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ANALYSIS OF CLIMATE VARIABILITY IN THE JINSHA RIVER VALLEY

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Abstract: Monthly mean surface air temperatures and precipitation at 20 meteorological stations in the Jinsha River Valley (JRV) of southwest China were analyzed for temporal-spatial variation patterns during the period 1961-2010. The magnitude of a trend was estimated using Sen's Nonparametric Estimator of Slope approach. The statistical significance of a trend was assessed by the MK test. The results showed that mean annual air temperature has been increasing by 0.08℃ /decade during the past 50 years as a whole. The climate change trend in air temperature was more significant in the winter (0.13℃/decade) than in the summer (0.03℃/decade). Annual precipitation tended to increase slightly thereafter and the increasing was mainly during the crop-growing season. Both the greatest variation of the annual mean temperature and annual precipitation were observed at the dry-hot valley area of middle reaches. Significant warming rates were found in the upper reaches whereas the dry-hot basins of middle reaches experienced a cooling trend during the past decades. Despite of the overall increasing in precipitation, more obvious upward-trends were found in the dry-hot basins of middle reaches whereas the upper reaches had a drought trend during the past decades.

Key words: temperature; precipitation; trend analysis; climate change; Jinsha River Valley

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1 INTRODUCTION

The nature of climate change is of great interest in terms of gaining a better understanding of climate behavior and the impact of climate on the environment, economy, and society (Fong et al.[1]). Climate change has already been a common phenomenon worldwide, and recent studies revealed a significant worldwide warming and a general increase in frequency and persistence of high temperatures (Guo and Xia[2]). Analyses of climate change over recent centuries and its impact on the environment and society have been performed at global, hemispheric, national, and regional scales (Jiang et al.[3]). Global surface temperature has increased by 0.85 ℃ since the late 19th century and by about 0.12℃/decade over the past 60 years, and the global average surface temperature will increase by 0.3-0.7 ℃ during 2016-2035, and 0.3-4.8 ℃ during 2081-2100[4]. During the period 1957-2004, the linear rise of mean temperature over China is 0.26℃/decade, although regional climate variations may differ from global trends (Liang et al.[5]). It is noted that regional climate changes can be much larger and considerable spatial and temporal variations may exist between climatically different regions. In addition, temperature and precipitation variations in a specific region or nation are of particular interest to that region and its economic activity (Zhi et al.[6]). Data on recent climate change are required to improve the certainty and accuracy of estimations of future climate, especially in assessing regional climate change (Baer and Risbey[7]).

The particular topography of Jinsha River Valley (JRV) and its location across the Tibetan Plateau, Yunnan Plateau and Sichuan Basin in southwest China imply a strong influence of local circulations. The Jinsha River is the major source river of the Yangtze River, which is the longest river in Asia and the third longest river worldwide. The source of the Jinsha River is situated at an elevation of about 4 800 m in the Tanggula Mountains of Tibetan Plateau. Tectonic collision between the South Asian and Eurasian continental plates, which formed the Himalayas, produced a series of north-south-oriented ranges in the southeastern Tibetan Plateau area, known as the Hengduan Mountains. In the steep terrain of this region, the Jinsha River plunges through deep gorges, flowing through Qinghai and Yunnan provinces before finally merging with the Min River at Yibin City in Sichuan province. From Yibin City,

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the Jinsha River is known as the Yangtze River. The length of the Jinsha River accounts for more than 55% of the length of the entire Yangtze River. So, the Jinsha River runs through mountains with elevations above 2 000 m in its upper reaches, 800-1 500 m in its middle reaches, and below 500 m in its lower reaches. Active tectonism in the region has resulted in varied topography and the development of special ecosystems influenced by unique environmental patterns.

On a regional scale, much progress has been made in understanding the climate characteristics of Tibetan Plateau, Yunnan Plateau and Sichuan Basin. Based on the data from 12 meteorological stations, Jang et al. [8] found that the annual mean temperature in the source regions of the Yangtze River in Qinghai-Tibetan Plateau has risen at a rate of 0.37℃/decade during the period 1971-2008, and experienced two abrupt changes from low to high in 1987 and 1998 respectively. Comparison of climate changes in the globe, the whole of China and the Tibetan Plateau shows that the response of the source regions of the Yangtze River to climate warming is most sensitive. Air temperature in the region, as a whole, has a rising trend with an annual amplitude of 0.7-0.8℃ and precipitation slightly increases in the recent 40 years (Yang et al.[9]). Linear trend analyses revealed that annual temperature over the Yunnan Plateau increased at a rate of 0.3℃/decade during the period 1961-2004 (Fan et al. [10]). A cooling trend of annual mean temperature with decreases of daily maximum temperature since the mid-20th century was observed in the Sichuan Basin (Ma et al.[11]). However, climatic variability is largely unknown along the JRV. Zhang et al.[12] explored the decreasing trend in annual average temperature and increasing trend in annual precipitation based on Yuanmou weather station of the JRV during the period 1950-2000.

On the basis of an extensive dataset from 20 meteorological stations of Tibetan Plateau, Yunnan Plateau and Sichuan Basin in southwestern China, this study aimed to examine the spatial and temporal temperature and precipitation variabilities with a view to better understanding climate change trends along the JRV during the period 1961-2010. Particular emphasis was put on investigating the overall warming trend and its spatial variability. An investigation of climate change in this area would provide evidence regarding the heterogeneous nature of climate change of both China and the globe and assist local governments with useful information in developing policy.

2 DATA AND METHODS

2.1 *Monitoring stations and meteorological data*

The JRV climate is influenced by the interaction of several circulation systems. Summer climate is co-dominated by the Southwest and East Asian summer monsoons during June to September, whereas the climate condition during winter is influenced by northern continental cold air masses and extra-tropical westerlies. Controlled by seasonal winds and under the influence of the Tibetan Plateau, the climatic conditions differ greatly within short distances and latitudes and from one area to another; moreover, the environment is complex. In terms of geography and climate, the entire region is characterized by different climatic patterns including the plateau temperate zone, subtropical zone and tropical zone.

With the aim of having a dataset that is widely available, 20 meteorological stations across the study area in the main part of JRV were selected as the typical sites according to geography and climate. Their location details and general situation are shown in Fig.1 and Table 1, respectively. The selected stations are distributed from the upper reaches to the lower reaches of the Jinsha River.

A dataset of monthly mean surface air temperature and monthly precipitation series (1961-2010) of these 20 stations were used to analyze the climate variation during the past 50 years. The data of each station are available from the National Meteorological Information Center (NMIC) of China and the China Meteorological Administration (CMA). Annual series and seasonal series were computed from the monthly data.

Reliable data are required for the present analysis, and the examined data were assessed visually from time-series plots. The dataset has also been quality-checked by NMIC. For each station, the time periods of the records and any changes in station location were carefully checked. None of the 20 stations were excluded from analysis due to problems related to relocation. Routine quality assessments and necessary error-correction procedures were performed following the methods described by Peterson et al. [13]. The datasets for all stations were subject to homogeneity tests using the von Neumann ratio and Bayesian procedures (Buishand [14]; Stephenson et al. [15]). These tests indicated significance at the 5% confidence level, based on a null hypothesis that the elements of the data series are independent and identically distributed.

2.2 *Interannual variability of data series*

Standard deviation (SD) and coefficient of variation (Cv) were used to measure the interannual variability of the mean temperature and precipitation time series, respectively. The calculation formula of the two indicators can be expressed in terms of Eq. (1) and Eq. (2) (Gough[16]).

$$SD=\sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(T_i-\bar{T})^2} \quad (1)$$

$$Cv=\sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(\frac{P_i}{\bar{P}}-1)^2} \quad (2)$$

where T_i and P_i are the temperature and precipitation data sets respectively, $\bar{T}$ and $\bar{P}$ are the mean values of

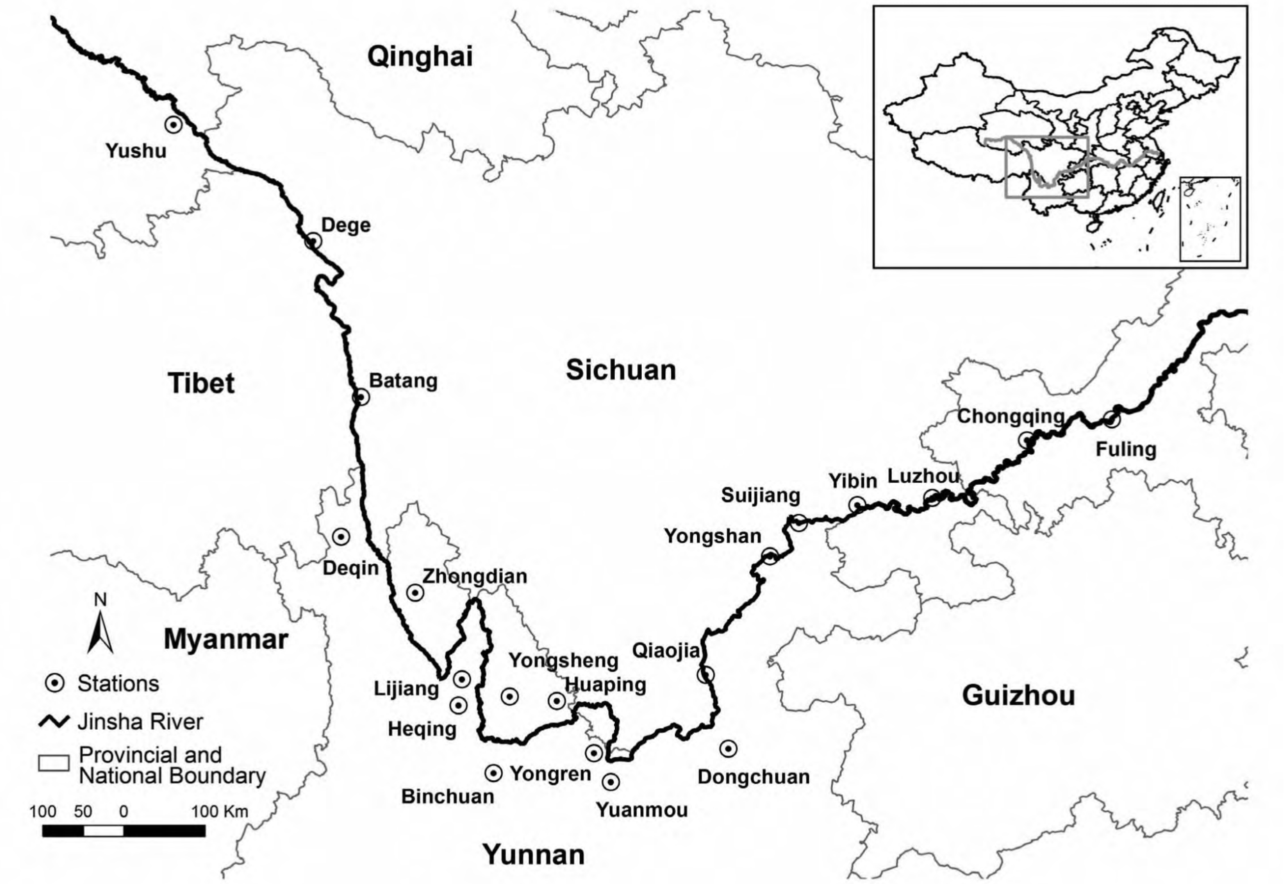

Figure 1. The map of the study area, showing the path of the Jinsha River and station locations. Data are from the National Meteorological Information Centre.

Table 1. General characteristics of the selected meteorological stations along the Jinsha River Valley

No.	Station	Longitude (°E)	Latitude (°N)	Elevation (m)	Climatic region
1	Yushu	97.02	33.02	3682.2	Plateau cold zone
2	Dege	98.57	31.73	3199.3	Plateau northern-temperate zone
3	Batang	99.10	30.00	3089.2	Plateau northern -temperate zone
4	Deqin	98.88	28.45	3488.0	Plateau northern-temperate zone
5	Zhongdian	99.70	27.83	3277.1	Plateau northern-temperate zone
6	Lijiang	100.22	26.87	2394.4	Northern-subtropical zone
7	Heqing	100.18	26.58	2198.4	Northern-subtropical zone
8	Yongsheng	100.75	26.68	2131.0	Northern-subtropical zone
9	Binchuan	100.57	25.83	1438.4	Southern-subtropical zone
10	Huaping	101.27	26.63	1244.8	Southern-subtropical zone
11	Yongren	101.68	26.05	1531.1	Central-subtropical zone
12	Yuanmou	101.87	25.73	1120.2	Northern-tropical zone
13	Qiaojia	102.92	26.92	840.7	Northern-tropical zone
14	Dongchuan	103.17	26.10	1253.4	Southern-subtropical zone
15	Yongshan	103.63	28.23	877.2	Central-subtropical zone
16	Suijiang	103.95	28.60	412.9	Central-subtropical zone
17	Yibin	104.60	28.80	340.8	Central-subtropical zone
18	Luzhou	105.43	28.88	334.8	Central-subtropical zone
19	Chongqing	106.48	29.52	351.1	Southern-subtropical zone
20	Fuling	107.42	29.75	273.5	Southern-subtropical zone

the T_i and P_i series respectively, n is the length of the data series, SD is the standard deviation of the annual mean temperature, and Cv is the coefficient of variation of the annual precipitation.

2.3 *Trends detection*

The magnitude of a trend in a time series is determined using a nonparametric method known as Sen's Nonparametric Estimator of Slope approach, shown below as (Yue and Hashino[17]):

$$b = median(\frac{X_{i'} - X_i}{i' - i}) \tag{3}$$

where b is an estimate of the slope of a trend, $X_{i'}$ is the data measurement at time i', X_i is the data measurement at time i, and i' is the time after time i. A positive value of b indicates an "upward trend", whereas a negative value of b indicates a "downward trend".

The statistical significance of a trend for annual or seasonal series at a site was analyzed using the Mann Kendall (MK) test, which is the rank-based nonparametric test often applied to a series of observations in order to find out whether or not there is a trend. This test is based on the statistic S defined as follows (He and Zhang[18]).

$$S = \sum_{j=i+1}^{n} \sum_{i=1}^{n-1} sign(x_i - x_j) \tag{4}$$

where x_j are the sequential data values, n is the length of the time series, and sign $(x_i - x_j)$ is -1 for $(x_i - x_j)<0$, 0 for $(x_i - x_j)=0$, and 1 for $(x_i - x_j)>0$. When $n \geqslant 10$, the statistic S is approximately normally distributed with the mean $E(S)$ and the variance Var(S) given as:

$$E(S)=0 \tag{5}$$

$$\mathrm{Var}(S) = \frac{n(n-1)(2n+5) - \sum_{p=1}^{q} t_p(t_p - 1)(2t_p + 5)}{18} \tag{6}$$

where t_p is the number of ties of extent p value and q is the number of tied values. The standardized test statistic (Z) is computed by:

$$Z = \begin{cases} \frac{S-1}{\sqrt{Var(S)}} & if \quad S>0 \\ 0 & if \quad S=0 \\ \frac{S+1}{\sqrt{Var(S)}} & if \quad S<0 \end{cases} \tag{7}$$

The presence of a statistically significant trend is evaluated using the Z value. For a two-tailed test, the null hypothesis (no trend) is rejected at significance level α if $|Z| > |Z_{\alpha/2}|$, where $Z_{\alpha/2}$ is the value of the standard normal distribution with an exceedance probability $\alpha/2$. In general, a significance level of 10/5/1 % is used to indicate that a trend exists in the temperature or precipitation series with a 90/95/99 % confidence level.

2.4 *Drought index*

Human activity, economic development, and ecological evolution have been closely linked with changes in climate (temperature and precipitation) and environment (dryness and wetness). A large number of climate change studies have appeared in recent decades, investigating the impact of temperature and precipitation anomalies on the life-supporting environment. Here a drought index for the area of interest was estimated using an approach proposed by Qian and Zhu[19]:

$$DI = \triangle T/S_T - \triangle P/S_P \tag{8}$$

where DI is the drought index, $\triangle T$ and $\triangle P$ are the anomalies (departures from the average for the full period of common record) of surface air temperature and precipitation, and S_T and S_P are the standard deviations of temperature and precipitation.

3 ANALYSIS AND RESULTS

3.1 *Interannual variation characteristics of mean temperature*

Figure 2 presents the spatial distributions of averaged annual and seasonal air temperatures and interannual variation of mean temperature from the upper reaches to the lower reaches along the JRV. The multiyear mean annual temperatures fluctuated in the range of 3.3 to 21.6℃, while it varied from 9.4 to 25.9℃ and from -2.9 to 18.3℃ during summer and winter respectively. Mean temperature shows a general increase from the upper reaches to the middle-lower reaches of the river, with an average annual temperature below 10℃ in the upper reaches area, and above 15℃ in the lower reaches area. The greatest mean temperature was observed at the Yuanmou dry-hot basin in the middle reaches, and the lowest mean temperature was observed at the Yushu high-elevation station in the upper reaches.

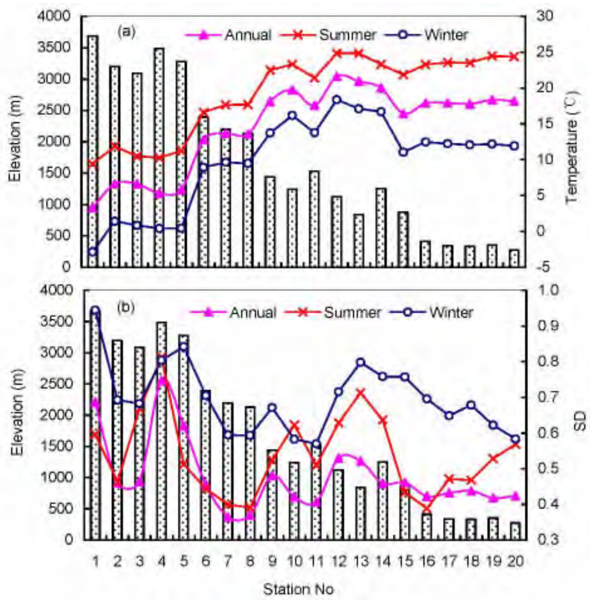

Figure 2. The spatial distributions of averaged annual and seasonal air temperatures (a) and interannual variations of mean temperatures (b) of each stations for the period of 1961-2010 along the Jinsha River Valley. The station number represents the station shown in Table 1.

The two peaks in the tendency of SD values indicate the notable interannual temperature variation areas of JRV. They are the region of high-elevation area of upper reaches and dry-hot valley area of middle reaches. Moreover, the interannual variation of mean temperature during winter was greater than that during summer. The interannual variation of annual mean temperature had a highest value in the Yushu station and a second-largest value in the Yuanmou station. The SD value was 0.94 and 0.80 in the winter, respectively while the smallest interannual variation of annual mean temperature was observed at Heqing station (SD=0.37).

3.2 *Trend analysis of mean temperature*

For the whole of the JRV, mean annual temperature has been slightly increasing by 0.08 ℃ /decade at the significance level (α) of 0.1 during the past 50 years (Fig.3). The warming rate during winter was 0.13 ℃ /decade at the significance level (α) of 0.05, while the positive value of trend magnitude (0.03℃ /decade) during summer did not pass the MK test. The overall warming on the JRV started around the beginning of 1980s and accelerated after 1990s.

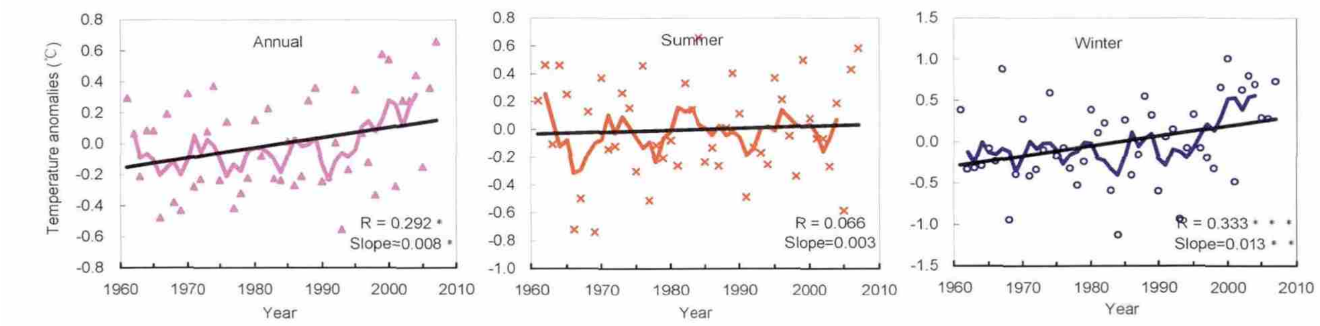

Figure 3. Regional averaged annual, summer and winter temperatures for the period of 1961-2010 derived from 20 stations along the Jinsha River Valley. The straight line shows the linear trend, and the curve represents 5-year moving average. R and Slope represent the correlation coefficient and the slope of linear regression, respectively. The "*", "**" and "***" represent significance at 90%, 95% and 99% level, respectively.

Sen's estimator of slope values in Fig.4 indicated the variation magnitude of the annual and seasonal mean temperature of each station for the period 1961-2010. Over the past 50 years, annual mean temperature increased at 14 stations and decreased at 6 stations, but statistically significant upward trends from 0.11℃/decade to 0.45℃/ decade were evident at 10 stations at the significance level (α) of 0.05. The 4 series with downward trends in annual mean temperature were evident at the significance level (α) of 0.05. The increasing trends with larger amplitudes are significant in the upper reaches. Furthermore, the warming rates during winter were greater than that during summer. In contrast, six stations in the middle reaches show a decreasing trend (by -0.10 to -0.13℃/ decade), with the decrease at Yuanmou station(located in a typical dry-hot valley) having the strongest statistical significance of $\alpha = 0.001$.

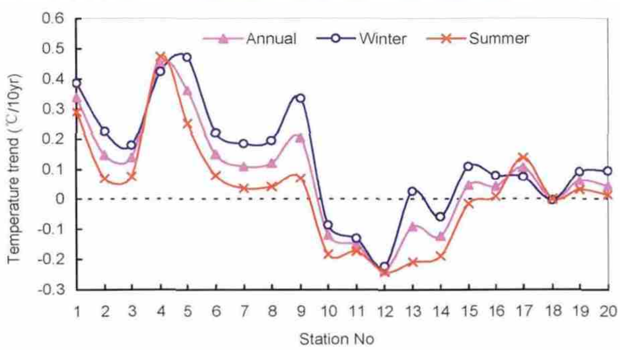

Figure 4. Spatial patterns of annual, summer and winter air temperature trends (℃/decade) of each station along the Jinsha River Valley for the period 1961-2010. The station number represents the station shown in Table 1.

3.3 *Interannual variation characteristics of precipitation*

Figure 5 shows the spatial distributions of annual and seasonal precipitation and its interannual variation from the upper reaches to the lower reaches along the JRV. The annual precipitation fluctuated in the range of 484.4 to 1 102.3 mm, while it varied from 484.1 to 1 028.9 mm and from 24.9 to 271.0 mm during summer and winter respectively. The largest precipitation was observed at the Fuling station in the lower reaches, and the smallest precipitation was observed at the Batang high-elevation station in the upper reaches. Precipitation is also uneven throughout the year. There is plenty of rain during the summer (rainy season, accounting for 80.7%-92.9% of the whole year), while precipitation is scarce in the winter (dry season), particularly from January to March, with the longest precipitation-free period lasting one month.

The peak of C_V values indicates the notable interannual precipitation variation area. The interannual variation of precipitation during winter was greater than that during summer. The C_V values of middle reaches were greater than that in upper reaches and lower reaches. The greatest interannual variation of precipitation was observed at Binchuan station (C_V=0.56) in the winter, and the smallest interannual variation appeared at Yushu

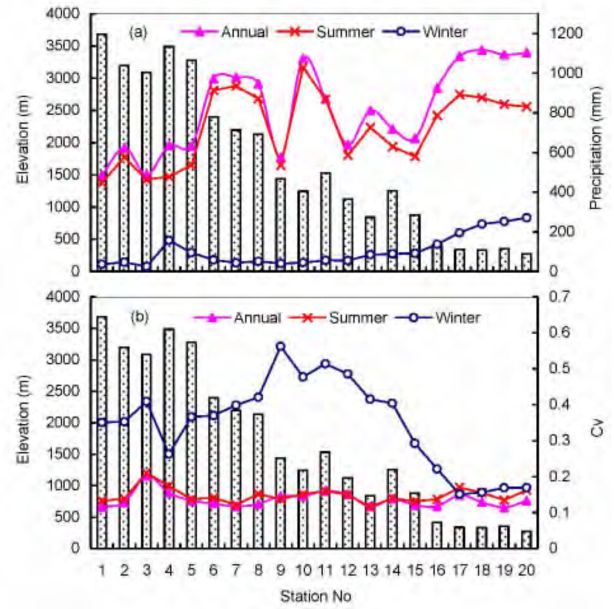

Figure 5. The spatial distributions of annual and seasonal precipitation (a) and interannual variations of precipitation (b) of each stations for the period 1961-2010 along the Jinsha River Valley. The station number represents the station shown in Table 1.

station (C_V =0.12).

3.4 *Trend analysis of precipitation*

Figure 6 shows the changes of the annual and seasonal precipitation of JRV as a whole for the period 1961-2010. According to the 5-year moving average curve of the annual precipitation, it was clearly demonstrated that the valley had been becoming wetter during the past 50 years. Though precipitation has decreased with more obvious fluctuations in rainy seasons since the early 1970s, the precipitation in most areas tended more or less to increase during the 1990s.

Sen's estimator of slope values in Fig.7 indicated the variation magnitude of the annual and seasonal precipitation of each station for the period 1961-2010. The results indicated that annual precipitation increased at 15 stations and decreased at 5 stations, and summer precipitation increased at 12 stations and decreased at 2 stations, but statistically significant downward trends from -45.49 mm/decade to -59.44 mm/decade (the sites located in the lower reaches) were evident at 2 stations at the significance level (α) of 0.05. The series with upward rates do not show a significant trend. Winter precipitation increased at 19 stations and decreased at 1 station, but statistically significant upward trends (the sites located in the upper reaches) were evident at 4 stations at the significance level (α) of 0.05.

3.5 *Drought index change*

It is indicated that higher surface air temperature and less precipitation will result in drier climate in the defined region. The year-to-year variation of the drought index at each station was calculated using Eq.(8). The *DI* increased at 14 stations and decreased at 6 stations. The upward trends at higher-elevation stations, located in the upper reaches, were statistically significant at α=0.05. However the sites with downward *DI* trends were located in the middle reaches. Recent and major periods of drought started in the 1990s for most of the stations in this region. However, drought development varied in different regions. In the north, major drought periods appeared in the late 1980s but in the early 1990s in the south. Trends of drought development over the upper reaches of the JRV will require special attention in the coming decade.

4 CONCLUSIONS AND DISCUSSION

Monthly mean temperature and precipitation from 20 stations were analyzed using different statistical tools in order to investigate the climate variations in the JRV from 1961 to 2006. The main conclusions can be summarized and discussed as follows.

(1) In the temporal scale, mean annual temperature has been slightly increasing by 0.08℃ /decade during the past 50 years as a whole of the JRV. On a seasonal basis, the climate change trend in air temperature was more significant in the winter (0.13℃ /decade) than in the summer (0.03℃ /decade), with precipitation showing converse behavior.

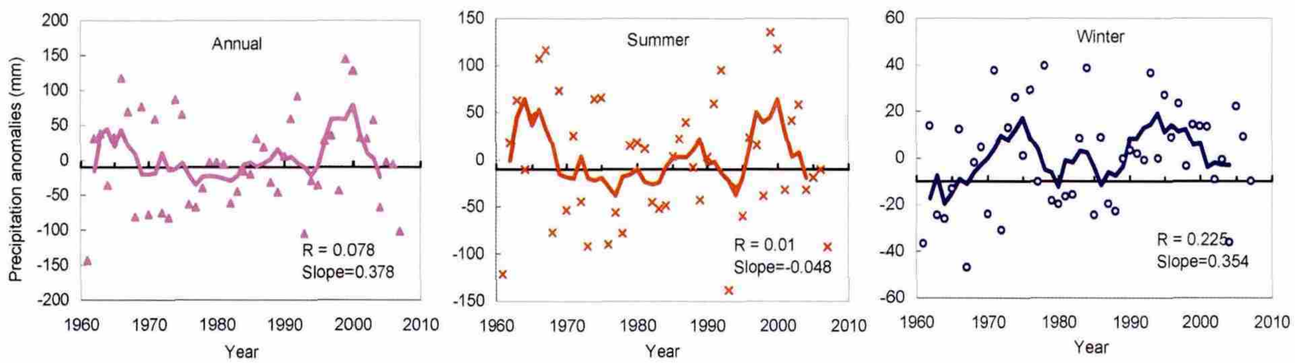

Figure 6. Regional annual, summer and winter precipitation for the period 1961-2010 derived from 20 stations along the JRV. The curve represents 5-year moving average. R and Slope represent the correlation coefficient and the slope of linear regression, respectively.

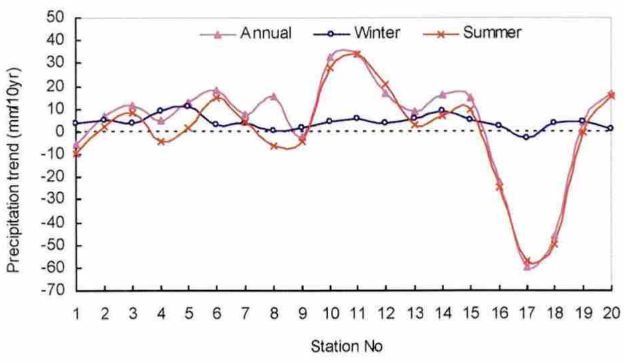

Figure 7. Spatial patterns of annual, summer and winter precipitation trends (mm/decade) of each station along the Jinsha River Valley for the period 1961-2010. The station number represents the station shown in Table 1.

(2) In the spatial scale, the greatest interannual variation of temperature and precipitation were observed at the dry-hot valley area of middle reaches. Most significant warming rates were found in the upper reaches (high-elevation) parts, whereas the dry-hot area of middle reaches experienced a cooling trend during the past decades. Though with overall increasing in precipitation, more obvious upward-trends was found in the dry-hot valleys of middle reaches, whereas the upper reaches (high-elevation) parts had a drought trend during the past decades.

In summary, the climatic complexity in a mountainous region is reflected by the temporal and spatial differences in the magnitude and significance of climate change. The overall warming rates over the JRV were lower than global mean (0.14℃/decade) (Qi et al.[20]) and the mean of the same latitudinal zone for the same period (Zhu et al.[21]). Compared with other regions in China, the climatic warming magnitude is relatively smaller. This preliminary observation provided a concrete picture of how JRV's climate has changed over the last 50 years. It provides the local authorities with useful information to assess the impacts of such climate change on human activities.

In contrast, cool and wet climate variability was detected in the dry-hot area over the past 50 years and this thus denotes a unique change. Consistent with the present study, Zhang found that the annual mean temperature in the Yuanmou dry-hot valley has declined by 1.1℃ from 1956 to 1999, accompanied by a slight increase in annual precipitation[12]. Occurrence of dry-hot valleys is a very striking geographical landscape in the Hengduan Mountains region of Southwest China. Because the extremely steep topography and elevation difference between valley floor and neighboring mountain ranges of more than 3 000 m, the dry-hot valleys are characterized climatically by much less precipitation and higher temperature and evaporation. Socio-economically, most dry-hot valleys are among highly populated areas and are often centers of human settlements and of agricultural development. It is however not clear that what are the main drivers of this unique climatic variability. According to related findings, the significant decreases in sunshine duration may attribute to the negative radiative force due to increasing atmospheric aerosol concentrations from regional pollutants, which was suggested to be the main contributor to surface cooling during the latter half of the 20th century in the Sichuan basin and its vicinity (Qian and Giorgi[22]). Though climate is chiefly under the control of macro-climatic system, the local environment change may have an impact on the local climate. Afforestation, for instance, has increased the forest coverage. Thanks to the development of hydrological engineering, both irrigated and crop sowing areas have expanded since the 1950s. With the implementation of the national project of soil erosion control since the 1980s, the driving forces to plant trees have been intensified and forest areas have been expanding at a faster speed. The increase of vegetation cover reduced solar radiation to land surface, surface reflection and temperature decrease (Zheng et al.[23]). Li et al.[24] used the theory of grey relative degree to analyze the mutual impact degree of climate factors in the dry-hot valley, and revealed that each climate factor has a close relation with the increase of irrigated land area. Moreever, the increase in precipitation and the decline in temperature may benefit the local agricultural production (Tang et al.[25]). The increase of air humidity has provided the local people with a more comfortable living environment. Nevertheless, light and thermal resources have reduced.

On the other hand, mountainous and highland regions are especially sensitive and vulnerable to climate change (Diaz et al.[26]). For example, average warming trends were observed at higher elevations on a global scale or at a regional scale such as on the Tibetan Plateau (Huang et al.[27]) and on the Ordos Plateau (Li and Zheng[28]). In the Tianshan Mountains, glacier melt was more sensitive to temperature change than to precipitation change, implying that modeling the effect of climate variability with increasing temperature should be further studied (Luo et al.[29]). Climate change for the 21st century over the Tibetan Plateau is projected using multiple climate models within Phase Five of the coupled model intercomparison project under the Representative Concentration Pathway 4.5 (RCP4.5) scenario. The results show an annual warming trend of 0.26℃/decade, which correlates positively with the topographical height (Hu et al.[30]). The results (significant upward trend in temperature, slight increasing trend in precipitation, and significant upward trend in drought index) calculated for the southeastern Tibetan Plateau over the upper reaches of the JRV need special attention in the coming decade. Climate variability has a pronounced impact on local environmental and economic systems, and may result in changes in land use and land cover. Climatic changes in this area will have a strong impact on the hydrological cycle, which is of great relevance for agriculture productivity and forestry. In the high-elevation area of JRV, the increase in precipitation affects the water availability in crop growing season, which must be of advantage to crop growth and crop productivity. As the temperature increment was mainly in crop non-growing season, it might have no significant effect on crop phenology (seen as a function of temperature) and crop productivity (mostly a function of precipitation) and the use of thermal heat resources for food crop production (Zhang et al.[31]). Further research and more detailed study are also needed to better understand the impact of these uncertainties and variations on regional climate, water resources, and crop productivity and to identify the specific/regional adaptation strategies to the changing climate.

Results obtained in this paper can be used as a reference for providing climatic backgrounds to solve problems related to water sources and ecological protection. This study does not conduct analyses associated with the change trend in the future. Future study may be needed to address this issue, which is beyond the scope of the present study. Future studies should analyze the nature of interactions between climate change and the ecosystem. We emphasize that the ecological impacts of climate change vary spatially, depending on the magnitude and significance of climate change, the structure and composition of vegetation, and synoptic conditions. Additional discussion on these topics is required, based on data from a greater number of observational sites.

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