



# ENVIRONMENT

## Precipitation fluctuations in the transitional zone between arid and semiarid regions of northwest China from the 1950s to the 1990s

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### Abstract

The transitional zone between arid and semiarid regions of northwest China is the most sensitive ecotone to the global climate change and also a severe land degradation area in China. Precipitation is the major water source for agricultural production and environmental improvement in this transitional area, and it has a great effect on the functions of the ecosystem. Studies of precipitation variability from the 1950s to the 1990s indicated that precipitation tended to decrease during the last 40 years. Furthermore, the year-to-year precipitation fluctuation was quite noticeable during this period. Precipitation was higher than normal from the late 1950s to the early 1960s. Frequent alternate wet and dry years were characteristics of the 1960s. The dry year anomalies are more significant than the wet year anomalies between the 1970s and the 1990s. Particularly there was a marked decrease in precipitation after 1980. The 250 mm isohyet is used as the climatic boundary line between arid and semiarid region and it shifts in the space with the occurrence of wet years and dry years. Compared with the position of the mean 250 mm isohyet during the last 40 years, the 250 mm isohyet in the wet year 1964 shifted northward about 55 km in the east part, 30 km in the middle part and 130 km in the east part of the transitional zone. In contrast, in dry year 1980, the 250 mm isohyet shifted southward about 110 km in the whole transitional zone. This means that the 250 mm isohyet has been displaced about 140 to 240 km between the wet year 1964 and the dry year 1980.

**Key words:** Climate variability, precipitation, arid, semiarid, northwest China.

### Introduction

Climate change has now become a pressing issue on the world's attention. It refers to shifts in climate occurring as a result of natural processes and human interference<sup>1,2</sup>. Meantime, desertification is one of the serious problems in the current global environment. Desertification was formally defined as "land degradation in arid, semi-arid and dry sub-humid areas resulting from various factors, including climatic variations and human activities" at the 1992 U.N. Conference on Environment and Development held in Rio de Janeiro<sup>3</sup>. Both climate and desertification interact at a variety of scales through a complex and still only partially understood series of feedback loops<sup>4</sup>. Climate has an important but often subtle influence on desertification processes through its impact on dryland soils and vegetation, on the hydrological cycle in drylands, and, ultimately, on human land use<sup>5</sup>. Natural climate variability can accelerate the process of desertification. Changes in the frequency and severity of drought contribute substantially to dryland degradation and desertification. This process has been most evident in the Sahel region of Northern Africa where rainfall levels have declined by 20-40% in recent decades and the land has been severely degraded. Declining rainfall can also cause changes in vegetation, with, for example, perennial grasses giving way to annual growth, and shrubs giving way to grass cover. Long periods of high winds can remove fertile top-soils causing soil erosion. Moreover, desertification in turn also has important impacts on climate changes. Modeling exercises carried out to date have clearly shown that large-scale changes in land-use characteristics can generate

climate change on local and regional scales<sup>6,7,8,9</sup>. Removal of vegetation results in an increase in albedo, thus reducing the surface absorption of solar energy<sup>10</sup>. Reduction or destruction of the permanent vegetation cover leads to increased runoff and potential evapotranspiration rates due to higher surface and near-surface temperatures, higher near-surface wind speeds and lower near-surface atmospheric moisture levels. The increase in runoff and evapotranspiration rates then leads directly to a decrease in soil moisture and a rapid decrease in amount of energy used to evaporate or transpire water into the atmosphere<sup>2,4,5,11,12</sup>. Obviously, desertification can lead to a reduction in species diversity and plant biomass, and a reduction in the overall productivity in dryland ecosystems with an attendant impoverishment of the human communities dependent on these ecosystems<sup>5</sup>. A combination of climatic stress and dryland degradation can lead to extreme social disruption, migrations, and famine. A number of research reports have suggested that climate change is responsible not only for changes in food production<sup>13</sup>, but also sometimes for population migrations<sup>14,15</sup>, for abandonment of some ancient cities or towns in present-day arid and semiarid regions<sup>16</sup> and even for the death of countless people and the disappearance of a whole civilization<sup>17,18</sup>. In China, Fang and Liu<sup>19</sup>, Wang<sup>20</sup> and Fang<sup>21</sup> found that there was close relationship between climatic change and migration of the nomad people in central Asia and the Mongolian grasslands<sup>19,20,21</sup>. Southward or eastward migration of the nomad people perhaps resulted from both livestock failure of the nomad people and crop failure of the Han Chinese during cold and/or dry climate period. Moreover, Fang<sup>21</sup> pointed out precipitation variations corresponded

well to the alternate farming and grazing culture<sup>21</sup>. Marginal areas at the transition between arid and semiarid ecosystem are subjected to serious land degradation and are particularly sensitive to climatic change<sup>22</sup>. Temporal and spatial climatic variability is one of the most notable features of arid and semiarid areas. Precipitation and temperature extremes, as well as substantial interannual fluctuations and innerannual changes, are characteristics of the temporal dynamics of the regions. Due to the fact that trend or long-term variability of precipitation is essential to understand the mechanism of desertification and combat desertification<sup>23</sup>, many studies on precipitation variability had been focused on Africa, Middle East and the U.S. arid zones<sup>24-39</sup>. Field observations and remote sensing data have confirmed very large spatial variations in dryland plant density and biomass, as well as equally important temporal fluctuations in biomass in response to seasonal and interannual fluctuations in rainfall<sup>28,35</sup>. Tucker et al.<sup>36</sup> found that desert margin vegetation cover expanding or contracting from year to year depended on the annual variations in rainfall<sup>36</sup>. During the LGM (*ca.* 20-18 ka BP), in the tropics (the Sahelian zone, Southern Arabia and Rajasthan) mean annual precipitation decreased by at least 300 mm as compared to the present and the 100 mm isohyet shifted to 13-14°N in Africa<sup>31</sup>. Aridization resulted in the spread of the extra-arid desert zone by 300-400 km towards the south in northern Africa as compared to the present situation<sup>32</sup>. During that period semidesert and dry savannah landscapes spread throughout the present-day zone of humid tropical forests at that period<sup>40</sup>. During the modern time, Nicholson<sup>35</sup> reported a sharp contrast in the Sahelian rainfall between the periods before and after 1950<sup>25,26</sup>. Lamprey<sup>21</sup> estimated the southern Sahara boundary had shifted southward in western Sudan 90-100 km between 1958 (a wet year) and 1975 (a dry year)<sup>41</sup>. Williams<sup>4,5</sup> stated that during the dry years 1980 to 1984, the 200 mm isohyet moved 240 km to the south, averaging a 60 km southward shift per year in the Sahel; during the next two years (1984 to 1986) the desert retreated north, 110 km on average from 1984 to 1985, and a further 33 km from 1983 to 1986<sup>4,5</sup>. Similarly, Sivakumar<sup>42</sup> reported that, in Niger, there was a clear mean annual rainfall decline after 1969 and the isohyets were displaced 100-150 km southwards<sup>42</sup>. These suggest that natural precipitation variability may have a great effect on the functions of the desert ecosystem. However, climate change literature (particularly English document) concerning precipitation in arid and semiarid regions of northwest China is scarce. Some discussions were included in the assessments of the Afro-Asian Transition Zone<sup>31,43,44,45</sup>. Arid and semiarid regions in China cover 53 % of the land area. The vast expanse of arid and semiarid lands in China suffers from very severe land degradation as a result of the dialectical relationship between climatic change and human disturbance<sup>46</sup>. The transitional zone between arid and semiarid regions of northwest China is the most fragile area in northwest China and thereby is the most sensitive ecotone to the global climate change<sup>47</sup>. It belongs to the monsoon edge areas and lies in the northwestern boundary of Farming-grazing Transitional Zone (located between 250-500 mm isohyet). Farming-grazing Transitional Zone is a narrow belt, extending northeastward from the Yellow River Valley and bordering Ordos Desert and Inner Mongolia. It was formed due to a feedback of climate-ecology-economy-society, and Fang<sup>21</sup> considered that this area was equivalent to Sahel zone in Africa to some extent<sup>21</sup>. Studies of spatial and temporal variability of precipitation at the transition between

arid and semiarid is a necessary step in understanding the current distribution and dynamics of ecosystems and the mechanism of desertification, as well as an important step in the process of predicting the potential effects of human-induced climate change. Understanding current climatic variability also helps us set up rational land use plans and carry out ecological evaluations. The objective of this paper is to analyze precipitation fluctuations in the transitional zone between the arid and semiarid regions of northwest China from the 1950s to the 1990s, and discuss spatial variation of 250 mm isohyet during the dry years and wet years.

### Data and Methods

Instrumental records for precipitation in the arid and semiarid regions of northwest China were a little late. The earliest records began in the 1930s and varied between different locations. Therefore, six meteorological stations across the transitional zone with relative longer precipitation records starting in the 1950s and ending in the 1990s were selected as representative stations from east to west to analyze precipitation fluctuations. Dongwumuzhuxin and Duolun stations represent two stations in eastern part of the transitional zone between the arid and semiarid region, Siwangzi and Tongxin represent two stations in the middle, and Jingyuan and Lanzhou represent two stations in western part of the transition. The descriptions of the six representative stations were shown in Table.1. The precipitation series of the pair stations in each part of the transitional zone were significantly correlated with other twenty surrounding weather stations at the significant level of 0.05. Standardized anomalies of precipitation for the six stations were used to determine dry year and wet year during the past 40 years. Then, using sixty meteorological stations records, the 200, 250 and 300 mm isohyets in dry and wet years and mean annual 250 mm isohyet during the past 40 years were mapped to illustrate spatial variations and its implications.

### Geography and Environmental Conditions

The transitional area between arid and semiarid regions of northwest China includes parts of Inner Mongolia Autonomous Region, Ningxia Hui Autonomous Region, Gansu and Qinghai Province with a total area of 260,000 km<sup>2</sup>, approximately 2.7% of the national territory<sup>48</sup> (Fig. 1). It runs through Hulun Buir Plateau and extends southwestward to the Ordos Plateau and western Loess Plateau as well as outer area of Chaidamu Basin. The climate of the transitional zone is influenced by three air masses<sup>47</sup>. Winters are dry and cool and dominated by a high-pressure air mass that originates in Siberia and Mongolia called the Siberia-Mongolian High<sup>49</sup>. The strong westerly flow of winter begins to weaken in the spring when two warm monsoon air masses with origins over the Indian Ocean (southwest monsoon) and the Pacific Ocean (southeast monsoon) begin to influence the region. Mean annual precipitation ranges from 250 to 350 mm, with 60-70% of precipitation falling summer months between June and September. Annual accumulated temperature above 0°C ranges from 1800 to 3200°C. The annual frost-free period varies between 100 and 180 days. The landscape of the transitional area is characterized by desert steppe. In the northeast, it is a transient area between typical steppe of Inner Mongolia Plateau and the Gobi Desert, and in the middle a transient area between the Loess Plateau and sandy desert. In the southwest, it features landscape of the Tibet Plateau. The current land use

patterns comprise grazing, farming and a mixed area where grazing and farming co-exist, which may be subdivided into the following types: (1) Animal husbandry area in northwestern Inner Mongolia Plateau, (2) Animal husbandry area in the Ordos Plateau, (3) Farming and animal husbandry area in northern Yinshan Mountains, (4) Farming and animal husbandry area in northwestern Loess Plateau, (5) Farming, forest and animal husbandry area in eastern Qinghai Province, and (6) Animal husbandry and forest area in northern Qilian Mountains and southeastern Chaidamu Basin (Fig.1). This paper mainly deals with precipitation fluctuations in the transitional area located in the Inner Mongolia Plateau and the Loess Plateau. Land degradation leading to desertification presents a serious environmental problem to the transient area. Most of the land is at risk from desertification because of climate variability, periodic droughts and population pressure. At present, there is conflict between land use and environmental protection. Large areas of grassland were reclaimed as farming fields, and much of the natural environment was destroyed. The eco-environments of the transitional belt have profound effects on the sustainable development of agriculture in middle and east China and of animal husbandry in northwest China. The belt serves as an ecological barrier for protecting the watershed in western China and against transporting dust into south China. There is an urgent need to restore and protect the natural environment of this area.

### Results and Discussions

#### *General trend of climatic changes in the arid areas of China:*

Arid area in China belongs to the so-called Sahara-Gobi desert belt, which is the most extensive arid area in the world. The belt stretching for more than 15,000 km from the Atlantic coast to northern China, includes the Sahara, deserts of the Arabian peninsula and the Thar, the Iranian highlands, the Karakumi and Kizilkumi deserts of the CIS Central Asia, the Takhla Makhan and the Gobi desert in Mongolia and China. Temporal synchronism of climatic changes in the Sahara, south-western Asia and northern China during the last glacial cycle and its correlation with monsoon activity were clearly shown by Petit-Maire and colleagues<sup>31,44</sup>. The time of the initial formation of desert landscapes in different parts of the Sahara-Gobi area is a matter of discussions. Presently there is no scientific consensus on the age of the Sahara, or that of the deserts of Western and Central Asia. It is known that arid conditions dominated in Northern Africa in the Miocene<sup>50</sup>. There is geological evidence of dust transport by north-western winds from the Sahara over the Atlantic in the Pliocene<sup>51</sup>. In the case of Central Asia, it was the dramatic lifting of the Tibetan Plateau and the formation of the Himalayan Mountains, which had a crucial impact on monsoon circulation and which caused aridization of climate. However, a strong general trend towards more arid conditions started during the Late Pliocene, being caused by series of global cooling intervals. During the Pleistocene this trend became stronger and the global cooling increased in the Late Pleistocene. A severe arid phase occurred everywhere during the LGM (ca. 20-18 ka BP). Cold and extremely dry conditions dominated in the temperate zone. A significant decrease of temperature (by 12°C at least) and of precipitation (by 100-200 mm) occurred in Mongolia and northern China<sup>31,45</sup>. Such climatic conditions caused a considerable spread of cold (and cool) deserts and semideserts in the Asian part of the belt, both northward and southward of the present-day desert zone. On the Loess plateau of China subtropical sub-humid forests

gave way to cold dry steppes with considerable aeolian loess accumulation<sup>45</sup>. During the Holocene, the global warming affected everywhere in the Sahara-Gobi desert belt. A significant increase of humidity generally occurred between 9-9.5 ka and 6.5-5.5 ka, varying according to regional geographical conditions<sup>31,32</sup>. Based on the analysis of proxy climate data of saline lake sediments, loess deposits and glacial advances in arid areas of northwestern China, Ji<sup>52</sup> divided the climatic changes during Holocene into three periods<sup>52</sup>: (1) 11-9 (or 8.5) ka BP, a warming period, with glaciers in western mountains in retreat, reduced rates of loess deposition and rising lake levels. (2) 9 (8.5) –3.5(3) ka BP, the Climate Optimum warm period when most arid regions became wetter, forests and steppe vegetation spread, deserts contracted and no glacial advances were recorded. (3) 3.5(3) ka BP-present, glaciers advanced, desert expanded and loess deposition rate increased and it became colder approaching the present climatic conditions. Meantime, Shi et al.<sup>43</sup> and Yan and Petit-Maire<sup>44</sup> reported that precipitation increased by more than 100 mm and the mean annual temperature -1.5°C higher during the period between 8.5 ka and 6.5 ka than at present<sup>43,44</sup>. On the Loess plateau of China desert landscapes with intensive aeolian loess accumulation gave way to temperate steppes on Luvic Phaenozems<sup>45</sup>. Similarly, Zhang et al.<sup>47</sup> analyzed the oscillations of the Monsoon Edge Area (area between 250 and 450 mm isohyets) in northern China during the Holocene<sup>47</sup>; the results indicated that the west part of the Monsoon Edge Area in north China had been displaced about 800 km, 400 km and 200 km at the time scale of 10000, 1000 and 10 yr respectively. During the historical time, climate in arid and semiarid regions of China also shows great variability. Wang and Zhao<sup>53</sup> and Xu et al.<sup>56</sup> analyzed drought frequencies in north China (including east part of the semiarid regions of China) during the historical period<sup>53,54</sup>. The results indicated that, during the past 520 years, there were obvious 100-130 years quasi-period for historical drought frequency<sup>54,55</sup>. The high frequency drought years were 1480s, 1610s, 1720s, 1830s and 1930s; and the high frequency wet years were 1560s, 1670s, 1770s and 1880s respectively (Fig. 2). The most serious drought in history often occurred in the high frequency years.

#### *Precipitation characteristics at the transition between arid and semiarid regions of northwest China during the last 40 years:*

Precipitation in the semiarid regions of China showed a decreasing trend during the last 40 years (Fig. 3, Table 2)<sup>55,56</sup>. In the western part of the semiarid region, there was a marked quasi-3 year periodicity. But in the eastern part, a quasi-35 year periodicity was noticeable<sup>54,57</sup>. In contrast, precipitation in the arid regions of China showed a marked increasing trend during the last 40 years. Xu et al.<sup>56</sup> interestingly pointed out that precipitation decrease in the semiarid regions of China might be associated with Sahara and the Middle East, while precipitation increase in the arid regions of China might be associated with Russia and its surrounding countries<sup>54</sup>. However, the general decreasing trend of precipitation in eastern semiarid regions of China in the early 20<sup>th</sup> century (before 1930s), followed by increases from the 1950s to the 1970s and decrease from the 1980s onwards is similar to the global precipitation variation pattern<sup>55</sup>. In the transitional zone between arid and semiarid region, annual precipitation analysis for the six representative stations over the period from the 1950s to the 1990s showed that precipitation tended to decrease during the last 40 years with a clear 2-3 years periodic oscillation (Figure 4). The



**Figure 1.** Location of the transitional zone between arid and semiarid regions of China.

standardized annual precipitation anomalies series are presented in Figure 5. The year-to-year fluctuation is quite noticeable. Precipitation seems higher than normal from the late 1950s to the early 1960s. Frequent alternate wet and dry years occurs in the 1960s, but the wet year anomalies are more significant than the dry year anomalies. However, the dry year anomalies are more significant than the wet year anomalies between the 1970s and 1990s. There was a marked decrease in precipitation and the amplitude of oscillation after 1980 except Duolun station (Fig. 4 and Fig. 5). The trends in precipitation variations were different for the six stations. The highest standardized anomaly indices ranged from  $-0.7$  to  $1.7$  for the Siwangzi and Tongxin stations, in contrast, standardized anomaly indices were  $-0.4$ – $0.7$  for the other stations. This may be attributed to the different air mass impacts on different regions. The Southeast Monsoon and the West Wind Circulation prevail in the eastern part of the transitional zone (Dongwumuzhuxin and Duolun stations), and Southeast Monsoon and Southwest Monsoon prevail in the western part of the zone (Jingyuan and Lanzhou stations). While the middle part of the transitional zone is influenced by three air masses, i.e. Southeast Monsoon, Southwest Monsoon and West Wind Circulation<sup>47</sup>. Seasonal precipitation also shares high variability at the transition area. Precipitation mainly occurs during the months between May and September (Figure 6). Sixty percent of annual precipitation is concentrated in the three summer months from July to September, and often in the form of heavy rain. Monthly precipitation is 1.4–3.3 mm in January, February or December; 4–17 mm in March, April or November; 21–62 mm in May, June or October, and 30–108 mm in July, August or September. In autumn, spring and winter, precipitation accounts for about 19%, 16% and 5% of the annual precipitation respectively. The average annual rainy days range from 61 to 99 days, of which over 70% of rainfall events are below 5 mm and 15% are in the range of 5–10 mm, whereas only about 1–2% are above 25 mm. The highest amount of rain in 1 day is 57–84 mm (August).

**Movements of the 250 mm isohyet during the dry and wet years during the last 40 years:** The 250 mm isohyet is used as the climatic boundary line between arid and semiarid region and it shifts in the space with the occurrence of wet years and dry years. The 250 mm isohyet is also considered as the northwestern boundary line of the

Monsoon Edge Area in northwest China<sup>17</sup>. Hou and Shi<sup>58</sup> investigated the oscillation of the Monsoon Edge Area between 1901 and 1989 and concluded that the Monsoon Edge Area had been displaced southwards in the 1920s and northwards between the 1930s and 1960s (Table 3)<sup>58</sup>. The frequency and magnitude of oscillation toward south or north tended to be same since 1970s. By comparing standardized anomalies of precipitation among six stations (Fig. 5), we select the year 1964 as a wet year and 1980 as a dry year. Precipitation in 1964 was 40–50% higher than the normal year, while precipitation in 1980 was 30–40% lower than the normal year. The 200, 250 and 300 mm isohyets in 1964 and 1980 and mean annual 250 mm isohyet during the last 40 years were mapped (Fig. 7). Compared with the position of the mean 250 mm isohyet (D) during the last 40 years, the 250 mm isohyet (B) in the wet year 1964 shifted northward about 55 km in the east part, 30 km in the middle part and 130 km in the west part of the transitional zone. The 300 mm isohyet (C) had shifted northward to the average annual 250 mm isohyet (D) position in the middle part of the transitional zone in 1964. In contrast, in the dry year 1980, the 250 mm isohyet (F) shifted southward about 110 km in the whole transitional zone. This means that the climatic boundary line between arid and semiarid region (250 mm isohyet) has been displaced about 140 to 240 km between 1964 and 1980. The 200 mm isohyets (A, E) and 300 mm isohyets (C, G) were also displaced northward in wet year 1964 and southward in dry year 1980 (Fig. 7).

### Implications

Precipitation is the major water source for agricultural production and environmental improvement in the transitional zone between arid and semiarid regions of northwest China. Precipitation change can affect surface runoff, groundwater recharge and soil water storage as well as the gross water resource volume. Moreover, precipitation is a major control over the structure and function of the transition ecosystem. Due to the fact that recent warming and drying has dominated the arid and semiarid areas and many studies have shown that anomaly or extreme climate events will occur more frequently and extensively in the future<sup>59,60</sup>, the amplitude of 250 mm isohyet displacement in dry or wet years suggests that climate change would enhance the vulnerability of the marginal land at the transition in the coming years. It is worth noting that, in 1997, most area of northwest China have had anomalous and continuous drought and hot weather in summer, which may be related to the E1 Nino event. Precipitation in Yellow River was 27.4 percent less than normal and thereby surface runoff was 42.5 percent less than the normal year. Gao and Hang<sup>60</sup> estimated the possible climate change in the coming 100 years in North China using instantaneous simulating results of five global ocean and atmospheric coupled climate models<sup>60</sup>. The results indicated that, under the consideration of greenhouse and aerosol effects, temperature will be increasing in the coming years and by the end of the 21st century temperature will increase by 4.3 compared with the present. Precipitation will have a small increase in the early 21st century, but show a decreasing trend since the mid 21st century. By the end of 21st century, precipitation will be 15 mm less than the present value. Higher increase in temperature may also lead to more evaporation and the small increase in precipitation may not compensate the water loss due to evaporation. It is apparent that the warming and drying trends are harmful to the water resource utilization and eco-environment, therefore effective measures should be taken to adapt climatic

changes. It is necessary to carry out uniform management of water resources, develop new water source and implement water-saving techniques. Moreover, various measures should be taken to prevent human activity from destroying eco-environment, such as planting trees, reducing reclamation and grazing, and protecting water source area. However, to successfully adjust climate change and offset its consequence, further research is needed to assess the complex feedback mechanism of climate-ecology-economy-society to desertification in the transitional zone between arid and semiarid regions.

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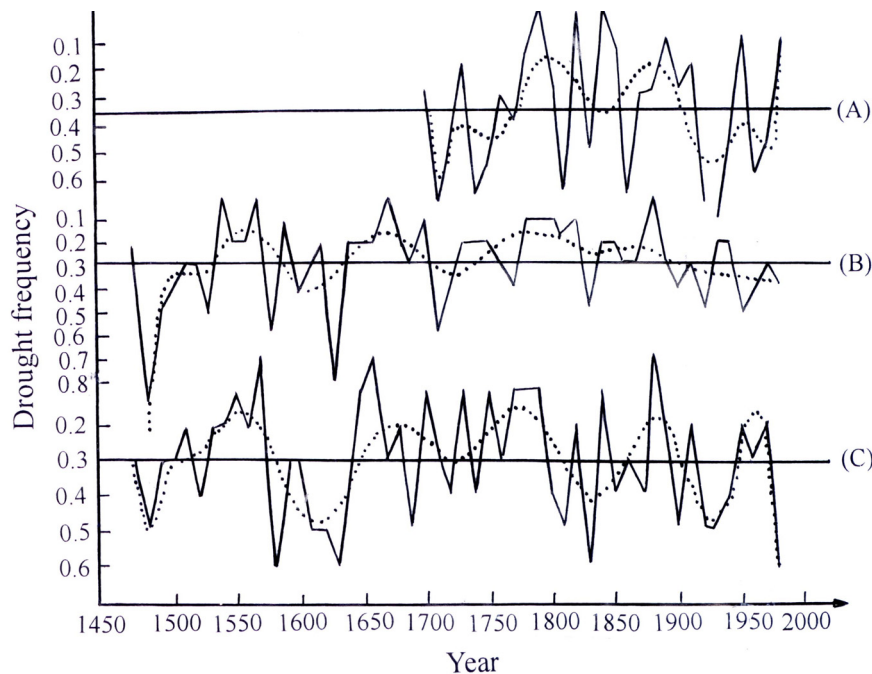
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**Figure 2.** Historical drought frequency during about the last 520 years in the arid and semiarid regions of China, solid lines represent measured value and dash lines simulated value, (A): eastern part of the arid region, (B): western part of the semiarid region, (C): eastern part of the semiarid region) (Source: Xu, 1997).

**Table 1.** Details of the six representative meteorological stations in the analysis.

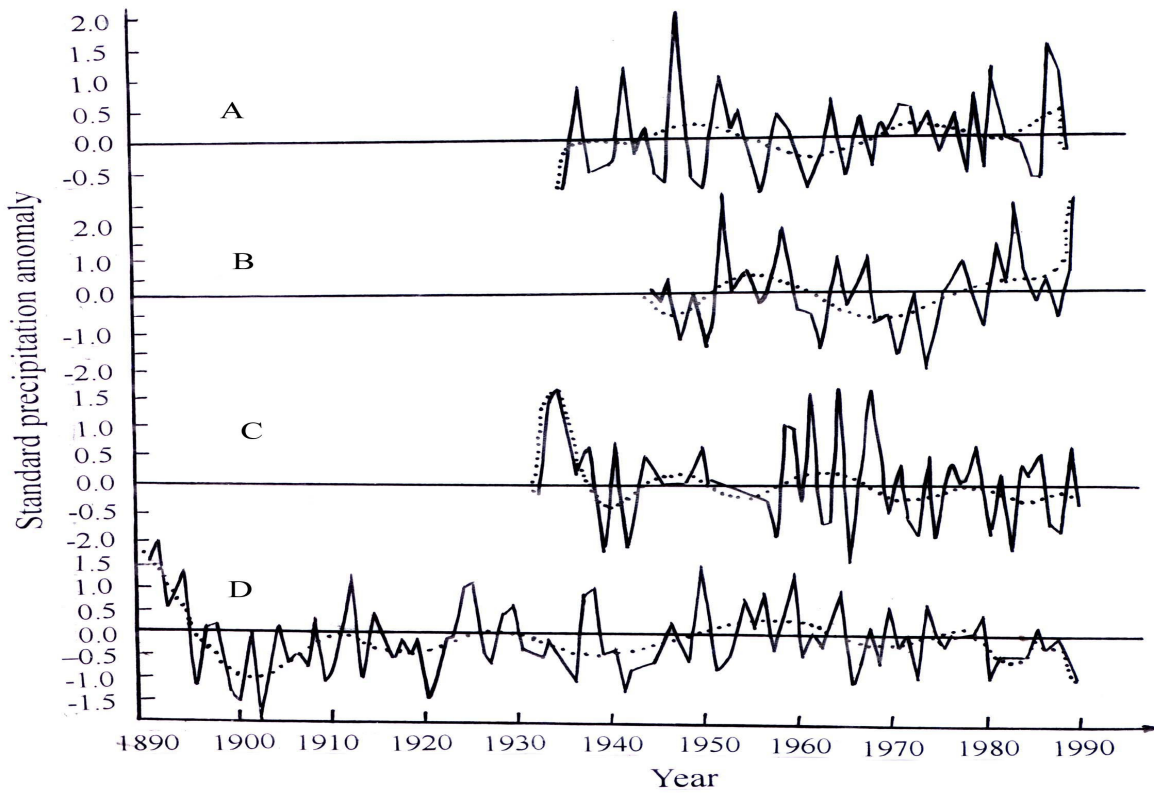
Station	Latitude(°N)	Longitude(°E)	Altitude(m)	Period of record	Mean annual precipitation (mm)	Maximum		Minimum		Standard deviation
						Precipitation(mm)	Precipitation(mm)	Precipitation(mm)	Precipitation(mm)	
Dongwuzhumuxin	45°31'	116°58'	538.7	1958-1997	285.1	481	166	69		
Duolun	42°11'	116°28'	1245.4	1958-1997	353.2	496	211	67		
Siziwang	41°33'	111°38'	1490.0	1956-1995	170.5	467	109	83		
Tongxin	36°59'	105°55'	1343.9	1955-1990	277.9	491	128	90		
Jingyuan	36°34'	104°40'	1397.8	1951-1997	237.6	416	135	62		
Lanzhou	36°03'	103°53'	1517.2	1951-1997	318.1	546	189	79		

**Table 2.** Standard precipitation anomalies during the period between 1890 and 1990 in the arid and semiarid regions of China (Source: Modified from Xu, 1997).

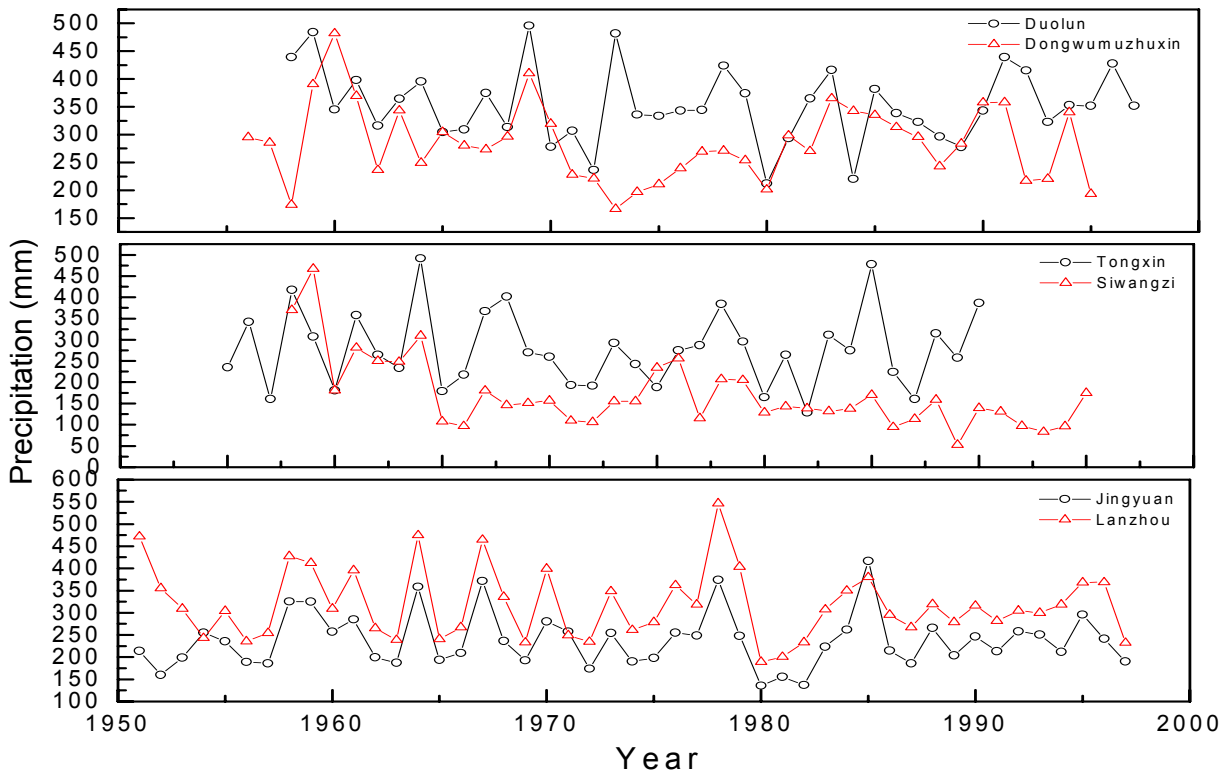
	1890s	1900s	1910s	1920s	1930s	1940s	1950s	1960s	1970s	1980s
	Eastern semiarid region	0.11	-0.56	-0.12	0.08	-0.21	-0.16	0.018	0.01	-0.08
Western semiarid region					0.44	0.02	-0.02	0.18	0.17	-0.09
Arid region					-0.20	0.09	0.05	-0.16	0.11	0.27

**Table 3.** Oscillation frequencies of the Monsoon Edge Area between 1901 and 1989 (Source: Modified from Hou & Shi, 1992).

	1901-1910	1911-1920	1921-1930	1931-1940	1941-1950	1951-1960	1961-1970	1971-1980	1981-1989
South	2	3	5	1	0	1	1	3	1
North	2	3	0	3	3	3	3	3	1
<b>Normal</b>	<b>6</b>	<b>4</b>	<b>5</b>	<b>6</b>	<b>7</b>	<b>6</b>	<b>6</b>	<b>4</b>	<b>7</b>



**Figure 3.** Precipitation changes for arid and semiarid regions of China from 1890 to 1989 (Source: Xu et al., 1992), solid lines represent measured value and dash lines simulated value, A: arid region, B: arid inland Heihe River runoff, C: western part of the semiarid region, D: eastern part of the semiarid region.



**Figure 4.** Annual precipitation for the six representative meteorological stations over the period from the 1950s to the 1990s.

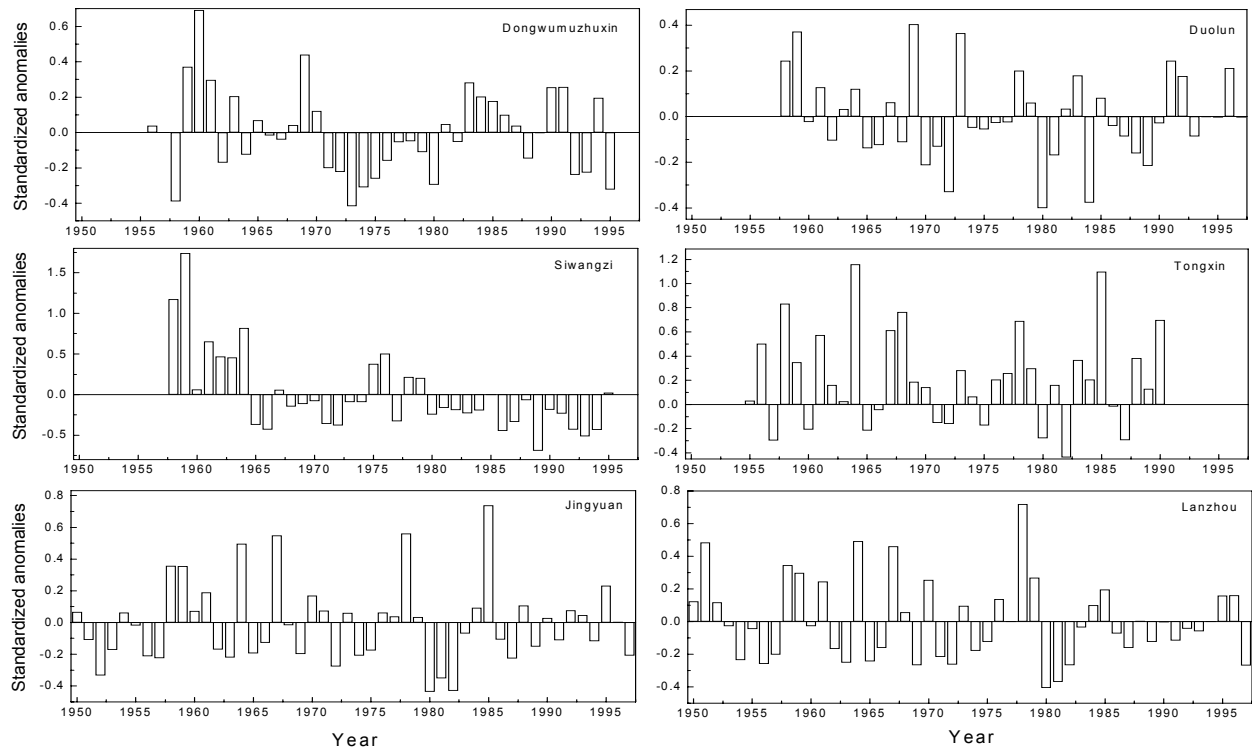


Figure 5. Standardized annual precipitation anomalies for the six representative stations from the 1950s to the 1990s.

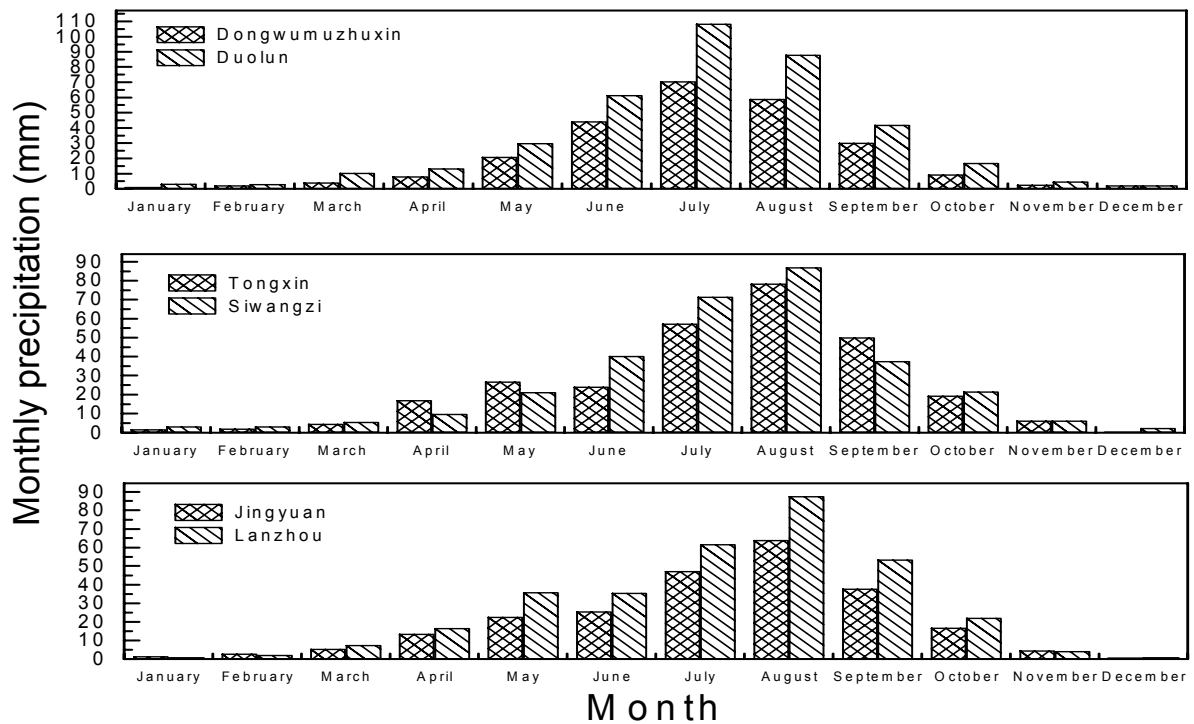
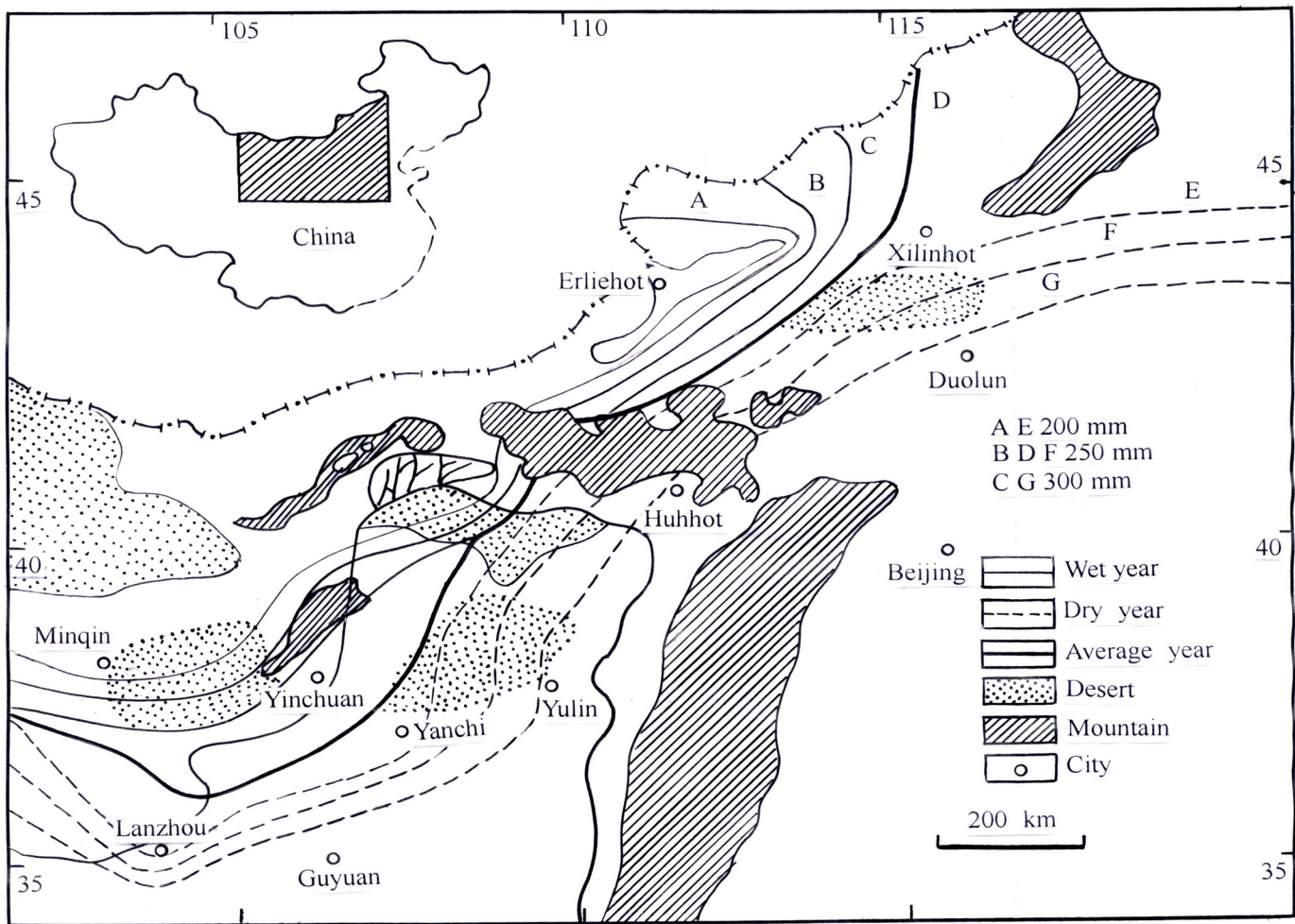


Figure 6. Mean monthly precipitation for the six stations over the period of the 1950s-1990s.



**Figure 7.** Displacement of isohyets in wet year 1964 and dry year 1980 in the transitional zone between arid and semiarid regions of northwest China, A, B, C represents 200, 250 and 300 mm isohyet in 1964 respectively; E, F, G represents 200, 250 and 300 mm isohyet in 1980 respectively, and D represents average annual 250 mm isohyet during the last 40 years.