Effect of ENSO on the annual precipitation anomaly in Guanzhong Basin and southern Shaanxi China

Y Chen1,2, M Guo1,2 and H Qian1,2,3

1School of Environmental Science and Engineering, Chang’an University, Xi’an, 710054, Shaanxi, China
2Key Laboratory of Subsurface Hydrology and Ecological Effect in Arid Region of Ministry of Education, Chang’an University, Xi’an, 710054, Shaanxi, China

E-mail: Qianhui@chd.edu.cn

Abstract. East Asia has a unique geographic location, a vast territory, complex terrain, and a large population. In recent decades, the frequency of climatic oscillations in East Asia has increased, and many factors affect the climate of East Asia, with El Niño and the Southern Oscillation (ENSO) serving as one of the most important factors. In this study, through the collection and collation of 50 years’ worth of meteorological data for southern Shaanxi and central Shaanxi, the characteristics of climate change in these regions is analysed since 1951, and the correlation between precipitation, drought conditions, and ENSO is evaluated. Results show that the rainfall in the study region during an El Niño year is less than that of a ENSO neutral year, often triggering extremely dry weather. Moreover, the rainfall in a La Niña year is increased compared an ENSO neutral year, confirming that ENSO does affect the rainfall through “teleconnections”. Furthermore, given that the Qinling Mountain tectonic belt serves to diminish the ENSO signal, a large difference in rainfall exists between the foothills in the south and those to the north of the Qinling Mountains. The response mechanism in the north and south regions of Qinling Mountains acting on ENSO is consistent, indicating that the blockage effect of the Qinling Mountains on water vapour is strong related to low-level airflow. Through this research, we can begin to understand the physical mechanisms behind this phenomenon in the central region of China and how we can effectively improve China’s short-term climate predictions. Such knowledge is tremendously important to China’s national livelihood and long-term economic development.

1. Introduction

The Loess Plateau is located in the hinterland of the East Asian continent, and its eastern part is close to the world’s largest ocean, that is, the Pacific Ocean. The western part of the Loess Plateau is adjacent to the highest altitude plateau in the world, the Qinghai–Tibet Plateau. Furthermore, the terrain of the entire Loess Plateau is extremely complex [1,2]. Considering the thermal differences between the ocean and the mainland, and the combined action of the heat and power of the Qinghai–Tibet Plateau, the Loess Plateau has become one of the most important regions of monsoon activities worldwide. Hence, the Loess Plateau has become globally known as the region with the richest loess deposits [3-5].

Meanwhile, El Niño and Southern Oscillation (ENSO) is one of the strongest phenomenon of sea–air interaction signals at the current interannual scale; once ENSO occurs, it directly affects atmospheric and oceanic circulation in the Pacific Ocean, and then it will have a huge impact on
the climate of the Loess Plateau in the hinterland of the East Asian continent through a series of feedbacks and teleconnections [6-10]. ENSO often causes meteorological disasters, such as droughts and floods at a global scale (citations) and many scholars have studied the impact of ENSO on climate change in China (citations). Most of the East Asian winter monsoon (EAWM) and ENSO facilitate an increase in winter precipitation on the East Asian continent; under the influence of ENSO, precipitation in the Loess Plateau and Southern China show a significant climate change impacts in the mid-1980s and at the end of the 20th century [11-13]. However, there is no in-depth study of climate change in the loess plateau and its mechanisms.

Guanzhong Basin, which is located at the junction of Southern China and the Loess Plateau, is strongly influenced by the East Asian monsoon and ENSO. Moreover, under the influence of the Qinling Mountains, the climate of Guanzhong Basin has a significant difference from that of the south part of the Qinling Mountains [13,14]. Since 6000 years ago, central Shaanxi has been one of China’s major granaries, and its water supply and agricultural production strongly depends on climate [15,16]. Therefore, an in-depth study of Guanzhong Basin’s response to ENSO and its spatial and temporal distribution characteristics of precipitation are substantial for the research on the changes in regional water resources, droughts, and floods. On the basis of the abovementioned points, the southern Shaanxi and Guanzhong Basin are selected for study for the following research objects: 1) discuss the chronological changes in the relationship between precipitation and its influencing factors in southern Shaanxi and Guanzhong Basin since the middle of the 20th century, and 2) summarize the impact of the Qinling Mountains structure on the climate of the region and 3) evaluate the chronological changes in the relationship between ENSO and central Shaanxi precipitation.

2. Materials and methods

2.1. Study area

![Figure 1. (a) Location of the selected Weather stations and (b) digital elevation model in Shaanxi Province, China.](image)

The Guanzhong Basin (107°01′–110°36′ E, 33°57′–35°33′ N) is located in the southern part of the Loess Plateau, bordering Qinling in the south, reaching Beishan in the north, starting at Baoji in the west, and reaching to Tongguan in the east. It is a Cenozoic fault basin that is surrounded by
mountains on three sides and opens in the east (figure 1) [15]. The study region is part of the warm-temperate, and semi-humid monsoon climate zones, and the regional topography is represented by the Weihe River Basin and Qinling Mountains. The Qinling Mountains have an average elevation of more than 2000 m, stretching thousands of miles in the east and west, and it is an important dividing line between north and south China. Located on the north of the Qinling Mountains, the Weihe River flows from west to east and is the largest tributary of the Yellow River. The back of southern Shaanxi sets against the Qinling Mountains, and its south side is adjacent to the Daba Mountain (105°46′~111°15′ E, 31°42′~34°45′ N). Meanwhile, the Han River flows from west to east, passing through three cities, Hanzhong, Ankang, and Shangluo. Given the influence of the Qinling's neotectonics, the north is steep and the south is moderated by the Qinling Mountains; the northern slopes are steep, the south slope is slightly less steep, and the valley is long [15,16].

Temperature and precipitation data are gathered from a national meteorological science data sharing platform (http://data.cma.cn) and are from 10 observatories (table 1 and figure 1). These stations are equipped with highly calibrated instruments and follow strict observation protocols for detecting weather and changes in natural climate signals. Individual observatories with missing data are interpolated based on the kriging method of the adjacent observatories and undergo strict quality control and uniform correction. The data period used in this study is from January, 1 1951 to December, 31 2015.

Table 1. Geographical information of the stations and record period of rainfall time series.

| Station name       | Station Code | Elevation(m) | Period-of-Record | Length of Record(year) |
|--------------------|--------------|--------------|------------------|------------------------|
| Guanzhong Basin    |              |              |                  |                        |
| Xi’an              | 57036        | 397.5        | 1951-2008        | 58                     |
| Wugong             | 57034        | 341.5        | 1954-2015        | 61                     |
| Huashan            | 57046        | 342.9        | 1953-2015        | 62                     |
| Baoji              | 57016        | 342.1        | 1951-2008        | 57                     |
| Southern Shaanxi   |              |              |                  |                        |
| Ankang             | 57245        | 324.3        | 1952-2015        | 62                     |
| Zheng’an           | 57144        | 332.6        | 1957-2015        | 58                     |
| Shiquan            | 57232        | 330.3        | 1959-2015        | 56                     |
| Foping             | 57134        | 333.1        | 1957-2015        | 58                     |
| Hanzhong           | 57127        | 330.4        | 1951-2015        | 64                     |
| Shangzhou          | 57143        | 335.2        | 1953-2015        | 62                     |

2.2. Methodology

2.2.1. Year and intensity determination of El Niño/La Niña. El Niño/La Niña years are determined for the detailed statistics of the observatories in southern Shaanxi and Guanzhong Basin according to data from the China Meteorological Data Service Center. Different countries and regions have varied standards for defining El Niño/La Niña. In this study, the standard for determination is that the equatorial East Pacific’s monthly mean sea surface temperature anomaly (SSTA) is greater than 0.5°C (or less than -0.5°C) with a duration greater than or equal to 6 months, and the interruption period is less than 1 month [17]. The intensity of El Niño/La Niña is quantified according to SSTA (table 2). The El Niño/La Niña intensity curve is drawn according to the year and intensity characteristics of ENSO.

| ENSO event quantization | El Niño | La Niña |
|-------------------------|---------|---------|
| Strong                  | 3       | -3      |
| Medium                  | 2       | -2      |
| Weak                    | 1       | -1      |
| Non ENSO years          | 0       |         |
2.2.2. **Standard Precipitation Index (SPI).** The SPI, which is widely used to evaluate drought conditions, has many advantages, such as multi-time scale, simple calculation, regional difference, and good calculation stability [18]. Observed precipitation trends are not strictly subjected to a normal distribution, but rather a skewed distribution with the assumption that the precipitation at time $X$ is subjected to the $\Gamma$ distribution, therefore the SPI can be normalized over time. This study uses the SPI indexes of 3-, 6-, and 12-month scales, namely, SPI3, SPI6, and SPI12, to analyze the temporal and spatial moisture characteristics of seasons and years. The criteria for determining the drought level corresponding to SPI in “Meteorological Drought Level” are shown in table 3 (the U.S. Drought Monitor (USDM)) [18].

| Level | SPI values | Class              |
|-------|------------|--------------------|
| 1     | -0.5 to -0.7 | Abnormally Dry     |
| 2     | -0.8 to -1.2 | Moderate Drought   |
| 3     | -1.3 to -1.5 | Severe Drought     |
| 4     | -1.6 to -1.9 | Extreme Drought    |
| 5     | -2.0 or less | Exceptional Drought|

3. Results

3.1. **Analysis of ENSO and regional precipitation characteristics**

Figure 2 illustrates that an El Niño event has occurred 13 times since 1961 (continuous El Niño year recorded as El Niño event) for a total of 17 years, with an occurrence probability of approximately 34%. Meanwhile, La Niña has occurred 10 times (continuous La Niña year recorded as La Niña event) for a total of 15 years, with an occurrence probability of approximately 30%. The rest of the years were recorded as neutral. Furthermore, El Niño/La Niña fluctuated periodically, and the general period was 2a to 7a. El Niño had three peak-intensity periods, from 1982–1983, 1986–1987, and 1997; the peak intensity of La Niña occurred four times, from 1973–1975, 1988–1989, 1998–2000, and 2007–2008. Overall, the intensity of El Niño was greater than that of La Niña, primarily due to the effects of global warming [19].

![Figure 2](image_url)

**Figure 2.** The relative intensity of ENSO events has occurred in the recent 50 years.

Combining the annual average precipitation since 1951 and ENSO intensity since 1961 changes in southern Shaanxi and Guanzhong Basin, we can conclude (figure 3) that although the annual average precipitation of southern Shaanxi was more abundant than that of Guanzhong Basin at the same time, both regions respond to ENSO in a consistent manner. In the mid-1980s and the mid-1990s, when the ENSO signal was increased, average annual precipitation decreased. After the mid-1990s, when the ENSO signal weakened, the average annual precipitation increased. According to statistics (figure 4), El Niño’s precipitation decreased significantly during the year, with 16 years precipitation being low, and only 1 years precipitation was normal. With regard to La Niña, its average annual precipitation
change was unclear; only the precipitation of 2 years tended to be normal, whereas the precipitation of the remaining 13 years was high. Notably, El Niño caused more precipitation in the following year. Statistics also showed that 12a El Niño’s precipitation increased significantly in the following year, except 1977 and 1984, which had decreased precipitation.

Figure 3. Relationship between average annual precipitation and the intensity of ENSO events in southern Shaanxi and Guanzhong Basin from 1951-2015.

Figure 4. Relationship between rate of precipitation and the relative intensity of ENSO.

3.2. SPI variation at different time scales
We examine trends from three SPI’s (3-, 6-, and 12-month) which that the Guanzhong Basin had a SPI value of -0.5 or more for 55 years; hence, the Guanzhong Basin does not experience frequent drought (figure 5). Given the influence of short-term precipitation, the SPI3 and SPI6 values fluctuate frequently and as the time scale increased, the SPI value is gradually reduced by short-term precipitation. The change in precipitation diminishes and the periodicity becomes increasingly apparent (figure 4). Long-term drought trends can be clearly seen in figure 5 with 1954, 1977, 1982–1983, 1997, 1998, and 2013 the Guanzhong Basin’s SPI3 and SPI6 values were all less than -2.0, indicating extremely dry conditions. Conversely, the corresponding SPI12 value was greater than -1 between 1996 and 1998, indicating that extremely dry conditions occurred in the Guanzhong Basin, and the corresponding SPI3 and SPI6 values revealed only light or moderate dryness (figure 5).

We see a similar pattern between the Guanzhong Basin and in southern Shaanxi since 1951 (figure 5). The SPI values at different time intervals were mostly greater than -0.5. At the same time, in 1955, 1984, and 1999, the SPI3 and SPI6 values were all less than -0.5, that is, during this period, southern Shaanxi suffered a special dry, and the corresponding SPI12 value was greater than -0.5. Southern Shaanxi’s SPI12 values were low in 1997, 1999–2000, and the SPI12 values were generally less than -2 (figure 6). Meanwhile, the corresponding SPI3 and SPI6 values show either moderate or no dry conditions.
Figure 5. Changes of SPI on different time scales in southern Shaanxi from 1951 to 2015.

The comparison of SPI values in Southern Shaanxi and Guanzhong Basin show that as the time scale increased, the start and end times of regional drying periods became delayed and increasingly continuous. The reason for this result is the cumulative effect of precipitation change on drought. Therefore, it is our contention that the SPI12 index best reflected the internal changes related to of regional dryness and ENSO [20]. At the same time, given the climate difference caused by the Qinling Mountain tectonic belt in southern Shaanxi and Guanzhong Basin, the average change trend of these two regions was compared, and the corresponding interannual dry changes were obtained. From the series of dry events, one dry event occurred in Guanzhong Basin for more than 10 years; the occurrence of dry events in Guanzhong Basin was higher from 1994 to 1998 (table 4). The years of dry occurred mainly in 1958–1959, 1982–1983, 1986–1987, 1997, 2001–2002, 2008–2009, and 2013–2014. Meanwhile, dry years in southern Shaanxi were mainly from 1958–1959, 1982–1983, 1986–1987, 1997, 2002–2003, and 2014. From the perspective of the degree of dryness, the Guanzhong Basin experienced extremely dry events, based on SPI12, from 1986–1987 and 1997, Moderately dry from in 1982–1983, and light dryness in the other drought periods. The most extreme dry events occurred in southern Shaanxi from 1986–1987, and light or moderate dry occurred in other drought years.
Figure 6. Changes of SPI on different time scales in Southern Shaanxi from 1951 to 2015.

Table 4. Drought years in the study area.

|                        | Guanzhong Basin                      | Southern Shaanxi                      |
|------------------------|--------------------------------------|---------------------------------------|
| Near normal            | 1958–1959, 2001–2002, 2008–2009, 2013–2014 | 1958–1959, 2002–2003, 2008–2009, 2014 |
| Moderately dry         | 1982–1983                             | 1982–1983, 1997                        |
| Very dry               | 1986–1987, 1997                       | 1986–1987                              |

4. Discussion

4.1. Discussion on the response mechanism of precipitation in Southern Shaanxi and Guanzhong Basin to ENSO

The East Asian monsoon and ENSO are the two major systems affecting the climate of Asia and more specifically China. El Niño/La Niña is not merely an event but a repetitive cycle [6]. According to the abovementioned data, during El Niño years, the average annual precipitation of southern Shaanxi and Guanzhong Basin is lower than normal. Southern Shaanxi and Guanzhong Basin are bounded by the Qinling Mountains, and the climate varies between these two regions. Southern Shaanxi is dominated
by a continental humid climate, whereas Guanzhong Basin is located in a continental semi-humid and semi-arid zone. The difference between the two is affected by the East Asian summer monsoon and the occurrence of ENSO has an impact on the East Asian monsoon circulation. When El Niño occurs, sea surface temperature of the equatorial central and eastern Pacific rises, causing high-altitude westerly winds and the low-level easterly wind to weaken (e.g., anti-Walker circulation). Through the coupling with the circulation of the East Asian meridional winds, the northerly winds of the East Asian meridian and the southerly winds of the low altitude are simultaneously weakened (e.g., anti-Hadley circulation anomaly). Consequently, the corresponding summer monsoon is weak, and the subtropical high shifts southward [21]. Once the summer monsoon weakens, the water vapor transport in southern Shaanxi and Guanzhong Basin also weakens, resulting in a decrease in precipitation in the two regions (figure 7). In the year following an El Niño event, abnormally high pressure in the Sea of Okhotsk in the northwestern Pacific Ocean hinders the Meiyu Front and the Western Pacific subtropical high northward movement. In addition, the subtropical high is clearly southerly and westward, with a large amount of water vapor transported to the Qinling Mountains. As the warm and cold air met it further increases the precipitation in the region [6,21,22].

Figure 7. Walker circulation. (a) Walker circulation in ordinary year, (b) Anti-Walker circulation in El Niño year.

In summary, in the El Niño years, China’s summer monsoon was weakened, and the monsoonal rain belt shifts southward. Central China is prone to decreased precipitation in summer, which often leads to drought conditions.

4.2. Influence of Qinling Mountain Structure on ENSO
The impact of the Qinling Mountains and their associate tectonic belt on the regions climate is mainly through dynamic and mechanical obstruction of low-level (500 m a.s.l.) airflow. Airflow passes through the mountains and climbs along the windward slope; water vapor cools and condenses, resulting in orographic clouds and precipitation. On the leeward slope, airflow sinks and the precipitation decreases. In the winter, the Qinling Mountains effectively block the polar continental air mass prevailing from northern China [22,23]. The influence of the Qinling Mountains on the climate is
mainly reflected in the temperature difference [24,25]. Under the control of the polar continental air mass, the temperature difference between the north and the south of the Qinling Mountains in Shaanxi varies from 3°C to 4°C. When the cold air transits, the blocking effect of Qinling Mountains is more evident and the temperature difference between the north and the south of the Qinling Mountains can exceed 10°C. In summer, tropical marine air masses are prevalent in China. Given that the thermal low is prevalent in mainland China, the temperature difference between the north and the south is not considerably different, so the barrier effect of the Qinling Mountains is mainly reflected in the difference in precipitation. In summer, the Qinling Mountains can block the humid southeast monsoon from moving northward; therefore, the climate north of the Qinling Mountains is dryer than that in southern China, and the average annual precipitation in Guanzhong Basin is greater than that in southern Shaanxi.

Although the southern Shaanxi and Guanzhong Basin differ largely in annual average precipitation, the response mechanism for ENSO is consistent. Thus, the climate in China and its response to ENSO events is related to dynamic effects on high-level airflow (More than 800 m a.s.l.). However, the specific mechanisms need to be further studied.

5. Conclusion
Through the analysis of average annual precipitation and the intensity of 1 ENSO events from 1951-2015 in the southern Shaanxi and Guanzhong Basin, this study finds the following.

- The influence mechanism of El Niño on the average annual precipitation in southern Shaanxi and Guanzhong Basin is pronounced. When an El Niño event occurs, the equatorial central and eastern Pacific sea surface temperatures increase, the Walker circulation and Hadley circulation are weakened, East Asian summer monsoon is weakened, the average annual precipitation in Southern Shaanxi and Guanzhong Basin decreases all resulting in extreme drought conditions.
- In the year following an El Niño event, the average annual precipitation in southern Shaanxi and Guanzhong Basin increases due to abnormally high pressure (More than 800 m a.s.l.) in the Pacific Northwest.
- Given the blocking effect of the Qinling Mountain tectonic belt on the low-level airflow, the annual average precipitation of southern Shaanxi is higher than that of Guanzhong Basin. However, the response mechanism of southern Shaanxi and Guanzhong Basin to ENSO is consistent, demonstrating that the climate response of ENSO on southern Shaanxi is mainly the result of changes in high-level airflow. Unfortunately pressure and airflow data from the regions are lacking; thus, the specific impact mechanism still need further studied.

References
[1] Guo Z, Ren X and Lv H 2016 Over the past 20 thousand years since the effects of climate change and human adaptation effect Chinese Proc. of the National Academy of Sciences 1 151-62
[2] Zheng L, Hao X, Zhuo B, Zhuo B and Liu Y 2016 Holocene palaeoenvironment evolution and human activity of the Hemudu-Tianluoshan Sites in Yuyao of Zhejiang Province J. Paleo. 18 879-94
[3] Guan H, Zhu C and Zhu T 2016 Grain size magnetic susceptibility and geochemical characteristics of the loess in the Chaohu lake basin: Implications for the origin palaeoclimatic change and provenance J. Asi. Ear. Sci. 117 170-83
[4] Wang X, Wei H and Khormali F 2017 Grain-size distribution of Pleistocene loess deposits in northern Iran and its palaeoclimatic implications Quat. Int. 429 41-5
[5] Sun D, Jan B and David K 2004 Bimodal grain-size distribution of Chinese loess, and its palaeoclimatic implications Catena 55 325-40
[6] Zhou L 2011 Impact of East Asian winter monsoon on rainfall over south-eastern China and its dynamical process Int. J. Climat. 31 677-86
[7] Zuo Z, Yang S and Wang W 2011 Relationship between anomalies of Eurasian snow and southern China rainfall in winter Environ. Res. Lett. 6 1-6
[8] Wu X and Mao J 2016 Interdecadal modulation of ENSO-related spring rainfall over South China by the Pacific Decadal Oscillation Climat. Dyn. 47 3203-20
[9] Chen W, Feng J and Wu R 2013 Roles of ENSO and PDO in the link of the East Asian winter monsoon to the following summer monsoon J. Climat. 26 622-35
[10] Jia X and Ge J 2016 Interdecadal change in the relationship between ENSO, EAWM and the wintertime precipitation over China at the end of the twentieth century J. Climat. 30 1923-37
[11] Ronglu G, Renhe Z, Min W, Tianran Li 2019 Interdecadal changes in the asymmetric impacts of ENSO on wintertime rainfall over China and atmospheric circulations over western North Pacific Climat. Dyn. 52 7525-36
[12] Lau K and Li M 1984 The monsoon of East Asia and its global associations-A survey Bull. Amer. Met. Soc. 65 114-25
[13] Li X, Li J and Li Y 2015 Recent winter precipitation increase in the middle-lower Yangtze River Valley since the late 970s: A response to warming in the tropical Indian Ocean J. Climat. 28 3857-79
[14] Zhang H, Lu H, Jiang S, Vandenbergh J, Wang S and Cosgrove R 2012 Provenance of loess deposits in the Eastern Qinling Mountains (central China) and their implications for the paleoenvironment Qua. Sci. Rev. 43 94-102
[15] Yuan X, Wang Q and Wang K 2015 China’s regional vulnerability to drought and its mitigation strategies under climate change: data envelopment analysis and analytic hierarchy process integrated approach Mitig. Adapt. Strat. Gl. 20 341-59
[16] Wu H, Qian H and Chen J 2017 Assessment of agricultural drought vulnerability in the Guanzhong Plain, China Water Resour. Manag. 31 1557-47
[17] Kiladis G 1982 Diaz Global climate anomalies associated with extremes in the Southern Oscillation Climate 2 1069-90
[18] McKee T B, DoeskenN J and Kliest J 1993 The relationship of drought frequency and duration to time scales Proc. Eighth Conf. of Applied Climatology (Anaheim, CA: Amer Meteor. Soc.) pp 179-84
[19] Yue C, Lu W and Xiao F 2010 A study on the impacts of latent heat parameterization scheme on prediction skill of ENSO with a simple ocean-atmosphere coupled model J. Trop. Meteor. 16 10-9
[20] Chen Y and Qian H 2019 Variation in runoff series regimes and the impacts of human activities in the upper Yellow River Basin Pol. J. Environ. Stud. 28 1071-82
[21] Huang R and Wu Y 1989 The influence of ENSO on the summer climate change in China and its mechanism Adv. Atmos. Sci. 6 21-32
[22] Wang W, Li J and Feng X 2011 Evolution of Streambed-aquifer hydrologic connectedness during pumping J. Hydrol. 402 401-14
[23] Chen T and Shih Y 2006 Interannual variation of the tropical cyclone activity over the Western North Pacific J. Climat. 19 5709-15
[24] Wang W, Li J and Wang W 2014 Estimating streambed parameters for a disconnected river J. Hydrol. 8 3627-41
[25] Xu H 2018 Analysis of spatial and temporal characteristics of drought in Shaanxi Province and evaluation of vulnerability (Shaanxi, China: Chang’an University) 55-61