Spatio-temporal evolutions of precipitation in the Yellow River basin of China from 1981 to 2013

Lei Wu, Xia Liu and Xiaoyi Ma

ABSTRACT

The partial thin plate smoothing splines method was applied to evaluate spatiotemporal trends of precipitation in the Yellow River basin from 1981 to 2013 by considering the basin's digital elevation model. Results indicate the following. (1) The spline method can greatly improve the spatial interpolation accuracy of meteorological data and can be applied to spatial modeling of meteorological elements for large regions with complex terrain. (2) Overall, annual precipitation in the Yellow River basin shows a decreasing trend from east to west, with the isohyet equipluve distribution of 400 mm being basically consistent with the dividing line between semi-humid and semi-arid regions in China. Sichuan has the highest annual average precipitation while Neimeng has the lowest; Shandong and Henan both have relatively significant changes of annual precipitation while Gansu and Qinghai have small changes. (3) The average monthly precipitation of the basin from 1981 to 2013 presents an overall increasing trend from north to south; the annual precipitation in each province was mainly concentrated in 7–9 months of the whole year. The highest monthly average precipitation in most provinces occurred in July, while the highest at Ningxia occurred in August. Results may provide a scientific basis for understanding future precipitation changes and improving our ability to cope with climate change.

Key words | partial thin plate smoothing splines, precipitation, spatial interpolation, spatio-temporal trend, Yellow River basin

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INTRODUCTION

Global climate change leads to changes of precipitation patterns, and precipitation is an important aspect of the study of climate change (Chen *et al.* 2011). The change of precipitation is closely related to ecological environment security (Ding *et al.* 2006), and it has a profound impact on water resources, agriculture and ecological systems (Ju *et al.* 2013; Yao *et al.* 2013). The Yellow River, located in the northern part of China, is an important source of water in North and Northwest China (Zhao *et al.* 2011). The Yellow River basin is an important grain production area, but water is scarce in this region. It contains 15% of China's cultivated land and 12% of China's population, reliant on 2% of runoff in China (Wang *et al.* 2013; Yan *et al.* 2015). So the basin's serious water shortage affects the development of industrial and agricultural production and urbanization.

Precipitation in the Yellow River basin is the fundamental source of water resources. Due to effects of atmospheric and monsoon circulations, precipitation varies significantly between various regions of the basin (Li *et al.* 2013). The seasonal distribution of precipitation is extremely uneven in the Yellow River basin due to changes of monsoon circulation intensity. The specific pattern of dry winter, drought-affected spring, rainy summer and rainy autumn has important effects on the agricultural production of the basin (Xu & Zhang 2006; Zhao *et al.* 2015). Based on observations of rainfalls over the last 50 years, the annual precipitation in the

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Yellow River basin shows a downward trend (Xu & Zhang 2006). The change of the extreme precipitation index is not obvious, but there are temporal and spatial differences (Zhao *et al.* 2015). Li *et al.* (2002) investigated spatiotemporal variations of summer precipitation over eastern China during 1880–1999. Zhang *et al.* (2015) evaluated temporal and spatial distributions of precipitation and air temperature in Shaanxi using average monthly climate data released by CRU (Climate Research Unit of the University of East Anglia). Cui *et al.* (2015) analyzed the distribution characteristics of temperature and precipitation in different seasons of China using the SVD (Singular Value Decomposition) method. Based on the summer monthly precipitation data of 310 stations from 1960 to 2012 in eight regions of China, Yin & Yin (2015) analyzed spatial and temporal distribution characteristics of summer precipitation by trend features index, Mann-Kendall mutation testing and spatial interpolation. In general, the spatial interpolation of meteorological information is an effective method to allow for the uneven distribution of the meteorological stations (Hutchinson 1998; Peng 2010; Bai *et al.* 2011; Wang 2014). Local fitting methods are commonly used in spatial data interpolation, such as the Thiessen polygon method, the polynomial interpolation method, the inverse distance weighted method, the spline function method, the Kriging method and so on (Hutchinson & Gessler 1994; Peter & Chris 1998; Lin *et al.* 2002; Liu *et al.* 2008; Cai *et al.* 2009; Kong & Xiang 2012; Hu & Shu 2014). Of all these methods, the Thiessen polygon method is suitable for intensive site areas; it demands basically identical terrain, and does not account for impacts of elevation (Wang & Chen 2003), The inverse distance weighted method adjusts spatial interpolation contour structure by changing weights, but this method does not consider the influence of topographical factors on rainfall (He *et al.* 2005). The spline function method, the global polynomial interpolation method and the local polynomial interpolation method all overcome shortcomings of the previous statistical models, which can improve the accuracy of spatial simulation (Zhao & Yang 2012). The Kriging method, based on statistical interpolation techniques using the semi variance function to reflect spatial correlation of interpolation objects, is considered to be the best spatial data interpolation method (Li *et al.* 2006). The thin plate smoothing spine method is a kind of spline function method (Wan *et al.* 2011), which gives attention to both the smoothness and precision of the interpolation surface (Liu *et al.* 2006). Hijmans *et al.* (2005) consider it to be the most suitable interpolation method for climate data.

Therefore, the partial thin plate smoothing splines method was applied to study spatial and temporal distribution characteristics of precipitation in the Yellow River basin from 1981 to 2013. By considering the digital elevation model, the results may help us to better understand the evolution of water resources, and assist in the scientific management of water resources, and the early warning of flood disasters.

MATERIAL AND METHODS

Study area

The Yellow River is the second longest river in China, and is also one of the great rivers of the world. The source of the Yellow River is Bayankala mountain in Qinghai Province; it flows through nine provinces, including Qinghai, Sichuan, Gansu, Ningxia, Inner Mongolia, Shaanxi, Shanxi, Henan and Shandong, and finally flows into the Bohai Sea in Kenli County of Shandong province. It has a total length of 5,464 kilometers (Figure 1(a)).

The Yellow River basin is located between 96°–119°E and 32°–42°N. Its length from east to west is 1,900 km, the width from north to south is 1,100 km, and the basin area is 7,52,443 km^2 (Figure 1(b)). The multi-year average runoff is 58 billion m^3, and the average annual runoff depth is 77 mm. The underlying surface types of the basin are complex, and the differences of the terrain and landforms are relatively large. The climate of the basin is broadly divided into three climate zones: arid, semi-arid and semi humid; on the whole, the west is arid and the east is humid. In this study, the precipitation data of 121 meteorological stations were used to study the spatiotemporal evolution of precipitation in the Yellow River basin (Figure 2(a)). The annual mean temperature in the basin is about −4–14 °C, and the mean annual precipitation is about 466 mm (Figure 2(b)). The precipitation over 6–10 months accounts for 65–85%

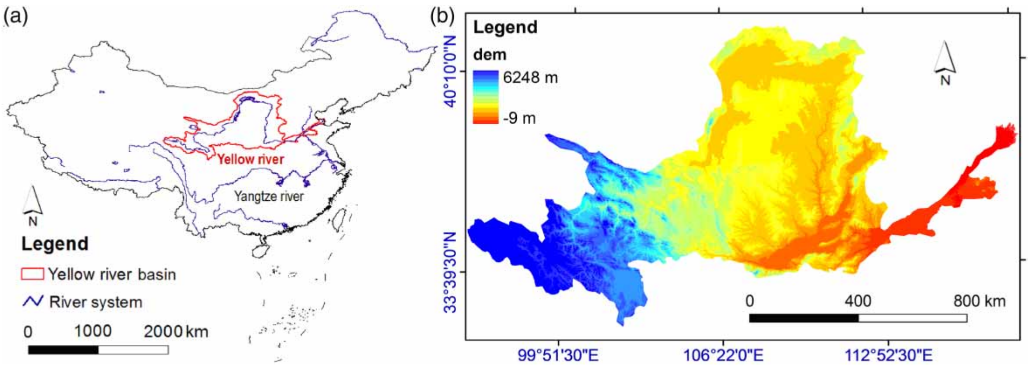

Figure 1 | The study area: (a) the relative location between the Yellow River basin and China; (b) longitude and latitude coordinates and digital elevation model (DEM) data of the Yellow River basin.

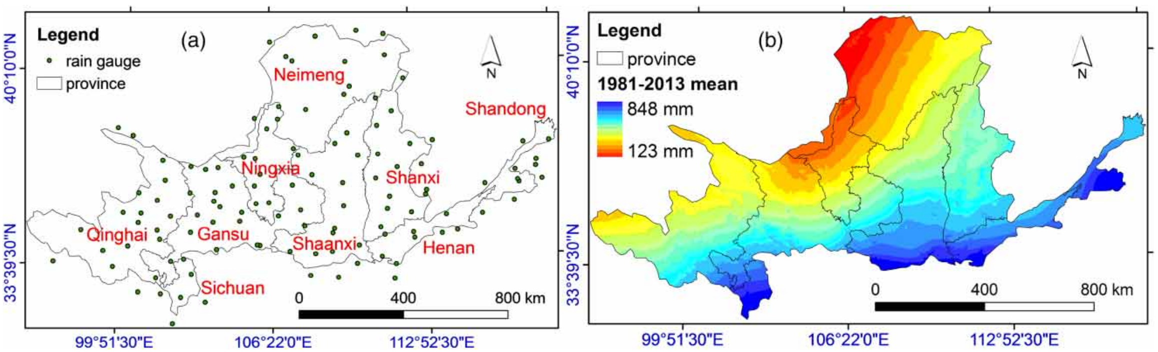

Figure 2 | (a) Provincial administrative divisions and rain gauge distribution of the Yellow River basin; (b) spatial distribution of annual average precipitation from 1981 to 2013 in the Yellow River basin.

of the annual precipitation, and the maximum rainstorm mainly occurs in 7–8 months.

Methodology

The partial thin plate smoothing splines method is an extension of thin plate smoothing splines; it introduces a linear covariant model in addition to ordinary spline independent variables, such as the correlation between precipitation and elevation (Liu *et al.* 2006, 2008). In this study, the ANUSPLIN meteorological interpolation model based on the partial thin plate smoothing splines method (Hutchinson 2006) was used to spatially interpolate long time series of precipitation in the Yellow River basin with complex terrain. In this application, latitude and longitude were used as the independent variables, and elevation was taken as the covariate. The optimal solution of the spline number was determined as three. The theoretical statistical model of partial thin plate smoothing splines (Liu *et al.* 2012) is expressed as

$$z_i = f(x_i) + b^T y_i + e_i \quad (i = 1, \cdots, n) \tag{1}$$

where each x_i is *a d*-dimensional vector of spline independent variables, f is an unknown smooth function of x_i, each y_i is a p-dimensional vector of independent covariates, b is an unknown p-dimensional vector of coefficients of the y_i, and each e_i is an independent, zero mean error term with variance $w_i\sigma^2$, where w_i is termed the relative error variance (known), σ_i is the error variance. The model reduces, on the one hand, to an ordinary thin plate spline model when there are no covariates ($p = 0$) and to a simple multivariate linear regression model when $f(x_i)$ is absent.

The function f and the coefficient vector b are determined by minimizing

$$\sum_{i=1}^{n}\left(\frac{z_i - f(x_i) - b^T y_i}{w_i}\right)^2 + \rho J_m(f) \quad (2)$$

where $J_m(f)$ is a measure of the complexity of f, the 'roughness penalty' defined in terms of an integral of mth order partial derivatives of f, and ρ is a positive number called the smoothing parameter. As ρ approaches zero, the fitted function approaches an exact interpolant. As ρ approaches infinity, the function f approaches a least squares polynomial, with order depending on the order m of the roughness penalty. The value of the smoothing parameter is normally determined by minimizing a measure of predictive error of the fitted surface given by generalized cross validation.

RESULTS AND DISCUSSION

Spatiotemporal characteristics and statistical analysis of annual precipitation

Figure 3 shows the spatial distribution of annual precipitation in the Yellow River basin from 1981 to 2013. It can be seen that the annual precipitation in the Yellow River basin has obvious regional *differences*. The distribution overall shows a significant decreasing trend from the southeast to the northwest. The climate also changes from the semi-humid climate in the southeast to the semi-arid and arid climate of the northwest. The precipitation in the northwest of the basin (in Inner Mongolia and Ningxia) is less than that of the other regions, and the precipitation in the southern regions of Shaanxi, Sichuan, Henan, and Shandong is more than that of the remaining two provinces. The isohyet equipluve distribution of 400 mm is basically consistent with the dividing line between semi-humid and semi-arid regions in China. Annual precipitation changes from 1981 to 2013 show that the annual precipitation in the northern part of Gansu province is decreasing. The annual variations of precipitation in local areas within the basin are obvious, where most areas of Shanxi province and the middle area of Shaanxi province showed the most significant variations.

Figure 4 displays changing trends of annual precipitation and multi-year average precipitation in each province of the Yellow River basin. Figure 4(a) shows annual precipitation and multi-year average precipitation in each province. It can be seen that the difference of precipitation in each province is obvious. The average annual precipitation in Sichuan province is the highest, with an average annual precipitation of 696 mm, and then Shandong province, with a precipitation amount of 661 mm. This is followed by Henan, Shaanxi, Shanxi, Gansu and Qinghai. The precipitation in Ningxia is 300 mm, and Inner Mongolia has the lowest precipitation of 271 mm. Figure 4(b) shows annual minimum precipitation and multi-year average minimum precipitation in each province. The multi-year average minimum precipitation over 500 mm occurs in Sichuan, Shandong and Henan. The multi-year average precipitation and the multi-year average minimum precipitation in Gansu have the biggest difference, between 457 mm and 220 mm. Figure 4(c) shows annual maximum precipitation and multi-year average maximum precipitation in each province. Eight provinces have annual average maximum precipitation over 500 mm, with Shaanxi having the highest precipitation amount of 848 mm, followed by Sichuan, Henan and Shandong. Inner Mongolia has the lowest precipitation amount of 431 mm. As far as each province is concerned, there is a significant change in annual precipitation, particularly in Shandong and Henan provinces. The annual precipitation amounts of Shandong province in 1990 and 2005 were 979 mm and 556 mm, respectively, decreasing by 43.2%. The annual precipitation amounts of Henan province in 1981 and 2005 were 797 mm and 485 mm, respectively, decreasing by 39.2%. The annual precipitation changes of Gansu province and Qinghai province are relatively small.

In summary, the water resources system is very sensitive to climate change in the arid and semi-arid area of the Yellow River basin, and the precipitation in the Yellow River basin has changed significantly in recent decades. In the 1990s, the precipitation in the Yellow River basin decreased significantly, and then increased slightly in the 21st century.

Spatiotemporal characteristics and statistical analysis of monthly precipitation

Figure 5 shows spatial distributions of multi-year average monthly precipitation from 1981 to 2013. It can be

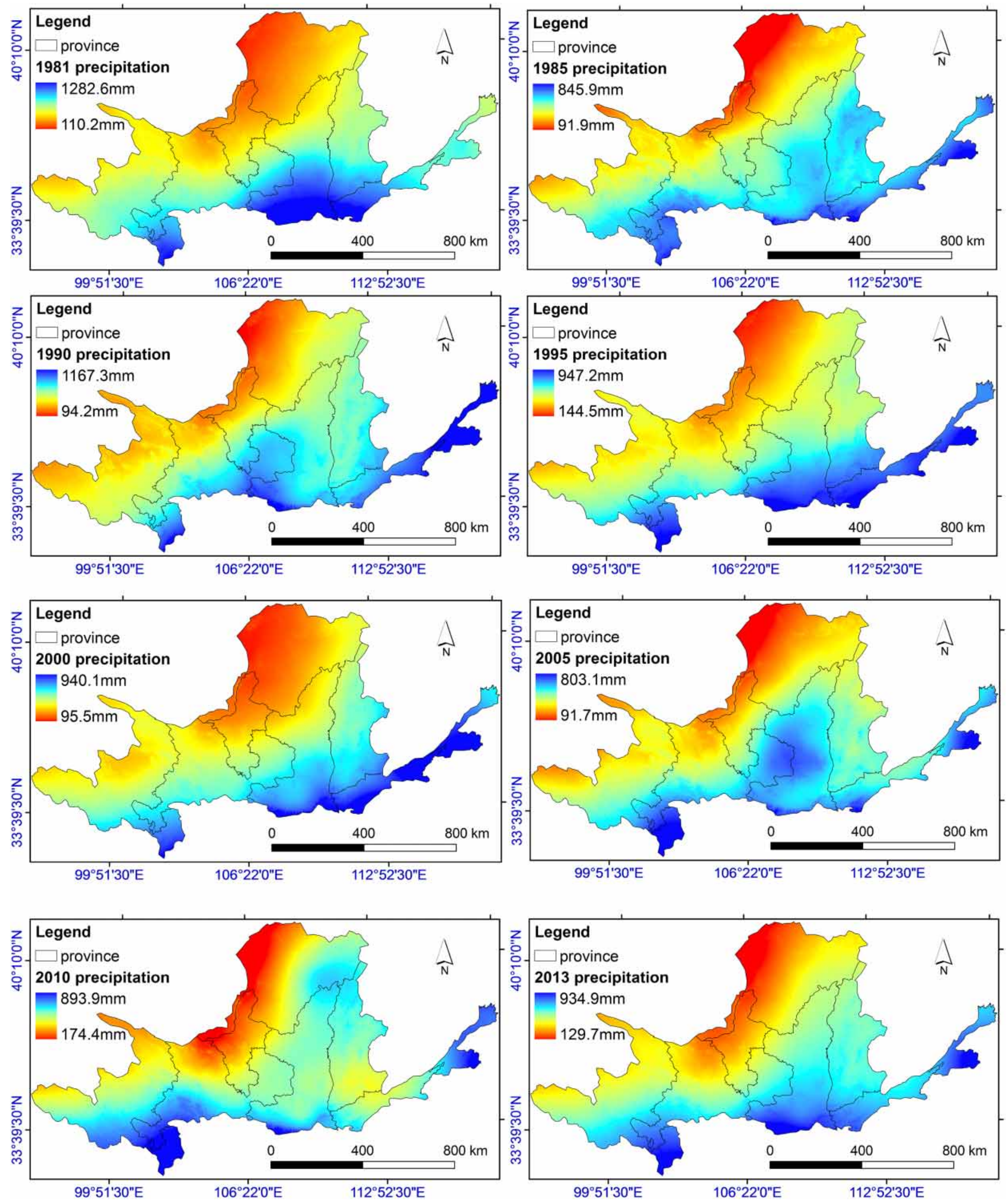

Figure 3 | Spatial distributions of annual precipitation in the Yellow River basin from 1981 to 2013.

seen that precipitation values from January to December have large spatial variations. Most of the remaining regions have less rainfall, and some local areas have precious little precipitation. The specific distribution area of precipitation concentration is shown in Table 1.

Figure 6 displays changing trends of multi-year average monthly precipitation, multi-year average monthly minimum precipitation, and multi-year average monthly maximum precipitation in each province of the Yellow River basin. As far as each province is concerned, the multi-year average monthly precipitations in each province

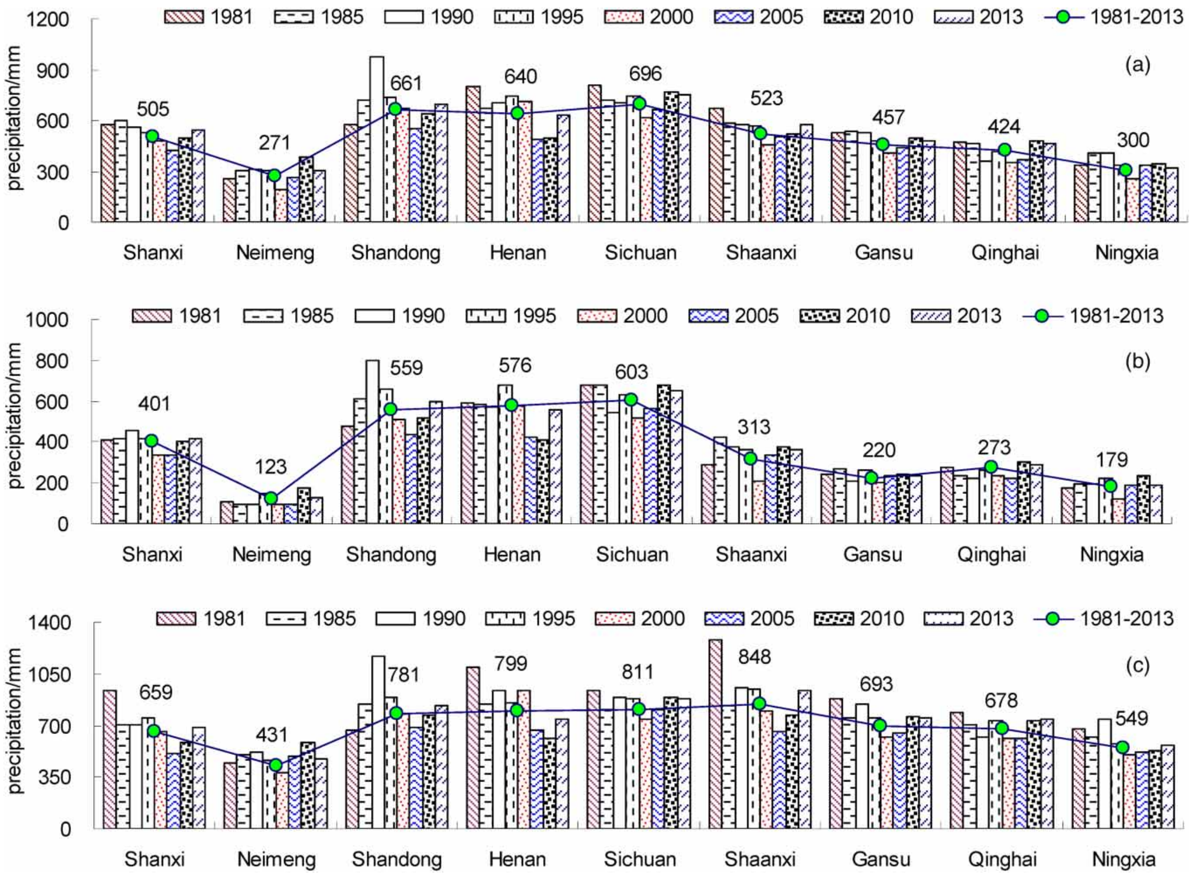

Figure 4 | Statistical analysis of annual precipitation in the Yellow River basin: (a) annual precipitation and multi-year average precipitation in each province; (b) annual minimum precipitation and multi-year average minimum precipitation in each province; (c) annual maximum precipitation and multi-year average maximum precipitation in each province.

are mainly distributed over 7–9 months, which most obviously occurred in Shanxi, Inner Mongolia, Shandong, Henan, Shaanxi, Gansu and Ningxia. The precipitation values in Qinghai and Sichuan are more concentrated over 5–10 months. As far as the monthly precipitation is concerned, the precipitation from July to September in Shandong province accounted for 65.8% of the annual precipitation, the precipitation from July to September in Henan province accounted for 62.2% of the annual precipitation, while the highest monthly average precipitation of all occurred in July, and the highest in Ningxia occurred in August. The changing trends of multi-year average monthly precipitation in each province are basically the same as for the multi-year average monthly minimum or maximum precipitation. Inner Mongolia has the lowest multi-year average monthly precipitation. The precipitation distribution of Sichuan province is relatively uniform; the difference of precipitation distribution in Shandong province is the most significant from January and December.

CONCLUSIONS

1. Based on the thin plate smoothing spline function, this study introduced the linear sub model to establish the partial thin plate smoothing splines method, which allows multiple independent variables and independent covariant variables to be used in the spatial interpolation of meteorological elements, and the model coefficients can be automatically determined according to the data. It can greatly improve the accuracy of spatial interpolation of meteorological factors. At the same time, the model can handle samples of more than two dimensions, so the method may provide a means of transparent

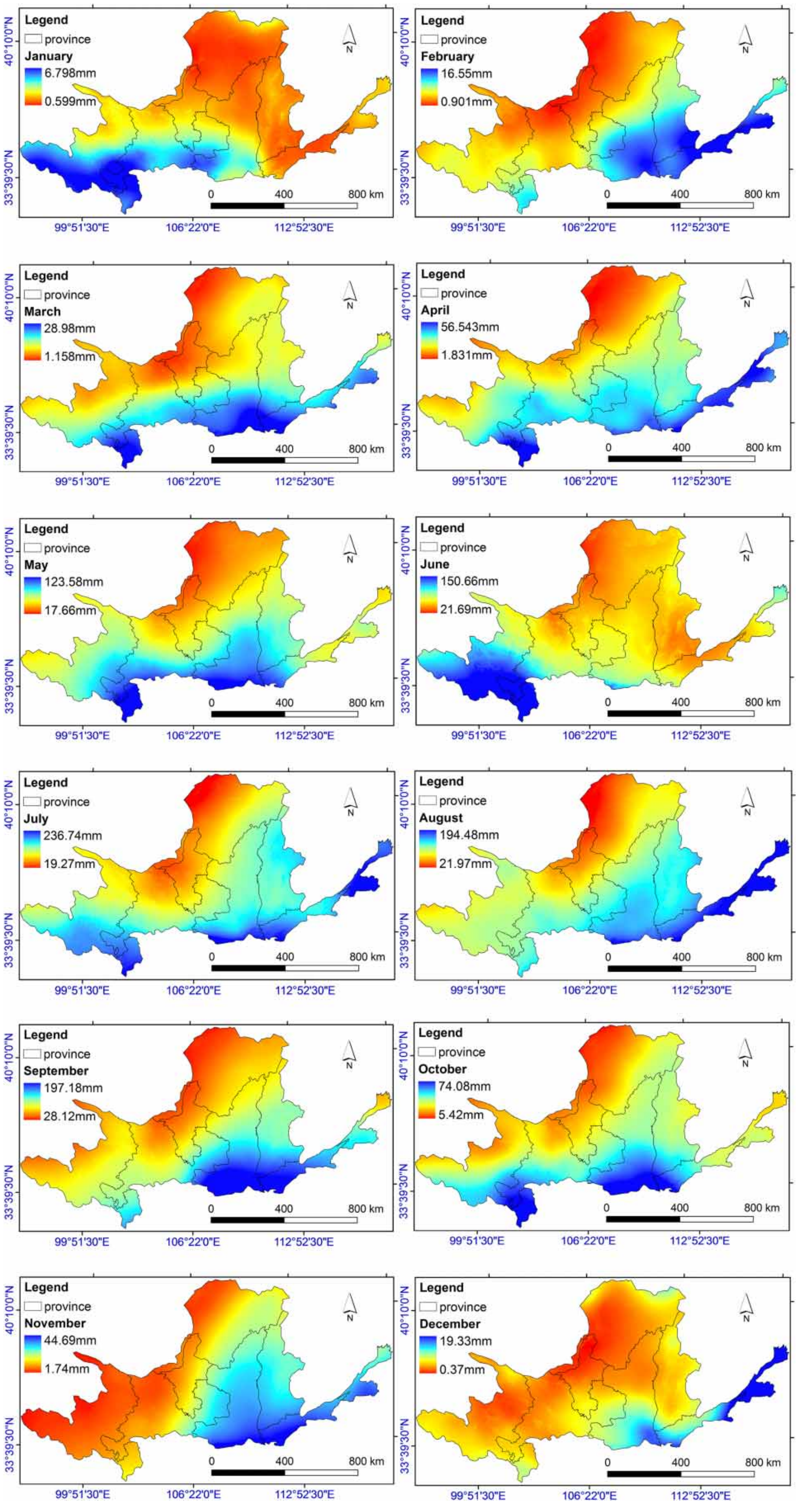

Figure 5 | Spatial distributions of monthly average precipitation in the Yellow River basin from 1981 to 2013.

Table 1 | Regional distribution of monthly rainfall concentration in Yellow River basin

Month	Regional distribution of precipitation concentration
January	Southwest area of the Yellow River basin (southern part of Qinghai, Sichuan)
February	Southeastern region of the Yellow River basin (southern part of Shanxi and Shaanxi, Henan, western area of Shandong)
March	Southern part of the basin (Sichuan, southern part of Shanxi, Henan)
April	Southeastern part of the basin and Sichuan (Shandong, Sichuan)
May	Southern region of the basin (Sichuan, southern part of Gansu and Shaanxi, southwestern part of Henan)
June	Southwest region of the basin (southern part of Qinghai, Sichuan, southwestern part of Gansu)
July	Southern part of Shaanxi, Sichuan, southwestern part of Henan, Shandong
August	Southern part of Shaanxi, Henan and Shandong
September	Southern part of Shaanxi and Shanxi, Henan
October	Southern part of Shaanxi and Sichuan
November	Southern part of Shaanxi and Henan
December	Southwestern part of Shaanxi, eastern part of Shandong

analysis and interpolation of noisy multi-variate data, and can be applied to the spatial interpolation of meteorological data for large areas with complex terrain.

2. The annual precipitation distribution in the Yellow River basin overall presents a decreasing trend from east to west; the isohyet equipluve distribution of 400 mm is obvious for the whole basin and basically consistent with the dividing line between semi-humid and semi-arid regions in China. Sichuan has the highest annual average precipitation of 696 mm, while Inner Mongolia has the lowest precipitation of 271 mm. The multi-year average minimum precipitation in Sichuan, Shandong and Henan is more than 500 mm. An annual average maximum precipitation over 500 mm occurs in eight provinces. Shaanxi has the highest precipitation of 848 mm, while Inner Mongolia has the lowest precipitation of 431 mm. Shandong and Henan provinces both have relatively significant inter-annual changes of precipitation in 1990 and 2005, with decreases of 43.2% and 39.2%, respectively.
3. The spatial distributions of multi-year average monthly precipitation from 1981 to 2013 show great changes.

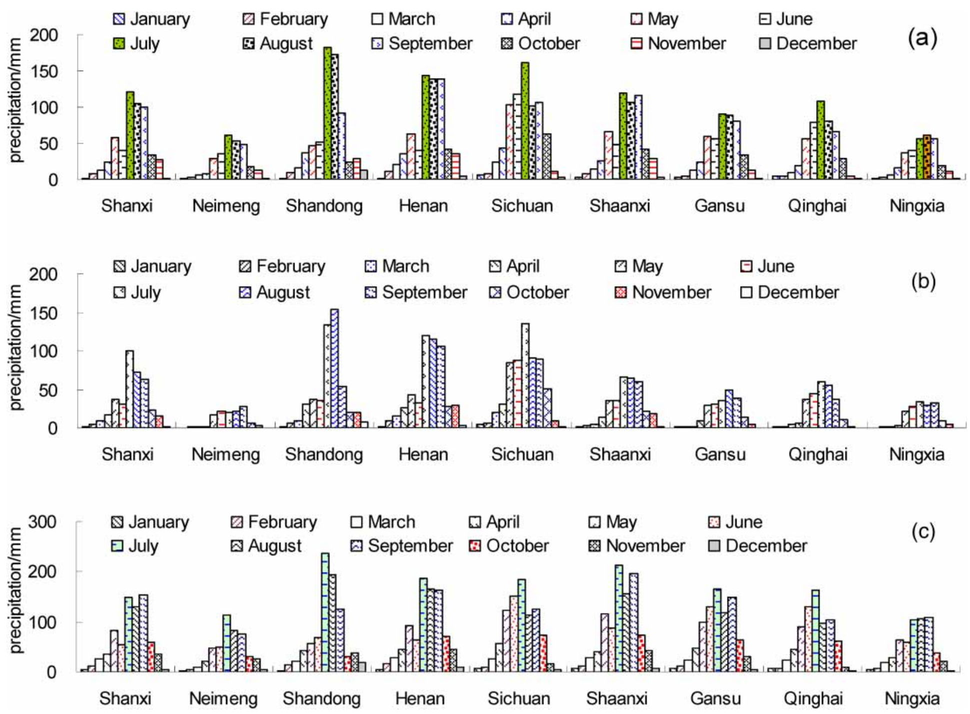

Figure 6 | Statistical analysis of monthly precipitation in the Yellow River basin: (a) multi-year monthly average precipitation in each province; (b) multi-year monthly average minimum precipitation in each province; (c) multi-year monthly average maximum precipitation in each province.

On the whole, precipitation is generally higher in the south than in the north. The multi-year average monthly precipitation in each province is mainly distributed over 7–9 months. The precipitation from July to September in Shandong and Henan provinces accounted for 65.8% and 62.2% of annual precipitation, respectively. The highest monthly average precipitation occurred in July in all provinces, except for Ningxia, which had its highest rainfall in August. The changing trends of multi-year average monthly precipitation in each province are basically the same as the trends for multi-year average monthly minimum and maximum precipitation.

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REFERENCES

Bai, J. T., Bai, J. J., Wang, L. & Xue, Z. B. 2011 Analysis on spatial interpolation of precipitation in Guanzhong-South Shaanxi based on GIS. *Journal of Anhui Agricultural Science* **39** (33), 20872–20876, 20895.

Cai, D. H., Guo, N. & Li, C. W. 2009 Interpolation of air temperature based on DEM over eastern region of Gansu. *Journal of Arid Meteorology* **27** (1), 10–17, 28.

Chen, F. H., Huang, W., Jin, L. Y., Chen, J. W. & Wang, J. S. 2011 Spatiotemporal precipitation variations in the arid Central Asia in the context of global warming. *Science China Earth Science* **41** (11), 1647–1657.

Cui, Y. P., Wei, H. N., Zhang, K. R., Yang, L., Xiao, B. H. & Ding, W. 2015 Analysis on relationship between precipitation and temperature variation in China from 1961 to 2000. *Modern Agricultural Science and Technology* (5), 239–242.

Ding, Y. H., Ren, G. Y., Shi, G. Y., Zheng, X. H., Zhai, P. M., Zhang, D. E., Zhao, Z. C., Wang, S. W., Wang, H. J., Luo, Y., Chen, L., Gao, X. J. & Dai, X. S. 2006 National assessment report of climate change (I): climate change in China and its future trend. *Advances in Climate Change Research* **2** (1), 3–8.

He, H. Y., Guo, Z. H. & Xiao, W. F. 2005 Review on spatial interpolation techniques of rainfall. *Chinese Journal of Ecology* **24** (10), 1187–1191.

Hijmans, R. J., Cameron, S. E., Parra, J. L., Jones, P. G. & Jarvis, A. 2005 Very high resolution interpolated climate surfaces for global land areas. *International Journal of Climatology* **25**, 1965–1978.

Hu, D. G. & Shu, H. 2014 Air humidity based on CoKriging interpolation. *Hubei Agricultural Sciences* **53** (9), 2045–2049.

Hutchinson, M. F. 1998 Interpolation of precipitation data with thin plate smoothing splines-part 1: two dimensional smoothing of data with short range correlation. *Journal of Geographic Information and Decision Analysis* **2** (2), 139–151.

Hutchinson, M. F. 2006 *ANUSPLIN Version 4.36: User Guide*. Publications Section: Centre for Resource and Environmental Studies, Australian National University, Canberra ACT 0200.

Hutchinson, M. F. & Gessler, P. E. 1994 Splines-more than just a smooth interpolator. *Geoderma* **62** (1–3), 45–67.

Ju, H., Velde, M. V. D., Lin, E., Xiong, W. & Li, Y. 2013 The impacts of climate change on agricultural production systems in China. *Climate Change* **120** (1–2), 313–324.

Kong, L. N. & Xiang, N. P. 2012 Research on precipitation spatial interpolation methods based on ArcGIS. *Geomatics & Spatial Information Technology* **35** (3), 123–126.

Li, X. D., Zhu, Y. F. & Qian, W. H. 2002 Spatiotemporal variations of summer precipitation over eastern China during 1880–1999. *Advances in Atmospheric Sciences* **19** (6), 1055–1068.

Li, J. L., Zhang, J., Zhang, C. & Chen, Q. G. 2006 Analyze and compare the spatial interpolation methods for climate factor. *Pratacultural Science* **23** (8), 6–11.

Li, B. F., Chen, Y. N., Shi, X., Chen, Z. S. & Li, W. H. 2013 Temperature and precipitation changes in different environments in the arid region of northwest China. *Theoretical and Applied Climatology* **112** (3–4), 589–596.

Lin, Z. H., Mo, X. G., Li, H. X. & Li, H. B. 2002 Comparison of three spatial interpolation methods for climate variables in China. *Acta Geographica Sinica* **57** (1), 47–56.

Liu, Z. H., McVicar, T. R., Li, L. T., Van Niel, T. G., Yang, Q. K., Li, R. & Mu, X. M. 2006 Modeling spatial distribution of pan evaporation based on quinat-variate thin plate spline function. *Science of Soil and Water Conservation* **4** (6), 23–30.

Liu, Z. H., McVicar, T. R., Li, L. T., Van Niel, T. G., Yang, Q. K., Li, R. & Mu, X. M. 2008 Interpolation for time series of meteorological variables using ANUSPLIN. *Journal of Northwest A&F University (Nat. Sci. Ed.)* **36** (10), 227–234.

Liu, Z. J., Yu, X. X., Wang, S. S. & Shang, G. D. 2012 Comparative analysis of three covariates methods in thin-plate smoothing splines for interpolating precipitation. *Progress in Geography* **31** (1), 56–62.

Peng, S. L. 2010 *Developments of Spatio-temporal Interpolation Methods for Meteorological Elements*. Master Degree Thesis, Central South University, Changsha.

Peter, M. & Chris, D. 1998 Mapping precipitation in Switzerland with ordinary and indicator Kriging. *Journal of Geographic Information and Decision Analysis* **2** (2), 65–76.

Wan, L., Ma, Q., Zhang, J. J., Fu, Y. L. & Zhang, X. P. 2011 Precise comparison of spatial interpolation for precipitation using KRIGING and TPS (Thin plate smoothing spline) methods in Loess Plateau. *Science of Soil and Water Conservation* **9** (3), 79–87.

Wang, L. N. 2014 *Algorithm Research and Application of Meteorological Spatial Interpolation*. Master's Dissertation, Chongqing University of Technology, Chongqing.

Wang, S. Y. & Chen, S. Y. 2003 Iterative optimal arithmetic of weighted average and its application. *Journal of Hydraulic Engineering* **35** (12), 1–7.

Wang, H. J., Chen, Y. N. & Chen, Z. S. 2013 Spatial distribution and temporal trends of mean precipitation and extremes in the arid region, northwest of China, during 1960–2010. *Hydrological Processes* **27** (12), 1807–1818.

Xu, Z. X. & Zhang, N. 2006 Long-term trend of precipitation in the Yellow River basin during the past 50 years. *Geographical Research* **25** (1), 27–34.

Yan, H. T., Wang, F., He, Y. & Mu, X. M. 2015 Impact assessment of human activities on runoff and sediment between paired years with similar weather condition in the source of the Yellow River. *Journal of Sediment Research* (2), 40–46.

Yao, J. Q., Yang, Q., Chen, Y. N., Hu, W. F., Liu, Z. H. & Zhao, L. 2013 Climate change in arid areas of Northwest China in past 50 years and its effects on the local ecological environment. *Chinese Journal of Ecology* **32** (5), 1283–1291.

Yin, F. Y. & Yin, S. Y. 2015 The spatial and temporal distribution characteristics of summer precipitation in China from 1960 to 2012. *Journal of Shaanxi Normal University (Natural Science Edition)*, **43** (3), 74–79.

Zhang, H. F., Pan, L. J., Lu, S. & Gao, H. Y. 2015 Variation characteristics of precipitation and air temperature from 1901 to 2012 in Shaanxi, China. *Journal of Desert Research* **35** (6), 1674–1682

Zhao, T. & Yang, X. Y. 2012 Research on spatial interpolation methods of annual average precipitation on Loess Plateau. *Ground Water* **34** (2), 189–191.

Zhao, C. C., Wang, Y., Ding, Y. J., Ye, B. S. & Yao, S. X. 2011 Spatial-Temporal variations of temperature and precipitation in Northern China in recent 50 years. *Plateau Meteorology* **30** (2), 385–390.

Zhao, C. P., Chen, Y., Wang, W. G. & Gao, Z. Y. 2015 Temporal and spatial variation of extreme precipitation indexes of the Yellow River basin in recent 50 years. *Yellow River* **37** (1), 18–22.

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