, especially in the western region of the basin, the lowest annual precipitation is only about 126mm.

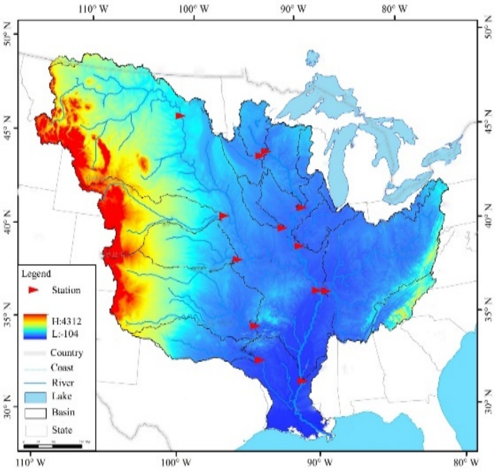

Figure 1: General situation of Mississippi River Basin.

## 2.2 Data and Methods

### 2.2.1 Data Source and Formatting

The precipitation data of Mississippi River Basin is from the website of Global Precipitation Climate Project (GPCP). We got the global monthly 0.5 ° from 1901 to 2013 grid precipitation data, and extracted the monthly grid precipitation data within the Mississippi River basin to calculate its annual precipitation. Considering the climate division of Mississippi River Basin and the division of upstream, middle and downstream, 13 hydrological stations were selected, shown in Figure 1. Each station was distributed in the upper, middle and lower reaches of the Mississippi River and the tributaries of the Missouri River. According to the basin range of hydrological stations, the basin surface precipitation data on the monthly scale of the selected stations were extracted, and their annual precipitation was calculated. The runoff data of the Mississippi River Basin were from the websites of the U.S. Geological Survey (USGS) and the global runoff data canter (GRDC), from which the monthly runoff and annual runoff data of the above 13 hydrological stations from 1970 to 2013 were obtained respectively.

### 2.2.2 Treatment Method and Support Platform

This paper constructed a spatial analysis platform based on ArcGIS and MATLAB software to analyse the spatial distribution characteristics of multi-year average precipitation, trend and mutation in the Mississippi River Basin. Multi-year average precipitation of 0.5 ° grid was calculated, and the results were converted into ASCII text. The final results were readied by ArcGIS software to make the spatial distribution map of multi-year precipitation. Based on this, combined with the precipitation tendency rate and the M-K test calculation method, the trend and mutation characteristics of its spatial distribution were calculated respectively (Liang et al., 2015; Zhang et al., 2016; Han et al., 2013). In order to verify the rationality of precipitation spatial analysis and analyse the evolution characteristics of runoff, cubic spline method and cumulative anomaly method were used to analyse and analysed its trend (Sun et al., 2012). Mann Kendall method was used to analyse its mutagenicity (Yan & Weng, 2016). The maximum entropy spectrum method and wavelet analysis method were selected to analyse its periodicity (Modern et al., 1999).

# 3 RESULTS AND DISCUSSION

## 3.1 Analysis of Precipitation Evolution Characteristics

### 3.1.1 General Situation and Spatial Distribution Characteristics of Precipitation

Figure 2(a) shows the spatial distribution of multi-year average precipitation in the Mississippi River Basin. It can be seen from the spatial pattern distribution that the multi-year average precipitation in the Mississippi River Basin increases from northwest to southeast. The high value area of multi-year average precipitation is mainly concentrated in the southeast of the basin, which is more than 800mm, especially in the lower reaches of Mississippi River and Tennessee River Basin. The low value area of multi-year average precipitation is mainly concentrated in the northwest of the basin, all below 200mm, especially in the upper reaches of Missouri River, the lowest multi-year average precipitation is only 177mm. The difference between the maximum and minimum annual average precipitation is 1526mm, which shows that the spatial distribution of precipitation in the Mississippi River Basin is very different, which may be caused by the great impact of climate change and human activities (Xi et al., 2014; Milly, 2005).

### 3.1.2 Trend and Spatial Change

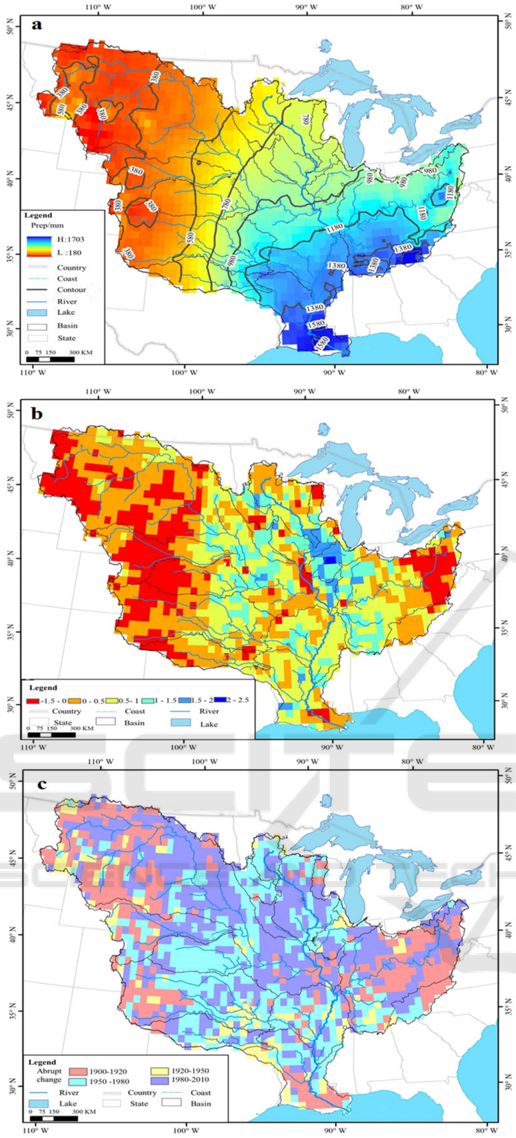

Figure 2: a. Spatial distribution of annual precipitation in Mississippi River Basin. b. Distribution of precipitation spatial tendency rate in Mississippi River Basin. c. Spatial analysis of abrupt change in Mississippi River Basin.

Figure 2(b) shows the distribution of precipitation tendency rate in the Mississippi River Basin, and its spatial distribution is characterized by decreasing from the east and west sides to the middle. The central region is the rising area of annual precipitation, especially in the middle and upper Illinois River Basin, the tendency rate is the highest, and the rising range is 2.5mm/10a. The tendency rate of the eastern and western marginal areas is the area where the annual precipitation decreases, especially in the Kansas River and Platte River basins in the northwest, the precipitation tendency rate is the lowest, and the decline range is -0.8mm/10a. In addition, combined with the cubic spline trend analysis method, this paper analyses the variation trend of surface precipitation controlled by 13 hydrological stations, and its spatial distribution characteristics are basically consistent with the above analysis. Figures 3(a), Among them, the station with the largest increase is MS station. From 1901 to 2013, which shows an overall increase trend, with an increase range of 16.2mm/10a. The station with the largest decrease range is MP station. From 1901 to 2013, which shows a decreasing trend, with a decreasing range of 0.7mm/10a.

### 3.1.3 Mutation and Spatial Variation

The spatial distribution of mutation time is shown in Figure 2(c). The mutation time on the east and west sides of the Mississippi River Basin is earlier than that in the middle, that is, the mutation time is generally delayed from high and low longitude areas to middle longitude areas. The mutation time of the eastern and western marginal regions mostly occurred between 1900 and 1920, the mutation time of the central region mostly occurred between 1950 and 1980, and the mutation time of the central and western regions mostly occurred between 1950 and 2010. Combined with the catastrophe analysis within the watershed of each hydrological station, four stations are selected in the upper, middle, lower reaches and Missouri River area for verification, The mutation time of MS station in the upstream area is 1973, MP station in the Missouri River area is 1965, MT station in the middle reaches of the Mississippi River is 1977, and VIC station in the downstream area is 1972. The results show that its spatial distribution characteristics are consistent with the spatial analysis.

### 3.1.4 Periodicity and Spatial Variation

According to the distribution of selected stations in the Mississippi River Basin, combined with the maximum entropy spectrum method and wavelet analysis method, the periodicity of 13 hydrological stations is analysed. It can be seen that their distribution characteristics are the characteristics of longer period in the eastern and western edge areas and shorter period in the central area. Figures 3(b) show the precipitation wavelet analysis results of the upper Mississippi River region. The MS station in the upper reaches has the strongest oscillation scale of 3-5a from 1970 to 1990. Combined with the analysis results of the maximum entropy spectrum method, the peak spectral density is 3a, and its main period is 3a.

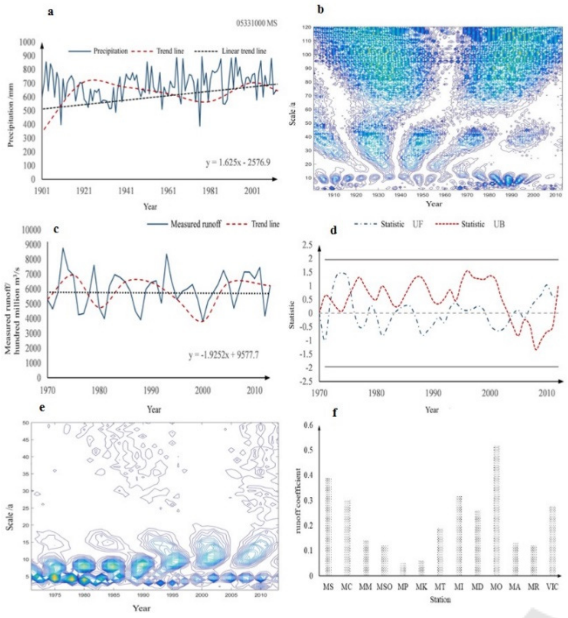

Figure 3: a. Cubic spline analysis of precipitation at MS precipitation station. b. Wavelet analysis of precipitation in the upper Mississippi River. c, d. Interannual variation and M-K analysis of annual runoff at sea inlet station. e. Analysis of maximum entropy spectrum and wavelet analysis of annual runoff at sea inlet station f. Runoff coefficient of each station.

## 3.2 Runoff Variation Characteristics

In addition to the runoff into the sea, the interannual variation characteristics of the runoff of the other 12 hydrological stations from 1970 to 2013 are listed in Table 1. It can be seen that the runoff of MSO (- 254 million m$^3$ / a) and MK (- 47 million m$^3$ / a) in the west of MS shows a decreasing trend, which is inconsistent with the precipitation trend (Qian et al., 2007). It may be that the MSO and MK basins are located in semi-arid areas, with large annual evaporation, and increased water intake and consumption for agriculture and industry. The runoff of MP (- 25 million m$^3$ / a) shows a decreasing trend, which may be caused by the decrease of precipitation. The runoff of MA (- 56 million m$^3$ / a) and MR (- 192 million m$^3$ / a) in the western area of the lower MS also shows a decreasing trend, which is inconsistent with the precipitation trend, which may be the increase of water intake caused by the westward migration of the American population (Griffin & Friedman, 2017). Although the precipitation of the MI in the eastern region shows an increasing trend, the runoff shows a decreasing trend, which is caused by land cover change (Knight et al., 2012; Tayyebi et al., 2015).

Table 1: Interannual runoff variation characteristics of hydrological stations in Mississippi River Basin.

| River | Runoff Trend | Variation range /million m$^3$·a-1 | Mutation time | Main cycle/a |
|---|---|---|---|---|
| MS | increase | 10.35 | 1982 | 9 |
| MM | increase | 0.50 | 1982 | 8 |
| MD | increase | 1.88 | 1982 | 9 |
| MC | increase | 29.00 | 1981 | 9 |
| MI | reduce | -1.16 | 1983 | 7 |
| MP | increase | 0.10 | 1977 | 11 |
| MK | increase | 1.07 | 2000 | 6 |
| MSO | reduce | -34.72 | 1984 | 15 |
| MO | reduce | -100.12 | 1982 | 6 |
| MT | increase | -11.24 | 1982 | 9 |
| MA | reduce | -48.80 | 1981 | 9 |
| MR | reduce | -13.86 | 1973 | 9 |
| MS | increase | 10.35 | 1982 | 9 |

Figure 3(c) respectively shows the annual change of runoff and the change process of cumulative anomaly value of estuary hydrological station (VIC) from 1970 to 2013. It can be seen that the average annual seawater inflow is 595.7 billion m$^3$, the maximum seawater inflow is 877 billion m$^3$ and the minimum seawater inflow is 381.7 billion m$^3$. Combined with the analysis results of cubic spline method, the water entering the sea shows a change process of "increase-decrease-increase-decrease-increase-increase", but the water entering the sea shows a decreasing trend (192 million m$^3$ / a) from 1970 to 2013. Figure 3(d) shows the change trend analysed by Mann-Kendell method at the estuary hydrological station. It can be seen that the abrupt changes occurred in 1972, 1976, 2004 and 2012 from 1970 to 2013. Figure 3(e) show the periodicity characteristics of the VIC station analysed by wavelet analysis method and maximum entropy spectrum method. It can be seen that the periodicity is the most significant from 1975 to 1980 from 1970 to 2013. Therefore, the main cycle is 5a and the secondary cycle is 10a.

## 3.3 Spatial Distribution Characteristics of Runoff Coefficient

The runoff coefficient can comprehensively reflect the influence of natural geographical factors on the relationship between precipitation and runoff. Figure 3(f) shows the multi-year average runoff coefficient of precipitation runoff series at each hydrological station. It can be seen that the runoff coefficient of

Mississippi River Basin increases from the west to the East. The high value area of Mississippi River runoff coefficient is mainly concentrated in the east, and the runoff coefficient of Ohio basin is the highest, which is 0.52. The low value area of runoff coefficient is mainly concentrated in the western region, and the runoff coefficient of Platte River Basin is the lowest, which is 0.05. In this paper, the cubic spline method is used to analyse the interannual variation process of runoff coefficient at each hydrological station. Compared with the change trend of runoff, the runoff coefficient is basically consistent with the change trend of runoff. However, MO and MT stations show the opposite trend, the interannual change of runoff coefficient of MO station in Mississippi River Basin, and its runoff coefficient generally shows a decreasing trend, which may be greatly affected by the change of land cover type. MT station is the station in the middle reaches of the Mississippi River (Zhang, 2010), while MO station is the station where it flows into the river, and the runoff is large. The change of runoff coefficient may be affected by the upstream tributary stations.

## 4 CONCLUSIONS

The evolution rules of precipitation and runoff in the Mississippi River Basin are summarized as follows:

The annual precipitation in the Mississippi River Basin increases gradually from the northwest to the southeast, and the trend of annual precipitation increases from the east and west edges to the middle. The mutation time of the eastern and western marginal regions is earlier than that of the central region, and the period of the eastern and western marginal regions is longer than that of the central region.

The runoff in the Mississippi River Basin increases from both sides to the middle, which is not consistent with the distribution of annual precipitation. It can be seen that the runoff change in the Mississippi River Basin is affected by human activities and climate change. The total amount of water entering the sea is decreasing. From 1970 to 2013, the runoff mutation point was 1972, 1976, 2004, 2012, the main cycle was 5 years, and the secondary cycle was 10 years.

The runoff coefficient of the Mississippi River basin increases from the west to the east. Most of the basin is much more affected by climate change.

In the future research, we should carefully discuss the influencing factors of the inter-annual variation trend of precipitation and runoff in the Mississippi River Basin, and distinguish the contribution rates of human activities and climate change, so as to provide scientific reference for the study of large-scale hydrological cycle in the basin and even the global hydrological cycle.

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## REFERENCES

Anderson, M. T., and Norton, P. A. (2007). Trends in Streamflow in the Missouri River Basin from 1957 to 2006. AGU Fall Meeting Abstracts.

Anderson, M. T., Stamm, J. F., and Norton, P. A. (2008). Changes in Monthly Streamflow Conditions in the Missouri River Basin from 1957 to 2007. AGU Fall Meeting Abstracts.

Arnell, N. W. (1992). Factors controlling the effects of climate change on river flow regimes in a humid temperate environment. *Journal of Hydrology, 132*(1-4), 321-342.

Elgaali, E., & Garcia, L. A. (2006). Effects of climate change on the distribution of the Arkansas River flow. *Hydrology Days*, *2006*, 49-60

Griffin, E. R., & Friedman, J. M. (2017). Decreased runoff response to precipitation, little missouri river basin, northern great plains, USA. *JAWRA Journal of the American Water Resources Association*, *53*(3), 576-592.

Han, X. Y., Yang, Q., & Yao, J. Q. (2013). Characteristics of precipitation change in Tianshan Mountain Area of Xinjiang in recent 51 years. *Research on Soil and water conservation*, *2*, 139-144.

Hubbart, J. P. K. A. (2010). The roles of precipitation increases and rural land-use changes in streamflow trends in the upper mississippi river basin. *Earth Interactions*, *14*(20), 1676-1683.

IPCC. Climate Change (2013). *The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.* Cambridge: Cambridge University Press.

Knight, R. R., Gain, W. S., & Wolfe, W. J. (2012). Modelling ecological flow regime: an example from the tennessee and cumberland river basins. *Ecohydrology*, *5*, 613-627.

Liang, F., Liu, D. D., and Wang, W. Z. (2015). Analysis on variation trend of summer precipitation in Northeast

China from 1961 to 2013. *Research on Soil and water conservation*, *5*, 6773

Liu, X. Q., Chen, Y. S., & Liu, Y. S. (2017). Statistical characteristics of climate change in Yulin City, Shaanxi Province from 1974 to 2012. *Journal of Desert Research*, *V37*(2), 355-360.

Lund, D. D., Project, C. E. A., & States, U. (2012). Assessment of the Effects of Conservation Practices on Cultivated Cropland.

Milly, P. C. D. (2005). *Trends in the Water Budget of the Mississippi River Basin, 1949-1997*. Reston, VA, Geological Survey (U.S.).

Milly, P. C. D., & Dunne, K. A. (2001). Trends in evaporation and surface cooling in the Mississippi river basin. *Geophysical Research Letters*, *28*(7), 1219-1222.

Munoz, S. E., & Dee, S. G. (2017). El nio increases the risk of lower mississippi river flooding. *Scientific Reports*, *7*(1), 1772.

Nair, A., Joseph, K. A., & Nair, K. S. (2014). Spatio-temporal analysis of rainfall trends over a maritime state (kerala) of india during the last 100 years. *Atmospheric Environment*, *88*, 123–132.

Onyutha, C., Tabari, H., Taye, M. T., Nyandwaro, G. N., & Willems, P. (2016). Analyses of rainfall trends in the nile river basin. *Journal of Hydro-environment Research*, *13*, 36-51.

Qian, T., Dai, A., & Trenberth, K. E. (2007). Hydroclimatic trends in the mississippi river basin from 1948 to 2004. *Journal of Climate*, *20*(18), 4599-4614.

Raj, P. P. N., & Azeez P. A. (2012). Trend analysis of rainfall in Bharathapuzha River basin, Kerala, India. *International Journal of Climatology*, *32*(4), 533–539.

Ren, G. Y., Ren, Y. Y., & Zhan, Y. J. (2015). Spatial-temporal variability of precipitation in Mainland China -ii. Modern Variation Trend. *Advances in Water Science*, *4*, 451-465.

Schilling, K. E., Chan, K. S., Hai, L., & Zhang, Y. K. (2015). Quantifying the effect of land use land cover change on increasing discharge in the upper mississippi river. *Journal of Hydrology*, *387*(3-4), 343-345.

Shao, X. M., Xu, Y. Q., & Yan, C. R. (2006). wavelet analysis of Precipitation Series in the Yellow River Basin. *Journal of Peking University (Natural Science Edition)*, *42*(4), 503-509.

Shi, J. L., Wang, X. R., & Li, S. F. (2017). Spatial and temporal variation characteristics of temperature and precipitation in Henan Province in recent 50 years. *Research of Soil and Water Conservation*, *24*(3), 151-156.

Simon, A., Artita, K. S., & Simon, G. L. (2016). 100 Years of Changing Hydrologic Conditions in the Mississippi River Basin: Precipitation and Water Yield. World Environmental and Water Resources Congress.

Stoneviius, E., Rimkus, E., Taras, A., Kays, J., & Valiukeviius, G. (2017). Climate change impact on the nemunas river basin hydrology in the 21st century. *Boreal Environment Research*, *22*, 49-65.

Sun, J. L., Lei, X. H., Jiang, Y. Z., & Wang, H. (2012). Change trend analysis of temperature, precipitation and runoff in the upper reaches of the Yangtze River Basin. *Hydropower and energy science*, *5*, 1-4.

Tayyebi, A., Pijanowski, B. C., & Pekin, B. K. (2015). Land use legacies of the ohio river basin: using a spatially explicit land use change model to assess past and future impacts on aquatic resources. *Applied Geography*, *57*, 100e111.

Teklesadik, A. D., Alemayehu, T., Griensven, A. V., Kumar, R., Liersch, S., & Eisner, S. (2018). Inter-model comparison of hydrological impacts of climate change on the upper blue nile basin using ensemble of hydrological models and global climate models. *Climatic Change*, *141*, 517–532.

Wang, H., Jia, Y.W. (2016). Theory and research method of "nature-society" dual water cycle in changing watershed. *Journal of Hydraulic Engineering*, *10*, 12191226.

Yan, D. M., & Weng, B. S. (2016). Analysis on evolution characteristics of hydrological elements in Northern Anhui. *China Rural Water Resources and Hydropowe*r, *6*, 58-63.

Zhang, L. (2010). U.S. water resources census. *Water Conservancy Development Research*, *10*(2), 71-75.

Zhang, Y. M., Tian, Y., & Lei, X. H. (2016). Analysis on variation characteristics of precipitation and runoff in the upper reaches of Sancha River in recent 50 years. *Hydrology*, *5*, 7984.

Zhao, L. N., Song, S. B., & Xie, P. P. (2009). Spectral analysis of annual runoff series in Northern Shaanxi. *Journal of Water Resources and Water Engineering*, *20* (6), 16-21.

Zhuang, X. W., Li, Y. P., Huang, G. H., & Wang, C. X. (2017). Evaluating climate change impacts on the hydrology of watershed in north-western China using a stepwise-clustered downscaling approach. *International Journal of Climatology*, *47*, 191–209.