Reconstruction of Precipitation Series for the last 300 Years over the Middle and Lower Reaches of the Yellow River

Ge Quansheng, Hao Zhixin &Zheng Jingyun

Institute of Geographic Sciences and Natural Resources Research, CAS, Beijing

October 29-30, 2003

Issues

- Study Region (17 stations)
- Data Source
- Reconstruction methodology of the precipitation series for the last 300 years over the Middle and Lower Reaches of the Yellow River
- Analysis & Conclusions

Study Region

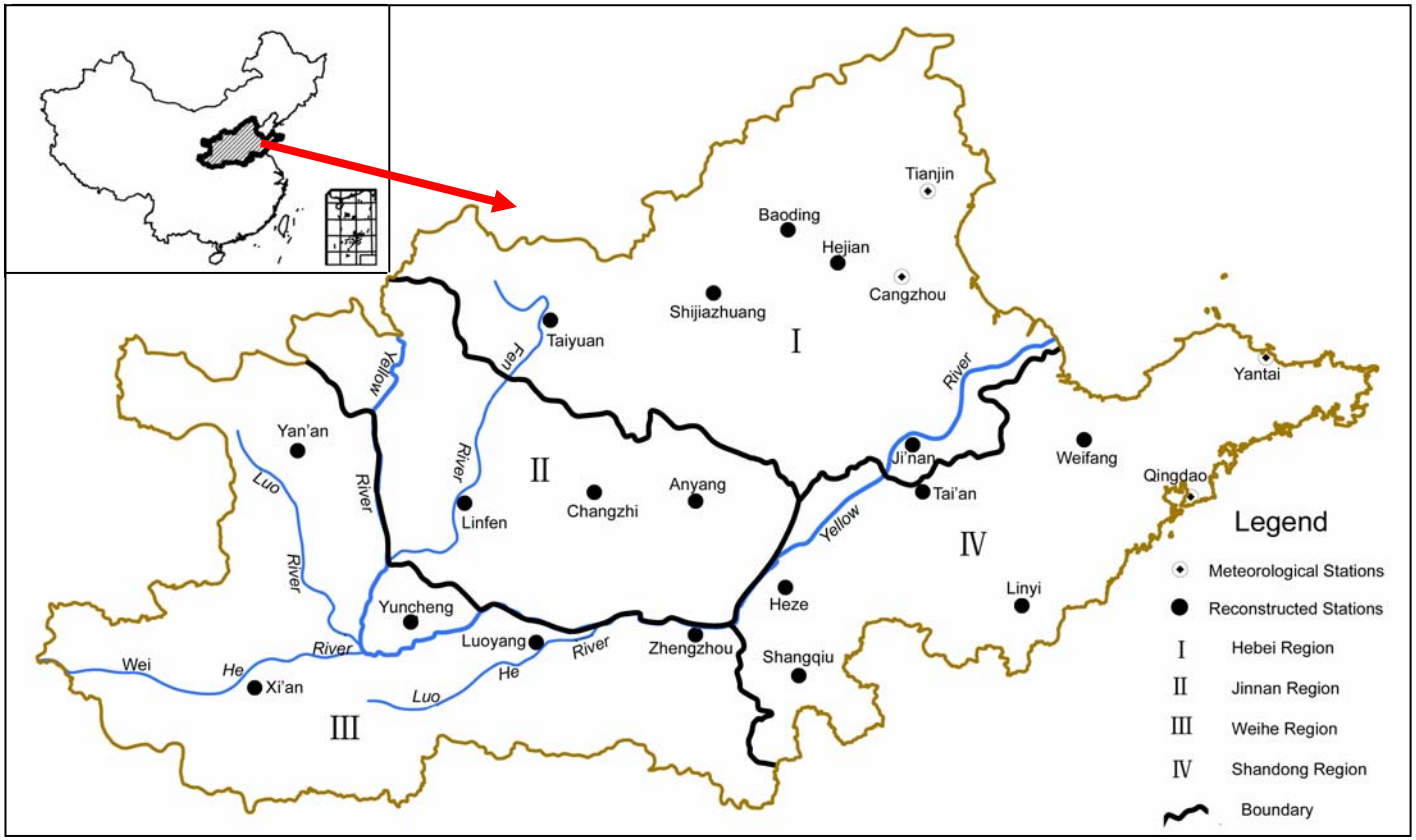


Fig.1 The Middle and Lower Reaches of the Yellow River

Data Source

The data source includes four parts:

- Snow and rainfall records of the 17 stations derived from the archives in the Qing Dynasty;
- Modern meteorological observation data;
- Soil moisture content observation data of the each agro-meteorological station (1951-2000);
- Observation data from artificial simulation rainfall and field infiltration experiment at Luancheng (Shijiazhuang city in Hebei province) agricultural ecosystem experimental station.

Data Source -- Snow and Rainfall archives in the Qing Dynasty

- **contents:** *Yu Fen Cun* --depth of rain infiltration

  Xue Fen Cun-- thickness of snow

- **unit:** *Cun* (about 3.2cm) and *Fen* (about 0.32 cm) in Qing Dynasty

- **period:** from AD.1693 to AD.1911

  continuous records were began at AD.1736

Data Source -- Snow and Rainfall archives in the Qing Dynasty

- **place:** in the farmland

  covering over the whole country (268 Fu of 18 Provinces)

- **observation method:**

  Yu Fen Cun -- After rainfall, people dig into soil in the even farmland, when the obvious transition-layer appears between dry and wet soil, measure the depth of this layer;

  Xue Fen cun -- directly measured the thickness of snowfall, which was same as that observation at present.

Data Source -- Snow and Rainfall archives in the Qing Dynasty

☞ **reporter:** reported by

Zongdu (the governor general); Xunfu (the provincial governor);

Buzhengshi (the official whom in charge of politics and economy);

Anchashi (the official whom in charge of interior affair for a province);

Zhifu (the city governor);

Yanzheng (the official whom in charge of salt products);

Xuezheng (the official whom in charge of education affair);

Zhizao (the official whom in charge of textile products);

Zongbing (the head of the troop in local);

Hedao (the official whom in charge of building watercourse) etc.

Data Source -- Snow and Rainfall archives in the Qing Dynasty

- **These reporters make the snow and rainfall records have some characters below:**
  - fixed spatial sphere(was consistent with the official presidial region);
  - detailed record contents;
  - uniform record formation.

Data Source -- Snow and Rainfall archives in the Qing Dynasty

☞ Characters of records:

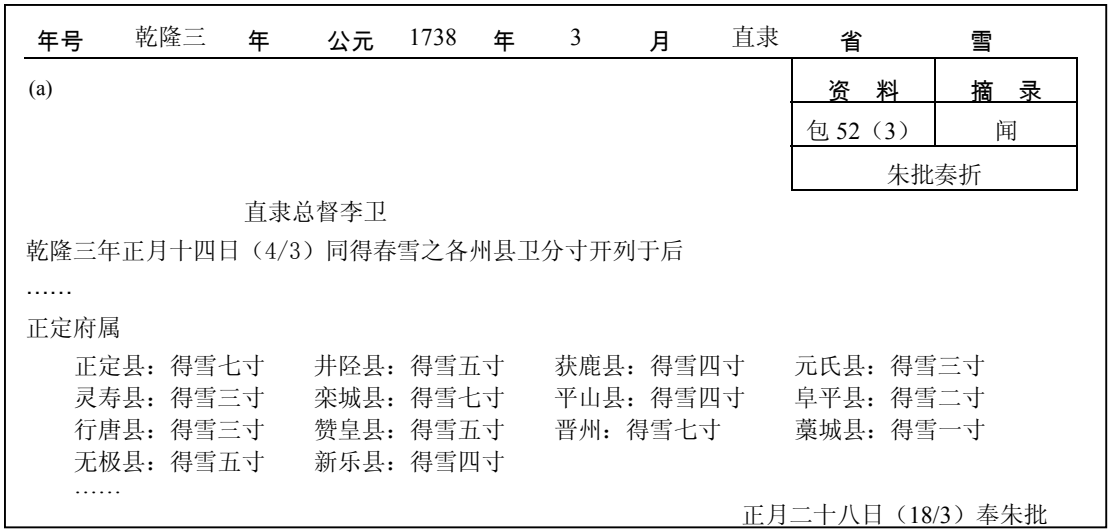
The snow and Rainfall archives can be grouped into two categories of quantitative and qualitative describing and expressions.

In the Middle and Lower Reaches of the Yellow River

- quantitative records:occupied about 70% of all;
- qualitative describing and expressions:

  occupied about 30% of all.

Data Source -- Snow and Rainfall archives in the Qing Dynasty



年号 乾隆三 年 公元 1738 年 3 月 直隶 省 雪

(a)

资 料	摘 录
包 52（3）	闻
朱批奏折	

直隶总督李卫

乾隆三年正月十四日（4/3）同得春雪之各州县卫分寸开列于后

……

正定府属

正定县：得雪七寸　井陉县：得雪五寸　获鹿县：得雪四寸　元氏县：得雪三寸
灵寿县：得雪三寸　栾城县：得雪七寸　平山县：得雪四寸　阜平县：得雪二寸
行唐县：得雪三寸　赞皇县：得雪五寸　晋州：得雪七寸　藁城县：得雪一寸
无极县：得雪五寸　新乐县：得雪四寸
……

正月二十八日（18/3）奉朱批

Fig.2 Examples of Snow and Rainfall archives (snowfall list)

This snowfall record was reported by Liwei, the governor general of Zhili province (today refers to three parts: Beijing, Tianjin and Hebei Province) from the memos on the 28th, the first month in lunar calendar of the third year of Qianlong Emperor (AD. 1738), and the thickness of snowfall on the 14th, the first month in lunar calendar as it follows: Zhengding county: 7-cun; Jingxing county: 5-cun; Fulu county: 4-cun; Yuanshi county: 3-cun; Lingshou county: 3-cun; Luancheng county: 7-cun; Pingshan county: 4-cun; ……

Data Source -- Snow and Rainfall archives in the Qing Dynasty

年号 宣统二 年 公元 1910 年 7~8 月 山东 省 雨

(b)	资 料	摘 录
	包 52（3）	瑾
	军机处录副	

山东巡抚孙宝琦

通省二百零七州县除栖县未报外，六月分各属得雨日期寸数清单

济南府属

历城：七日（13/7）雨五寸，十八日（24/7）雨五寸，二十日（26/7）雨五寸

章邱：七日（13/7）雨一寸，十七日（23/7）雨一寸，十八日（24/7）雨五寸，二十二日 （28/7）雨一寸

邹平：七日（13/7）雨四寸，十七日（23/7）雨四寸，十八日（24/7）雨深透，二十二日（28/7）雨四寸

长山：七日（13/7）雨五寸，十八日（24/7）雨深透，二十日（26/7）雨二寸

……

八月十六日（9 月 19 日）

Fig.2 Examples of Snow and Rainfall archives (rainfall list)

This rainfall record was reported by Sun Baoqi, provincial governor of Shandong (today refers to Shandong Province) from the memos on the 16th, the eighth month in lunar calendar of the second year of Xuantong Emperor (AD. 1910), and the depth of rainfall infiltration in the sixth month in lunar calendar as it follows: Licheng county: 7-cun on Jul. 13, 5-cun on Jul. 24, 5-cun on Jul. 26; Zhangqiu county: 1-cun on Jul. 13, 1-cun on Jul. 23, 5-cun on Jul. 24, 1-cun on Jul. 28; ……

Data Source -- Snow and Rainfall archives in the Qing Dynasty

年号 同治十二 年 公元 1873 年 春～秋 月 直隶 省 雨、农

(c)

资 料	摘 录
包 36-39，9	丽
军机处录副	

直隶总督 李鸿章

本年直隶地方自春徂夏雨泽尚为调匀，二麦可称中稔。查各属二麦约收分数：……正定、顺德、大名、宣化、易州、赵州、定州等十一府州属约收六分余，……。自六月以后（23/7 以后）大雨时行……。夏秋之交雨水过多；秋后又晴，积潦渐涸，农民俱已乘时广种麦田。……

十月初一日（20/11）奏

Fig.2 Examples of Snow and Rainfall archives (describing expressions of rainfall)

This record expressed the following informations: from spring to summer, the rainfall is enough for wheat harvest. But after Jul. 23, it was raining for many days……. Which indicated overabundance rain at the turn of season from summer to autumn. In Oct. it was shiny, and the farmers took this opportunity to sow the seeds ……

Data Source -- Snow and Rainfall archives in the Qing Dynasty

So, from the examples, we can draw a conclusion that the qualitative describing and expressions are used to reconstruct precipitation only after quantified.

☞ Quantification method:

"*Shen Tou*" and "*Tou Zu*" (means the enough rainfall for a rain process) ≈7 cuns;

"*Yu Shui Tiao Yun*", "*Yu Yang Shi Ruo*"(means the normal snowfall for a certain period) ≈mean value;

"*Ji Wei Tou Zu/Shen Tou/You Wo*" (means the abundant rainfall or snowfall for a certain period) ≈150% of mean value;

"*Lian Qing Bu Yu*", "*Lian Ri Qing Ji*" and "*Wang Ze Shen Yin*" (means no rainfall process occurred in the period) ≈0.

Data Source -- Soil moisture content data

The soil moisture content observation data are derived from agro-meteorological stations.

- the place of observation is set in the farmland;
- the date of observation was happened on 8th, 18th and 28th of each month;
- the items of observation include: the apparent specific gravity, field capacity, wilting coefficient of the soil for different layers (0-5cm, 5-10cm，10-20cm，20-30cm，30-40cm，40-50cm).

Data Source -- Field infiltration experimental observation data by artificial simulation rainfall

Photo of experiment by artificial simulation rainfall

Data Source -- Field infiltration experimental observation data by artificial simulation rainfall

- Date: from May 30 to Jun. 16, 2002
- Place: Luancheng agricultural ecosystem experimental station
- Item: the apparent specific gravity;

  field capacity;

  soil moisture content before the rainfall and after for different layers (0-5cm, 5-10cm, 10-20cm, 20-30cm, 30-40cm, 40-50cm).

Methodology

- According to the different data source, precipitation reconstruction process includes 3 steps:
  - ✓ **At the period of 1736-1910**, using the Snow and Rainfall archives; it involves two aspects: rainfall and snowfall reconstruction.
  - ✓ **At the period of 1911-1950**, using instrumental observation data;
  - ✓ **At the period of 1951-2000** (above).

At the period of 1736-1910--rainfall reconstruction

We consider from the surface water balance theory, under the condition of taking no account of Evaporation, the equation can be expressed with:

$$P_r = F + R$$

P_r indicates rainfall, F indicates infiltration, R indicates runoff

At the period of 1736-1910--rainfall reconstruction

- in non-rainy season(from Oct. to May of next year), precipitation equals to the infiltration approximately;

$$P_r \approx F$$

- in rainy season (from Jun. To Sep.), there existed a relationship between the infiltration and rainfall, which can be expressed by equation

$$R = \alpha P_r ;$$

$$\alpha + \beta = 1; \Rightarrow P_r = F / \beta$$

$$P_r = F + R;$$

Where P_r is rainfall; F is infiltration capacity; β is infiltration coefficient; α is runoff coefficient; R is runoff

At the period of 1736-1910--rainfall reconstruction

The calculation of infiltration has been given by the equation (1951-2000):

$$F = (\theta_s - \theta_i) \times \rho \times Z_f$$

θ_s is the saturated moisture content, θ_i is the initial moisture content, ρ is the apparent specific gravity of the soil, Z_f is the depth of infiltration (namely *Yu Fen Cun*)

- **Presumption:** the soil physical parameters (θ_s ρ) is constant in the studied periods

At the period of 1736-1910--rainfall reconstruction

θ_s, θ_0 and ρ from agro-meteorological stations were listed below(table 2)

station	depth	ρ (g/cm^3)	θ_0 (%)	θ_s(%)	station	depth	ρ (g/cm^3)	θ_0 (%)	θ_s(%)
Shijiazhuang	0 ~ 20cm	1.32	21.0	32.0	Anyang	0 ~ 20cm	1.46	21.9	31.0
	20 ~ 50cm	1.61	21.0	32.0		20 ~ 50cm	1.49	19.9	30.0
Hejian	0 ~ 20cm	1.18	22.1	35.0	Yan'an	0 ~ 20cm	1.28	21.0	30.0
	20 ~ 50cm	1.20	27.6	40.0		20 ~ 50cm	1.33	19.0	30.0
Taiyuan	0 ~ 20cm	1.31	29.8	35.0	Xi'an	0 ~ 20cm	1.37	20.4	30.0
	20 ~ 50cm	1.39	30.0	35.0		20 ~ 50cm	1.52	22.6	31.0
Linfen	0 ~ 20cm	1.43	21.1	30.0	Ji'nan	0 ~ 20cm	1.45	22.4	32.0
	20 ~ 50cm	1.45	21.9	30.0		20 ~ 50cm	1.35	23.8	34.0
Changzhi	0 ~ 20cm	1.18	26.9	36.0	Taian	0 ~ 20cm	1.37	20.4	29.1
	20 ~ 50cm	1.37	26.3	36.0		20 ~ 50cm	1.52	22.6	32.3
Yuncheng	0 ~ 20cm	1.43	21.9	30.0	Heze	0 ~ 20cm	1.34	25.9	37.0
	20 ~ 50cm	1.48	20.3	29.0		20 ~ 50cm	1.56	23.5	33.6
Luoyang	0 ~ 20cm	1.36	22.0	37.0	Linyi	0 ~ 20cm	1.43	21.0	30.0
	20 ~ 50cm	1.49	21.8	37.0		20 ~ 50cm	1.43	24.0	34.3
Zhengzhou	0 ~ 20cm	1.32	22.4	30.0	Weifang	0 ~ 20cm	1.41	20.1	28.7
	20 ~ 50cm	1.62	19.9	29.0		20 ~ 50cm	1.45	19.8	28.3
Shangqiu	0 ~ 20cm	1.36	22.0	30.0					
	20 ~ 50cm	1.32	23.9	31.0					

At the period of 1736-1910--rainfall reconstruction

θ_i(initial moisture content)

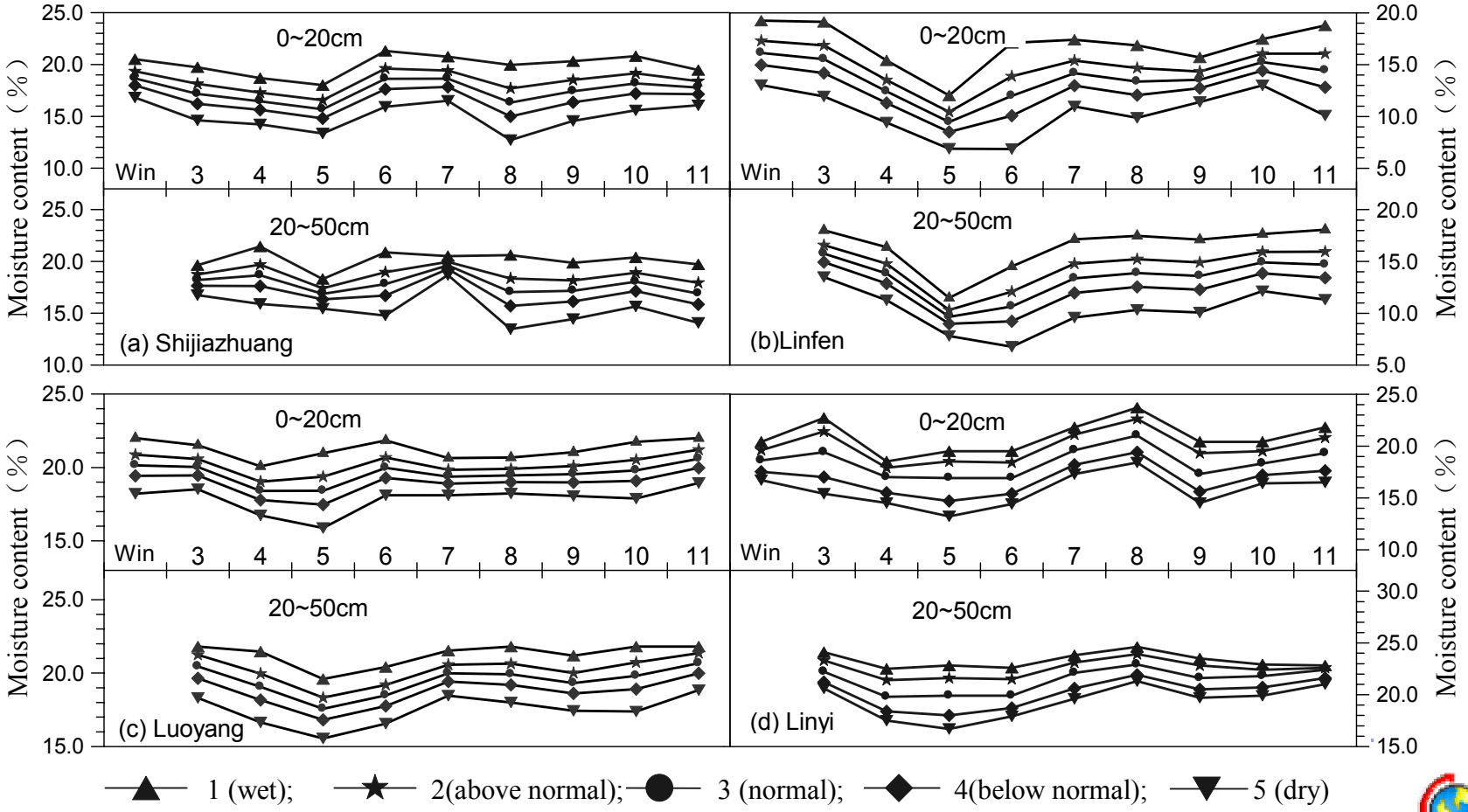


Fig. 3 Soil moisture content of 0-20cm and 20-50cm layer for the part of stations

At the period of 1736-1910--rainfall reconstruction

β can be obtained by the relationship of rainfall and intensity in rainy season

Tab. 4 Infiltration coefficients of the part of stations

Station	Mon.	P_r/mm. month	F/mm. month	β	P_r/mm. month	F /mm. month	β	P_r/mm. month	F /mm. month	β
Shijia zhuang	6, 9	≤ 70	≤ 59	1.0				>70	>59	0.84
	7	≤ 190	≤ 137	0.72				>190	>137	0.46
	8	≤ 110	≤ 80	0.72				>110	>80	0.46
Linfen	7	≤ 110	≤ 110	1.0	110~170	110~145	0.84	>170	>145	0.72
	8	≤ 100	≤ 100	1.0	100~160	100~135	0.84	>160	>135	0.72
Luo yang	7	≤ 130	≤ 130	1.0	130~200	130~170	0.84	>200	>170	0.72
	8	≤ 120	≤ 120	1.0	120~180	120~155	0.84	>180	>155	0.72
	9	≤ 90	≤ 90	1.0				>90	>90	0.84
Linyi	6, 9	≤ 50	≤ 50	1.0	50~130	50~100	0.84	>130	>100	0.72
	7	≤ 110	≤ 85	0.84	110~250	85~145	0.72	>250	>145	0.46
	8	≤ 100	≤ 80	0.84	100~190	80~110	0.72	>190	>110	0.46

At the period of 1736-1910--snowfall reconstruction

Xue Fen Cun corresponds to the thickness of snow in modern meteorological data, so we can convert them into snowfall directly, based on the relationship between snowfall and thickness of snow. The conversion equation is:

$$P_s = H_s \times \rho_s$$

Where P_s is snowfall; H_s is snow thickness of each snowfall, namely *Xue Fen Cun*; ρ_s is the snow density.

At the period of 1736-1910--snowfall reconstruction

The statistical analysis using observation data in 1951-2000 indicates there exists a good relationship between snowfall and thickness of snow, so ρ_s *can be calculated*

Tab.5 Snow density at the part of stations

Station	Taiyuan	Shijia zhuang	Linfen	Anyang	Xi'an	Yan'an	Ji'nan	Zhengzhou	Heze
Sample size	18	22	21	14	44	30	16	20	9
Coefficient	0.8411	0.8341	0.9084	0.8688	0.7886	0.8937	0.7886	0.8229	0.9048
Snow density(g/cm^3)	0.0704	0.0757	0.0790	0.0814	0.0834	0.0838	0.0926	0.0962	0.1204

passed 1% significance level

Note: the snow density of stations without data is replaced by that of the next station

At the period of 1736-1910-- precipitation reconstruction

If we stat monthly precipitation combining with the two parts (rainfall and snowfall), the seasonal and annual (from Mar. of this year to Feb. of the next year) precipitation can be reconstructed.

At the period of 1736-1910-- precipitation reconstruction

- Interpolation

Because records of Xu Xue Fen Cun were missing by discontinuous for 15 years (such as 1751), the drought/flood index (such as *Yearly Charts of Dryness/Wetness in China for the Last 500-year Period)* is used to be interpolated.

Reliability verification for the reconstructed results

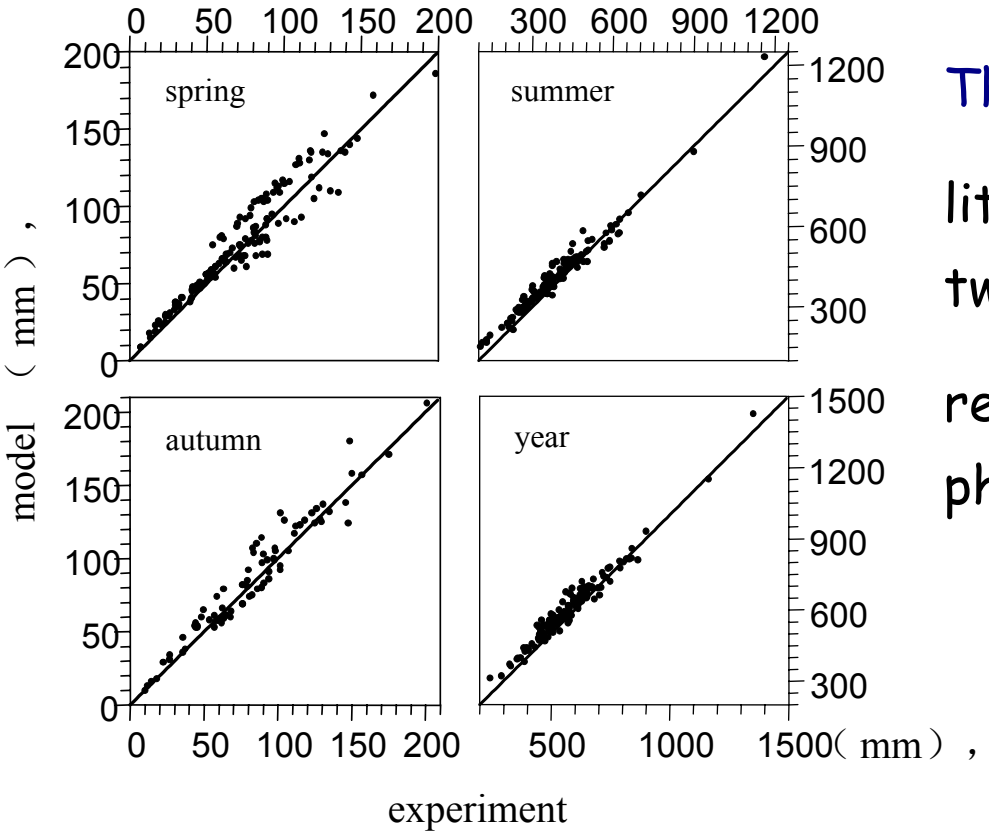
In order to validate the series reliability, a field experiment has been done for testing in Shijiazhuang station.

The relationship between rainfall and depth of infiltration using the experimental data can be expressed:

$$P_r = 0.0002\ Z_f^2 + 0.1298\ Z_f$$

Where P_r indicates artificial rainfall, Z_f indicates the depth of infiltration, (N=41, R=0.9325, R^2=87%).

Reliability verification for the reconstructed results



The figure shows that:

little difference between the two methods;

reconstruction method of physical model is reliable.

Fig.4 Seasonal and yearly precipitation contrasting with two method of physical model and field experiment in Shijiazhuang

At the period of 1911-1950

At the period of 1911-1950, only 11 stations have the instrumental observation data, the reconstructed method is as it follows:

✓ firstly, the study area is classified into 4 regions, the relationship for annual mean precipitation between the stations which has observation data at the period of 1911-1950 and regional average is established using the data in 1951-2000;

✓ then, based on the relationship above, the annual mean precipitation series of 4 regions is established in 1911-1950.

At the period of 1951-2000

The instrumental observation data from 1951 to 2000 is combined with the reconstructed precipitation in historical times, and the precipitation continuous series for the last 300 years can be established over the Middle and Lower Reaches of the Yellow River.

Significance test have been done with level of 99% for all stations.

precipitation series

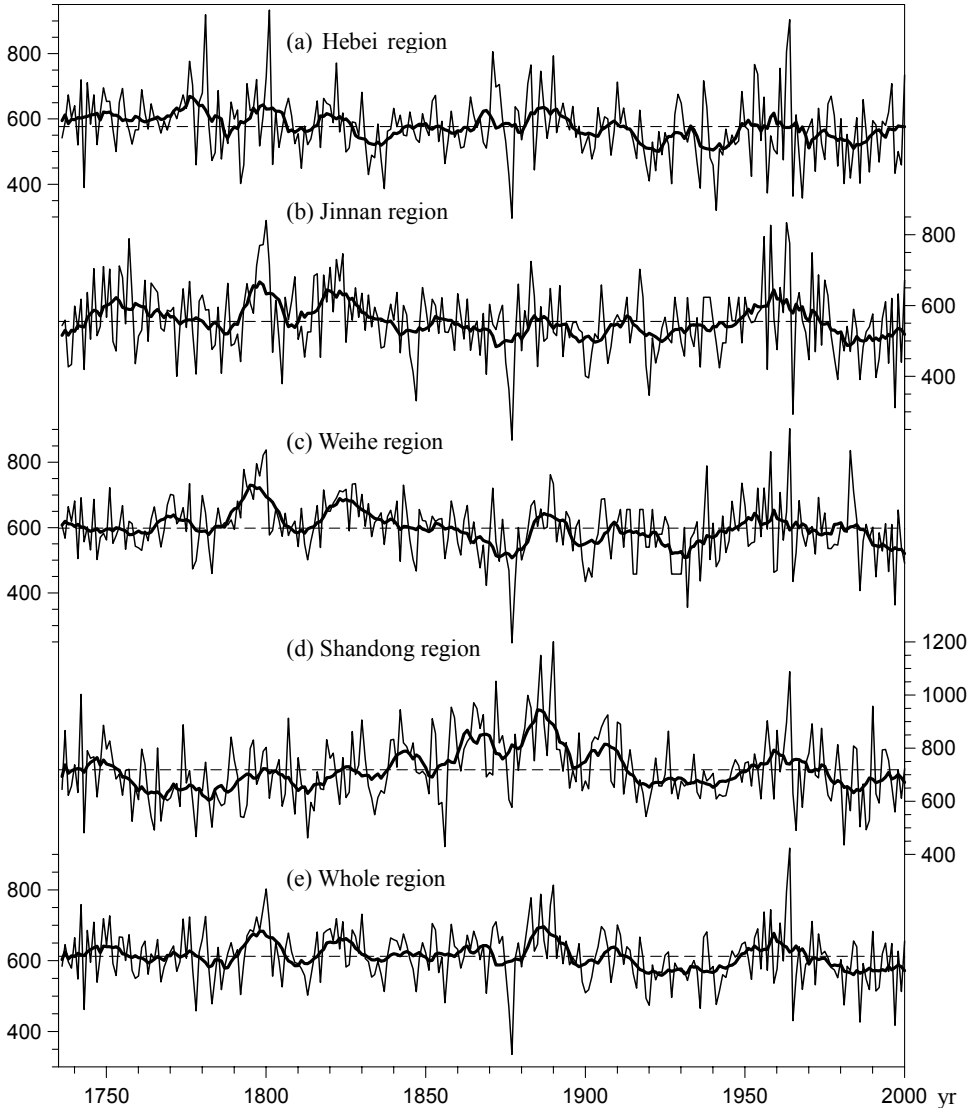


Fig.5 Annual precipitation series of the Middle and Lower Reaches of the Yellow River and its 4 sub-regions


ThankYou

Study Region

Return

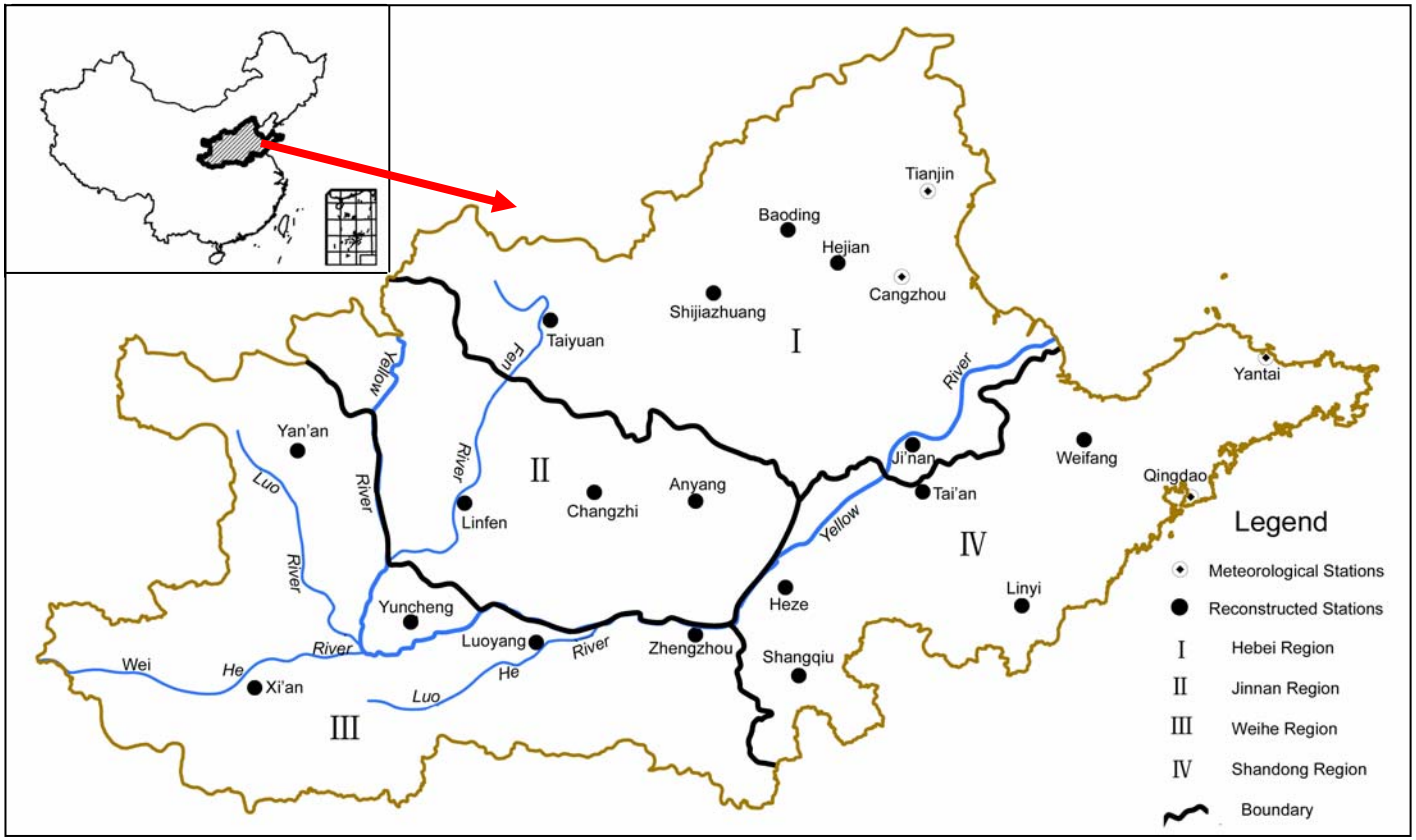


Fig.1 The spatial subarea distribution by the precipitation patterns over the Middle and Lower Reaches of the Yellow River