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Monthly/8-km Grid Meteorological Dataset at the Middle and Upper Reaches of the Yellow River Basin of China (1980–2015)

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Abstract: Climate conditions are important factors for the China's strategy toward the ecological protection and high-quality development of the Yellow River. The monthly/8-km grid meteorological dataset at the middle and upper reaches of the Yellow River basin of China (1980–2015) was developed on the basis of the monthly average temperature, maximum temperature, minimum temperature, average relative humidity, average wind speed, precipitation (accumulated from 20:00 of the previous day to 20:00 of the current day), sunshine hours, and potential evapotranspiration calculated using the Penman–Monteith algorithm at 195 stations surrounding the middle and upper reaches of the Yellow River basin. Using the platform of ANUSPLIN, this study constructed the smooth spline functions of thin plates with different variables by comprehensively considering the influence of topography on the spatial differentiation of air temperature, wind speed, and humidity; and the effects of radiation, humidity, and wind speed on potential evapotranspiration. The dataset includes the following: (1) boundary data of the upper and middle reaches of the Yellow River basin; and (2) monthly/8 km average temperature, maximum temperature, minimum temperature, average relative humidity, average wind speed, precipitation, sunshine hours, and potential evapotranspiration data from 1980 to 2015. The dataset was archived in .shp and .img data formats and consists of 3,463 data files with a size of 672 MB (compressed to a single file with a size of 138 MB).

Keywords: Yellow River basin; meteorological; climate change; spatial interpolation

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1 Introduction

The Yellow River basin across four geomorphic units (i.e., Qinghai–Tibet Plateau, Inner Mongolia Plateau, Loess Plateau, and North China Plain) covers nine provinces from the west to east. It is an important ecological barrier and economic belt in northern China, and it plays a vital role in ecological security and high-quality economic and social development in China. Most of the Yellow River basin is located in the arid and semi-arid areas of China, which has a continental climate[1]. The issue of water resources is severe and thus seriously restricts the ecological protection and high-quality development of the Yellow River basin[2–4]. According to previous studies, climate change is one of the main factors affecting hydrological processes, and it is closely related to the spatial distribution, utilization patterns, and security of water resources in the Yellow River basin[2]. To improve China's forest coverage, the national government implemented the compulsory tree-planting campaign in 1980. Moreover, the pilot work of returning farmland to forest and grassland was conducted in the middle and upper reaches of the Yellow River in 2000. After nearly 40 years of unremitting efforts, the vegetation condition in the Yellow River basin has improved significantly[5]. However, the ensuing issues of water resources have become aggravated and are characterized by increased ecological water demand, increased evapotranspiration, decreased runoff production, reduced water and increased sediments from different sources, dry stratified soil, and shortage of water resources downstream[6–11]. Therefore, clarifying the climate conditions and taking efficient measures to restore ecological protection and manage natural resources on the basis of limited water resources are important in implementing and promoting the national strategic goals proposed by Chairman Xi to achieve ecological protection and high-quality development in the Yellow River basin. These approaches are also important steps to achieve the spirit of "The urban development, land use, population size and production scale should be determined based on local water resource.".

Theoretically, precise grid meteorological datasets should be gathered by high-density station networks. However, economic, technical, and topographic issues result in limited meteorological stations with an uneven spatial distribution and insufficient density[12]. Generally, the observation data from meteorological stations at fixed points cannot be directly used in other areas without observation data. These engaged regions can only be estimated using the observation data of adjacent meteorological stations and certain mathematical algorithms (i.e., spatial interpolation of meteorological data)[13]. At present, the commonly used spatial interpolation approaches can be divided into deterministic interpolation and geo-statistical interpolation[14]. Deterministic interpolation mainly includes polynomial interpolation, trend surface analysis, and inverse distance weighting methods. Geo-statistical interpolation methods include Kriging and Spline methods. The Kriging methods are based on the known spatial distribution of meteorological stations and fit surfaces through mathematical functions, while spline methods can fit surfaces and quantify errors through statistical and mathematical methods[15]. For different meteorological factors and regions, each interpolation approach has its own advantages and disadvantages. In recent years, interpolation software called ANUSPLIN based on the spline function method has been widely used because of its high interpolation accuracy[16–18]. ANUSPLIN is professional meteorological data interpolation software developed by Australian scientist Hutchinson on the basis of thin plate spline theory. The software allows the introduction of multiple covariant quantum models to process 2D splines into multidimensional ones and perform a spatial interpolation of multiple surfaces; hence, it is suitable for the interpolation of time series meteorological data[19]. Therefore, on the basis of the observation data of the meteorological stations surrounding the Yellow River basin from 1980 to 2015, a monthly grid meteorological dataset with a resolution of 8 km was obtained by interpolation in the current work. Moreover, climate change in the Yellow River basin in the past 36 years was analyzed to provide a scientific basis for the ecological protection and high-quality development of the basin.

2 Metadata of the Dataset

The metadata of the Monthly/8-km grid meteorological dataset at the middle and upper reaches of the Yellow River basin of China (1980–2015)[20] is summaried in Table 1.

Table 1 The metadata summary of the Monthly/8-km grid meteorological dataset at the middle and upper reaches of the Yellow River basin of China (1980–2015)

Items	Description
Dataset full name	Monthly/8-km grid meteorological dataset at the middle and upper reaches of the Yellow River basin of China(1980-2015)
Dataset short name	MeteoDataYellowRB_1980-2015
Authors	Wang, Y. Q., Institute of Geographic Sciences and Natural Resources Research, CAS, University of Chinese Academy of Sciences, wangyq.14b@igsnrr.ac.cn Sun, L., Institute of Geographic Sciences and Natural Resources Research, CAS; University of Chinese Academy of Sciences, sunlin-cas@hotmail.com Li, H. Y., Institute of Geographic Sciences and Natural Resources Research, CAS; University of Chinese Academy of Sciences, lihy.15b@igsnrr.ac.cn Luo, Y., Institute of Geographic Sciences and Natural Resources Research, CAS; University of Chinese Academy of Sciences, luoyi@igsnrr.ac.cn
Geographical region	The Middle and upper reaches of the Yellow River basin of China
Year	1980–2015 Data format .shp, .img Data size 672 MB
Temporal resolution	Monthly Spatial resolution 8 km×8 km
Units	Average temperature, maximum temperature, minimum temperature:°C; average relative humidity: %; average wind speed at 2 m: m/s; precipitation (accumulated from 20:00 of the previous day to 20:00 of the day): mm; sunshine hours: h; potential evapotranspiration: mm
Data files	(1) The boundary data of the upper and middle reaches of the Yellow River basin; (2) the monthly/8-km average temperature, maximum temperature, minimum temperature, average relative humidity, average wind speed, precipitation, sunshine hours, and potential evapotranspiration data from 1980 to 2015. The dataset is archived in .shp and .img data formats, and consists of 3,463 data files. From January 1980 to December 2015, each meteorological factor file is named in the form of YYYY mm. img. For example, 198001 is ×× data in January 1980
Foundations	Ministry of Science and Technology of P. R. China (2016YFC0501603); Chinese Academy of Sciences (XDA20060301)
Date Computing environment	ANUSPLIN4.3
Data publisher	Global Change Research Data Publishing & Repository, http://www.geodoi.ac.cn
Address	No. 11A, Datun Road, Chaoyang District, Beijing 100101, China
Data sharing policy	***Data*** from the Global Change Research Data Publishing & Repository includes metadata, datasets (in the *Digital Journal of Global Change Data Repository*), and publications (in the *Journal of Global Change Data & Discovery*). ***Data*** sharing policy includes: (1) ***Data*** are openly available and can be free downloaded via the Internet; (2) End users are encouraged to use ***Data*** subject to citation; (3) Users, who are by definition also value-added service providers, are welcome to redistribute ***Data*** subject to written permission from the GCdataPR Editorial Office and the issuance of a ***Data*** redistribution license; and (4) If ***Data*** are used to compile new datasets, the 'ten per cent principal' should be followed such that ***Data*** records utilized should not surpass 10% of the new dataset contents, while sources should be clearly noted in suitable places in the new dataset[14]
Communication and searchable system	DOI, CSTR, Crossref, DCI, CSCD, CNKI, SciEngine, WDS/ISC, GEOSS

3 Data Source and Methods

3.1 Data Source

The meteorological station data used in this dataset are the daily surface climatic data of China shared by the China Meteorological Data Service Center[1]. The observation

[1] China Meteorological Data Service Center-China Meteorological Data Network [OL]. http://data.cma.cn/.

data are mainly obtained from the basic and benchmark meteorological stations and automatic stations in China. The monthly/8-km grid meteorological dataset at the middle and upper reaches of the Yellow River basin of China (1980–2015) was developed on the basis of the monthly average temperature, maximum temperature, minimum temperature, average relative humidity, average wind speed, precipitation (accumulated from 20:00 of the previous day to 20:00 of the current day), sunshine hours, and the potential evapotranspiration calculated using the Penman–Monteith (P-M) algorithm at 195 stations surrounding the middle and upper reaches of the Yellow River basin. The boundary of the middle and upper reaches of the Yellow River basin was extracted from the SRTM 90 m resolution digital elevation model built using the hydrological modeling tool in the extension module toolbox of ARCGIS10.3 Spatial Analyst. The spatial range of the Yellow River basin was determined according to the situation of the river, flow direction, and outlet. Furthermore, the Huayuankou station was taken as the dividing line between the middle and upper reaches of the Yellow River basin and the lower reaches.

3.2 Methods

3.2.1 Potential Evapotranspiration Calculation

The P-M algorithm is widely applied to calculate potential evapotranspiration[22] as it considers the physiological characteristics and aerodynamic parameters of crops. This algorithm is suitable for calculating the land surface evapotranspiration of vegetation covering landscapes. It comprises a radiation term in radiation balance and an aerodynamic term based on temperature, wind speed, and water pressure difference. Its expression is as follows:

$$ET_0 = \frac{0.408\Delta\left(R_n - G\right) + \gamma \dfrac{900}{T+273}\mu_2\left(e_s - e_a\right)}{\Delta + \gamma\left(1 + 0.34\mu_2\right)} \tag{1}$$

where ET_0 is the potential evapotranspiration (mm); Δ is the slope of the curve between the saturation vapor pressure and the air temperature (kPa/ºC); R_n is the net radiation received at the surface (MJ/m^2); G is the soil heat flux (MJ/m^2); e_s and e_a, respectively, denote the saturated vapor pressure and actual vapor pressure (kPa); γ is the dry and wet constant, (kP/ºC); μ_2 is the wind speed at 2 m (m/s); and T is the average temperature (ºC). R_n is a variable of the received solar radiation and is generally estimated using the empirical formula based on sunshine hours, which can be expressed as

$$R_s = \left(a_s + b_s \frac{S}{N}\right) R_a \tag{2}$$

where a_s and b_s are linear empirical parameters, which are the most widely estimated errors in solar radiation calculation. For the monthly/8-km grid meteorological dataset in our study, the observed pan evaporation data were used as the potential evapotranspiration data computed by the P-M algorithm; thus, the empirical parameter values of a_s and b_s were back stepped. The potential evapotranspiration computed by the P-M algorithm is indeed water surface evaporation, which represents the maximum evaporation capacity of the region. According to the previous expressions, geographical factors (i.e., latitude and elevation) and meteorological factors (i.e., wind speed, minimum temperature, maximum temperature, sunshine duration, relative humidity, and pan evaporation) should be used as inputs in the calculation of potential evapotranspiration.

3.2.2 Interpolation Method

The monthly/8-km grid meteorological dataset was interpolated using the model in Table 2. Specifically, the minimum temperature, maximum temperature, average temperature, wind speed, relative humidity, and radiation were interpolated with longitude and latitude as the independent variables and with elevation as the coverable. Meanwhile, potential evapotranspiration was interpolated with longitude and latitude as the independent variables and with radiation, relative humidity, and wind speed as coverable. Sunshine duration was interpolated with longitude and latitude as independent variables. As precipitation is characterized by randomness, inhomogeneity, and large numerical range, square root transformation was performed herein, with longitude and latitude taken as independent variables.

Table 2 Spatial interpolation model of meteorological factors

Meteorological factor	Model	Independent variables	Covariable	Data conversion	Number of spline
Maximum temperature	TVPTPS	Longitude and latitude	Elevation		2, 3
Minimum temperature	TVPTPS	Longitude and latitude	Elevation		2, 3
Average temperature	TVPTPS	Longitude and latitude	Elevation		2, 3
Wind speed	TVPTPS	Longitude and latitude	Elevation		2
Precipitation	BVTPS	Longitude and latitude		Square root transformation	2
Relative humidity	TVPTPS	Longitude and latitude	Elevation		2
Sunshine hours	BVTPS	Longitude and latitude			2, 3
Potential evapotranspiration	QVPTPS	Longitude and latitude	Radiation, relative humidity, wind speed		2, 3, 4

Note: BVTPS, bivariate thin disk smooth spline function; TVPTPS, three-variable local thin disk smooth spline function; QVPTPS, variable local thin disk smooth spline function.

4 Data Results and Validation

4.1 Data Files

The monthly/8-km grid meteorological dataset at the middle and upper reaches of the Yellow River basin of China (1980–2015) includes the following:

(1) Boundary data of the upper and middle reaches of the Yellow River basin;
(2) Grid data of monthly maximum temperature;
(3) Grid data of monthly minimum temperature;
(4) Grid data of monthly average temperature;
(5) Grid data of monthly average wind speed;
(6) Grid data of monthly precipitation (accumulated from 20:00 of the previous day to 20:00 of the current day);
(7) Grid data of monthly average relative humidity;
(8) Grid data of monthly sunshine hours;
(9) Grid data of monthly potential evapotranspiration.

The dataset is archived in .shp and .img data formats and consists of 3,463 data files with a size of 672 MB (compressed to a single file with a size of 138 MB) and monthly temporal and spatial resolutions of 8 km × 8 km. Files are stored by meteorological factors and labeled in the following format: YYYYmm.img.

4.2 Data Results

4.2.1 Analysis of Climate Conditions across the Yellow River Basin

The climatic conditions (i.e., 1980–2015) across the Yellow River basin have an apparent spatial heterogeneity (Figure 1). For example, the spatial distribution pattern of temperature is shown in Figs.1a, 1b, 1c,the annual average temperature decreased from west to east with the elevation and showed an increasing trend (Figure 1c) with a variation range of −11.7–15.1 ºC. The annual mean temperature was 5.8 ºC. Sunshine hours showed a decreasing trend from southeast to northwest (Figure 1d), and the average annual sunshine hours were 2,562 h. The relative humidity decreased from 77.5% to 42.8% from south to north, and the average value was 58%. The average wind speed in the northern source region of the Yellow

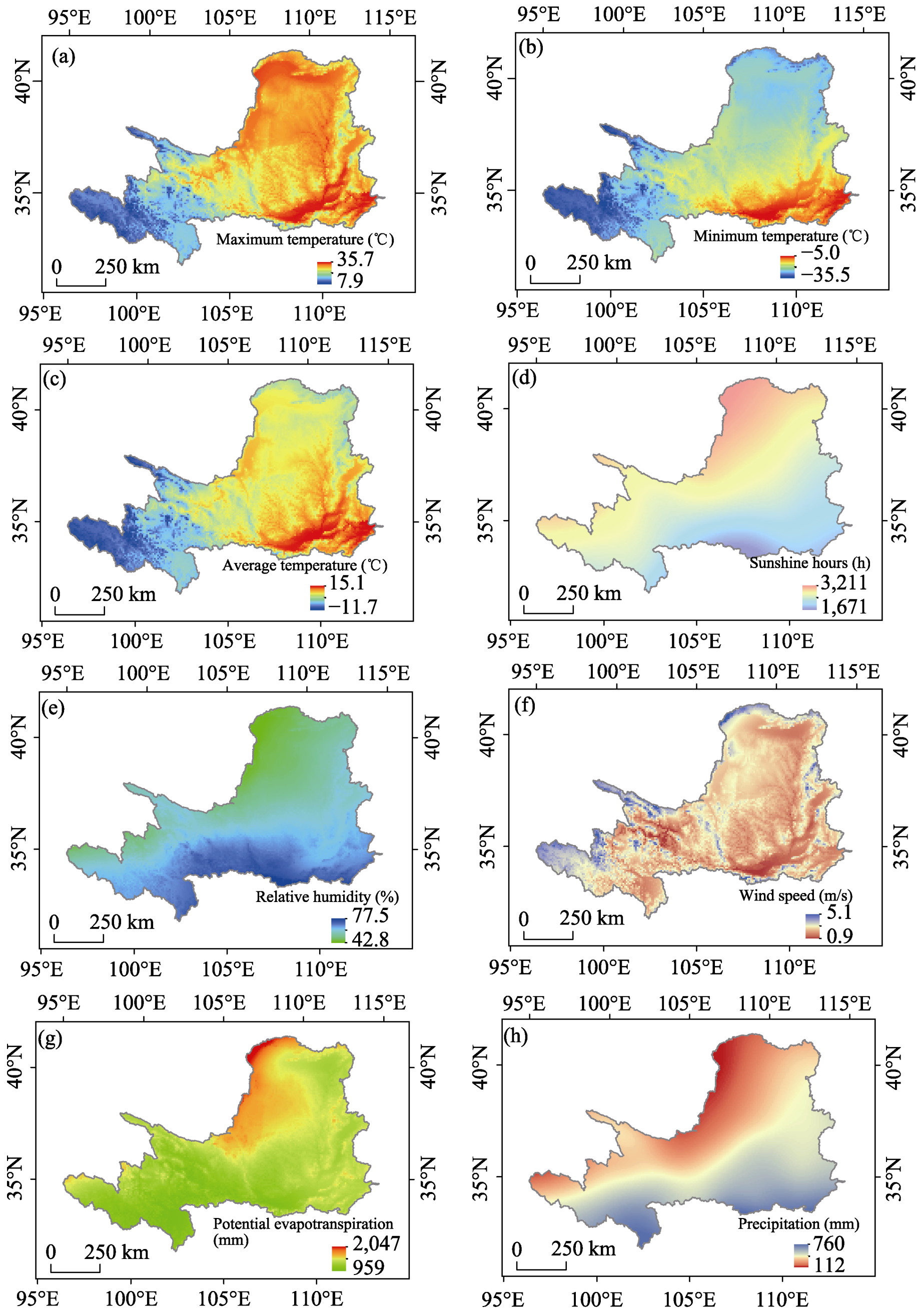

Figure 1 Spatial pattern of meteorological factors across the Yellow River basin

River and the high-altitude region is relatively large (Figure 1f), with a maximum value of 5 m/s and an annual average value of 2.5 m/s. The annual average potential evapotranspiration in the middle reaches of the Yellow River gradually increased from southeast to northwest (Figure 1g). The maximum potential evapotranspiration in the arid region of the northwest of the Yellow River was over 2,000 mm. The mean annual precipitation gradually decreased from 760 mm in the southeast to 112 mm in the northwest (Figure 1h). Generally, the climate conditions of the Yellow River can be depicted as follows:

(1) low temperature, high sunshine hours, high wind speed, and low potential evapotranspiration for the source region;
(2) low precipitation and humidity for the northern region;
(3) high precipitation and humidity for the southern region.

Meanwhile, the climate conditions of the middle reach of the Yellow River basin can be depicted as follows:
(1) high humidity and temperature, short sunshine duration, low wind speed, large precipitation, and small potential evapotranspiration for the southeastern region;
(2) dry climate characterized by low temperature in winter and high temperature in summer, long sunshine duration, high wind speed, small precipitation, and large potential evapotranspiration for the northwestern region.

4.2.2 Temporal Climate Variations in the Yellow River Basin

(1) Seasonal variation

The climate conditions in the Yellow River basin show obvious seasonal variations. With regard to temperature, it increases in spring, reaches a maximum of 18.6 ºC in July in summer, gradually decreases in autumn, and drops to −8.7 ºC in winter. For relative humidity, it is the lowest in April at 48.2%, it reaches the maximum value of 69.9% in August, and remains stable in winter in the range of 51.6%–53.4%. For the sunshine duration, it increases gradually in spring, reaches a maximum of 3,332 h in August, and fluctuates slightly in winter. For wind speed, the maximum occurs in April at 3 m/s. For precipitation, the average value in summer (July) is 87.5 mm, and the total precipitation in winter is only 10.3 mm. Meanwhile, the potential evapotranspiration from April to June is relatively large at 504.8 mm, which in May is the maximum at 180.6 mm and in winter at 129.1 mm. Generally, the seasonal characteristics of the climate conditions in the Yellow River basin can be depicted as follows: 1) In spring, sunshine duration, temperature, and wind speed increase; precipitation slightly increases; relative humidity slightly decreases; and potential evapotranspiration thus increases and reaches the maximum annual value. 2) In summer, precipitation increases significantly, sunshine duration demonstrates a fluctuation obviously characterized as decreasing slightly at first and then increasing, temperature increases significantly, wind speed gradually decreases, relative humidity increases, and potential evapotranspiration thus gradually decreases. 3) In autumn, with the decrease of sunshine duration, temperature, precipitation, wind speed, relative humidity, and potential evapotranspiration also decrease. 4) In winter, with the slight fluctuations in sunshine duration, precipitation, wind speed, and relative humidity, the temperature continues to decline, and potential evapotranspiration gradually decreases to the minimum value.

(2) Inter-annual variability

From 1980 to 2015, the inter-annual variation of the meteorological factors in the Yellow River basin showed great spatial and temporal heterogeneity. For the mean values, the temperature showed a significant upward trend, and the inter-annual change rate (i.e., linear regression coefficient) was 0.5 ºC/10a. The relative humidity and wind speed showed a significant decreasing trend, and the inter-annual change rates were −0.7%/10a and −0.1 m/(s·10a), respectively. Sunshine duration, precipitation, and potential evapotranspiration showed no obvious inter-annual variation trend. According to the spatial distribution pattern of the annual variation of the meteorological factors, the temperature increase in the source region of the Yellow River was significantly greater than that in the middle reaches of the Yellow River. The mean warming amplitudes of the maximum temperature, minimum temperature, and average temperature were very close (0.5 ºC/10a), but their spatial distribution patterns were different (Figure 4a, 4b, and 4c, respectively). The sunshine duration in the southern region showed an increasing trend while that in the eastern region showed a decreasing trend (Figure 4d). The relative humidity of the source region, southeastern region, and northern region of the Yellow River showed a decreasing trend while that from the Qilian Mountains to the Qinling Mountains, the inner flow region of Ordos, northern Shaanxi, and central and southern Ningxia showed an increasing trend (Figure 4e). The mean wind speed of the source region of the Yellow River and the northwestern region of the middle reaches showed an increasing trend, while the wind speed of the southeastern region showed a decreasing trend (Figure 4f). Moreover, 30.7% of the

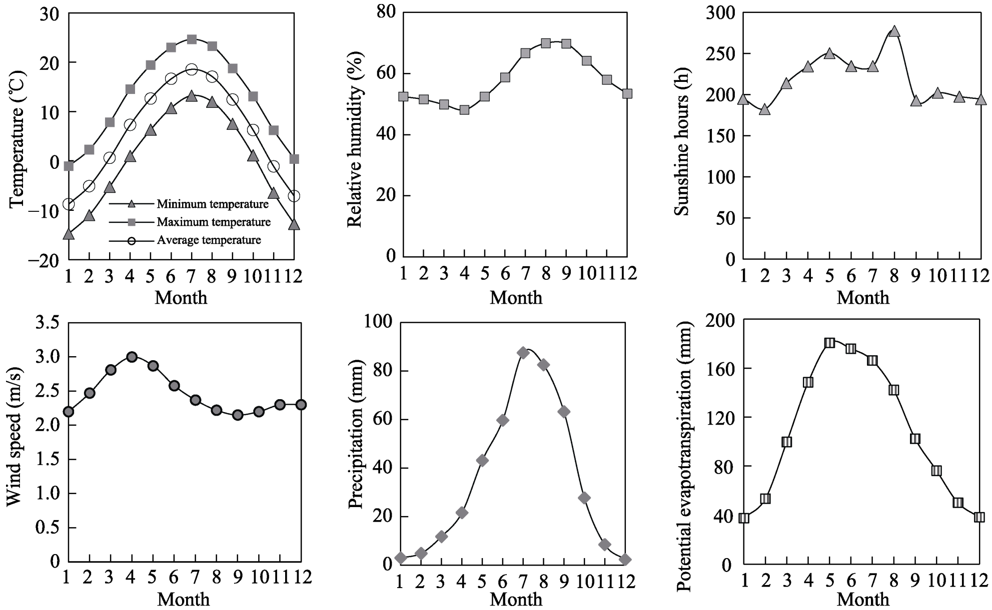

Figure 2 Seasonal variation of meteorological factors across the Yellow River basin

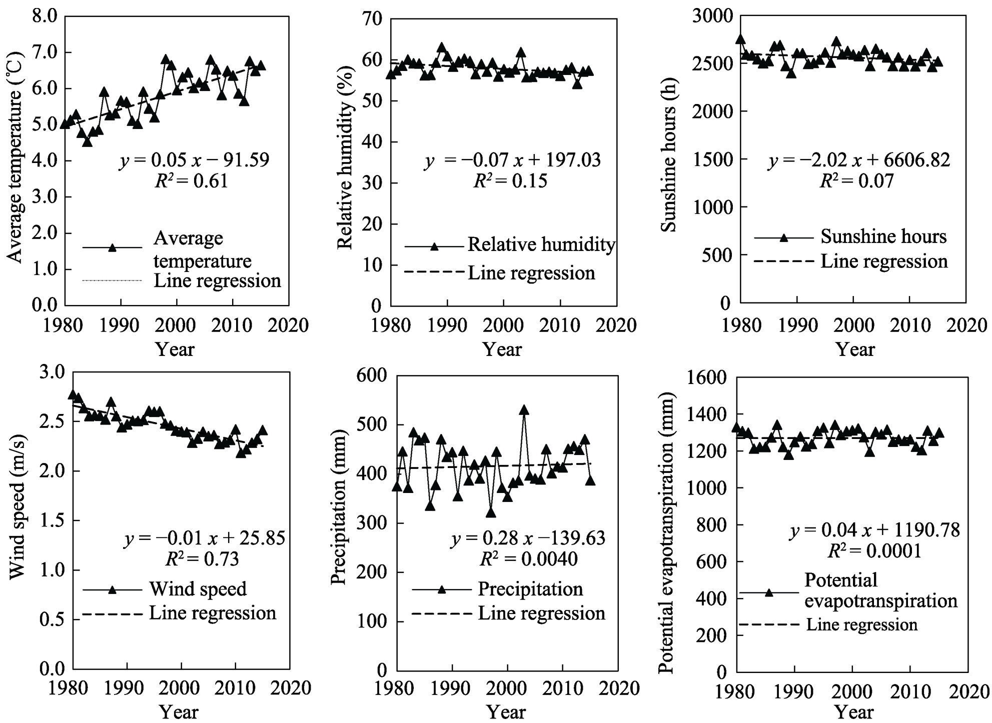

Figure 3 Inter-annual variation of meteorological factors across the Yellow River basin

regions showed a decreasing trend, which was mainly distributed in the southern part of the Yellow River basin and with the average inter-annual change rate being −9.0 mm/10a; 69.3% of the regions showed an increasing trend, which was mainly distributed in the northern part and with the average inter-annual variation rate being 8.1 mm/10a (Figure 4h). About 51.2% of the potential evapotranspiration showed a decreasing trend, which was mainly distributed in the source and northwestern regions of the Yellow River and with the average inter-annual change rate being −18.3 mm/10a. In addition, 48.9% of the potential evapotranspiration showed an increasing trend, which was mainly distributed in the central, southern, and eastern regions of the Yellow River basin. The average inter-annual change rate was 20.0 mm/10a (Figure 4g).

4.3 Data Validation

The standard errors of prediction of the monthly/8-km grid meteorological dataset were assessed. The standard errors of the minimum temperature, maximum temperature, and average temperature were 1.18 –1.33 ºC, 0.86 –1.06 ºC, and 0.80 –0.95 ºC, respectively. The standard errors of the mean wind speed, relative humidity, potential evapotranspiration, precipitation, and sunshine hours were 0.69–0.83 m/s, 4.54–5.55 mm, 6.52–7.88 mm, 1.03–1.21 mm, and 19.43–21.84 h, respectively (Table 3). With respect to the spatial distribution, the regions with large standard errors of prediction are mainly located in the northwest and in the regions with relatively few meteorological stations at high altitudes. With respect to the temporal distribution, the standard error of the mean monthly temperature prediction in summer is significantly smaller than that in winter. The standard error of the mean minimum temperature prediction is the largest. The standard error of the monthly mean precipitation forecast in winter is smaller than that in summer and is positively correlated with precipitation. The error of the potential evapo-transpiration prediction from April to August is relatively large.

Table 3 The standard errors of prediction of the monthly/8-km grid meteorological dataset

Meteorological factor	Item	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sept	Oct.	Nov.	Dec.	Mean
Minimum temperature	Min	1.72	1.45	1.17	1.08	1.03	0.97	0.86	0.87	0.94	1.10	1.35	1.62	1.18
	Max	1.91	1.62	1.33	1.21	1.15	1.09	0.99	1.03	1.07	1.20	1.51	1.81	1.33
	Mean	1.75	1.48	1.21	1.11	1.05	0.99	0.89	0.90	0.96	1.11	1.40	1.65	1.21
Maximum temperature	Min	0.94	0.94	0.86	0.96	0.86	0.78	0.81	0.82	0.79	0.81	0.85	0.92	0.86
	Max	1.15	1.17	1.10	1.16	1.02	0.97	1.02	0.99	0.96	0.97	1.02	1.15	1.06
	Mean	0.99	1.00	0.94	1.00	0.90	0.86	0.86	0.87	0.84	0.84	0.89	1.00	0.92
Average temperature	Min	1.12	0.94	0.73	0.74	0.70	0.68	0.63	0.62	0.67	0.74	0.93	1.09	0.80
	Max	1.28	1.09	0.94	0.89	0.82	0.81	0.77	0.77	0.80	0.86	1.06	1.25	0.95
	Mean	1.15	0.97	0.82	0.77	0.73	0.71	0.67	0.67	0.70	0.76	0.96	1.15	0.84
Sunshine hours	Min	21.31	17.17	18.28	18.19	19.33	20.62	22.00	20.90	17.87	17.59	18.25	21.67	19.43
	Max	23.76	19.40	20.75	20.39	21.99	23.01	24.64	23.74	20.14	19.73	20.42	24.09	21.84
	Mean	21.82	17.68	18.87	18.70	19.95	21.12	22.59	21.57	18.40	18.06	18.72	22.18	19.97
Wind speed	Min	0.74	0.69	0.7	0.67	0.64	0.61	0.6	0.6	0.61	0.63	0.71	0.74	0.69
	Max	0.87	0.83	0.81	0.79	0.74	0.72	0.7	0.7	0.7	0.73	0.85	0.87	0.83
	Mean	0.77	0.72	0.72	0.7	0.66	0.63	0.62	0.62	0.62	0.65	0.74	0.77	0.72
Relative humidity	Min	5.50	4.90	4.32	4.04	4.05	4.02	3.75	3.93	4.32	4.60	5.30	5.80	4.54
	Max	6.48	6.00	5.26	5.06	4.80	4.79	4.98	5.02	5.21	5.36	6.29	6.72	5.50
	Mean	5.79	5.14	4.57	4.32	4.22	4.24	4.12	4.26	4.53	4.79	5.60	5.99	4.80
Precipitation	Min	0.58	0.66	0.79	0.93	1.15	1.38	1.83	1.72	1.20	0.87	0.70	0.57	1.03
	Max	0.68	0.76	0.92	1.09	1.33	1.63	2.13	2.03	1.44	1.05	0.80	0.66	1.21
	Mean	0.60	0.68	0.82	0.97	1.20	1.45	1.91	1.79	1.26	0.91	0.72	0.59	1.08
Potential evapotranspiration	Min	4.22	4.59	6.73	8.46	9.32	8.9	8.49	7.57	5.87	4.97	4.59	4.58	6.52
	Max	4.63	5.15	7.77	10.08	11.3	11.24	10.86	9.82	7.49	6.1	5.15	5.01	7.88
	Mean	4.31	4.71	6.98	8.86	9.82	9.48	9.09	8.12	6.29	5.27	4.71	4.67	6.86

5 Discussion and Conclusion

In this study, the influence of topography on the spatial differentiation of air temperature, wind speed, and humidity; and the effects of radiation, humidity, and wind speed on potential evapotranspiration were comprehensively considered. Moreover, the smooth spline functions of thin plates with different variables were constructed to effectively express the spatial differentiation characteristics of meteorological factors. Potential evapotranspiration was calculated using the P-M algorithm recommended by FAO. To determine the two

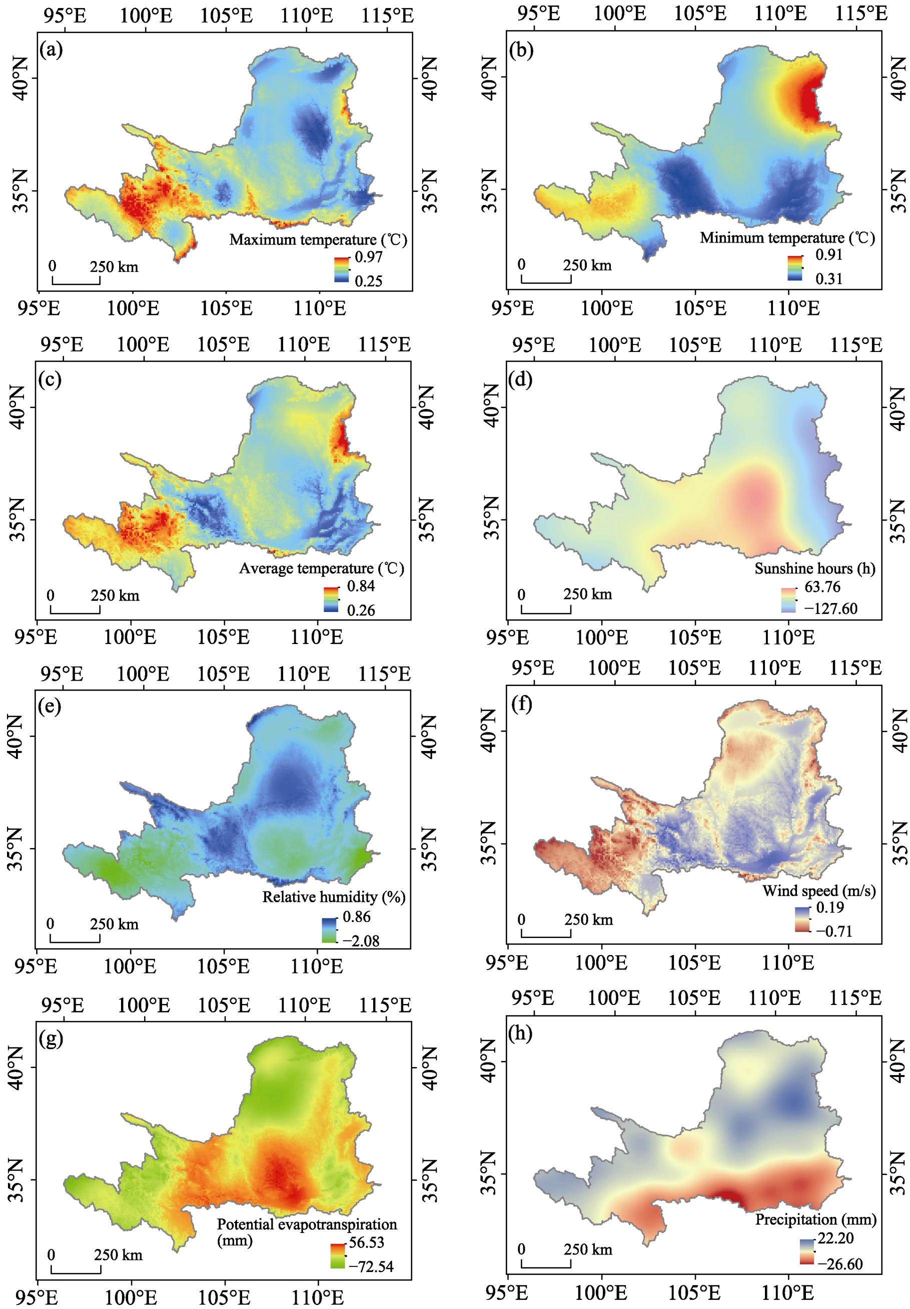

Figure 4 Spatial distribution pattern of inter-annual variation of meteorological factors across the Yellow River basin

empirical parameters a_s and b_s in the formula of solar radiation in different regions, this study used pan evaporation as the target value of parameter calibration. Therefore, the potential evapotranspiration in this study actually refers to water surface evapotranspiration rather than land surface evapotranspiration and represents the maximum evaporation capacity of the region. The potential evapotranspiration in the current work is slightly higher than that in previous studies[23–27]. However, these values are basically consistent with those related to pan evaporation[28]. Furthermore, Liao confirmed that the spatial distribution of pan evaporation and that of potential evapotranspiration based on the P-M method are highly consistent[29] and show a high correlation, which suggests that potential evapotranspiration in the Yellow River basin can be estimated.

On the basis of the observation data of meteorological stations, this study developed the monthly/8-km grid meteorological dataset at the middle and upper reaches of the Yellow River basin of China (1980–2015) and performed generalized cross-validation. The climate characteristics, inter-annual variation trends, and spatial distribution patterns of the middle and upper reaches of the Yellow River basin were then analyzed. The main conclusions are as follows:

(1) The precision of spline interpolation based on ANUSPLIN is affected by station distribution and seasonal variation. The error of interpolation is large in regions with sparse meteorological stations at high altitudes. In terms of temporal distribution, the interpolation accuracy for temperature, relative humidity, and wind speed is higher in summer than in winter. Meanwhile, the interpolation accuracy for sunshine hours, precipitation, and potential evapotranspiration in summer is lower than that in winter. The errors for sunshine hours, precipitation, and potential evapotranspiration reach the maximum values in July, with the average values of the first two factors being 22.6 h and 1.9 mm, respectively. The error for potential evapotranspiration reaches the maximum value in May, with the average value being 9.8 mm.

(2) The climate conditions in the Yellow River basin have obvious spatial heterogeneity and strong seasonal characteristics. The climate characteristics of the Yellow River are as follows: a) low temperature, long sunshine duration, high wind speed, and low potential evapotranspiration for the source region; b) low precipitation and humidity for the northern region; and c) high precipitation and humidity for the southern region. Meanwhile, the climate characteristics of the middle reaches of the Yellow River basin are as follows: a) the climate in the southeast is relatively humid, with high temperature, short sunshine duration, low wind speed, large precipitation, and small potential evapotranspiration; b) the climate in northwestern China is dry and is characterized by low temperature in winter and high temperature in summer, long sunshine duration, high wind speed, low precipitation, and high potential evapotranspiration.

(3) From 1980 to 2015, the climate in the Yellow River basin changed significantly. The main characteristics are as follows: a) the temperature increased significantly with an inter-annual change rate of 0.5 ºC/10a; b) the relative humidity and wind speed showed a significant decreasing trend, and the inter-annual change rates were −0.7%/10a and −0.1 m/(s·10a), respectively; c) the inter-annual variation trends of sunshine duration, precipitation, and potential evapotranspiration were not obvious.

Author Contributions

Luo, Y. provided general guidance for the research and development of the dataset. Sun, L. calculated the potential evapotranspiration, collected and sorted the data of the stations, and extracted the boundaries of the middle and upper reaches of the Yellow River basin. Li, H. Y. converted the interpolated data into the required formats. Wang, Y. Q. performed spatial interpolation and prepared the data papers.

Conflicts of Interest

The authors declare no conflicts of interest.

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