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Trends for pan evaporation during 1959-2000 in China

Qiang Liu[1,2], Zhifeng Yang[2]*, Xinghui Xia

(1. Key Laboratory for Water and Sediment Sciences, Ministry of Education, School of Environment, Beijing Normal University, Beijing 100875, China; 2. State Key Laboratory of Water Environment Simulation, School of Environment, Beijing Normal University, Beijing, 100875, China)

Abstract

Evaporation, influenced by water and energy conditions, reflected the combined effects of climate, vegetation and soil in different basins. Trend analyses of pan evaporation were conducted on 298 stations and significant trends were also explored by the Kendall τ and Linear fitted model method during 1959-2000 in China. The causes for the changes of pan evaporation were discussed in different basins of China. The results presented that decreasing trends were detected in most of stations of China, which ranged from -0.02 to -30.48 mm a^{-2}. The spatial distribution of trends presented that most of negative trends stations were detected in mid-latitude regions of China, followed by basin in south region, Northeast region and southwest region. The causes for the changes of pan evaporation, influenced by the water and energy conditions, changed in different basins of China and generally sunshine hours and maximum air temperature were the most important meteorological variables to influence the changes of pan evaporation, followed by relative humidity, wind speed, average air temperature and minimum air temperature in the whole country.

Keywords: *pan evaporation; temporal trend; climate chagnes; Kendall τ method; China*

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1. Introduction

Evapotranspiration is the transfer of water from the landscape to the atmosphere, a combination of evaporation from soil and plant transpiration, which is one of the most important variables in the water cycle. The temporal-spatial patterns of evapotranspiration influence the eco-hydrological processes, which control the evolution of surface ecosystem [1, 2, 3, 4]. In this context, evapotranspiration has been regarded as one of the key variable to diagnose climate change and reveal the eco-environment response to climate changes [1, 5].

Evapotranspiration is difficult to measure directly, however, and is usually calculated using a semiempirical equation that combines a climatic component, vegetation characteristics, and water availability [20]. In order to obtain the evapotranspiration, several terms has been used to address evaporation demand in different ideal condition, e.g., potential evapotranspiration and reference crop evapotranspiration. According to Shuttleworth (1993) [6], potential evaporation is defined as the quantity of water evaporated per unit area, per unit time from an idealized, extensive free water surface under existing atmospheric conditions. Reference evapotranspiration is defined as ‘‘the

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* Corresponding author. Tel.: +86-10-58807596; fax: +86-10-58807596.
E-mail address: zfyang@bnu.edu.cn.

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rate of evapotranspiration from a hypothetical reference crop with an assumed crop height of 0.12 m, a fixed surface resistance of 70 s m^{-1} and an albedo of 0.23, closely resembling the evapotranspiration from an extensive surface of green grass of uniform height, actively growing, well-watered, and completely shading the ground'' [7]. However, as equation methods need several climatic data, such as air temperature, wind speed, net radiation and relative humidity, it is limited in lack data regions. Measurements of evaporation from pans have traditionally been used to represent the evaporative demand of the atmosphere when estimating crop water requirements [8, 9, 10]. Pan evaporation, influenced by changes in environmental condition, e.g., surface resistance, radiation, can be different from potential evaporatranspiration, which also has been widely used to represent the potential evapotranspiration through data correlation.

Recently, "the evaporation paradox", reported in many regions of the world, e.g. Australia [10, 11], China [12, 13, 14], North America [15, 16]; Europe [17], has drawn great attention to reveal causes of decrease of pan evaporation or reference evapotranspiration despite the increases in average temperature in the past 30 or 50 years [10, 14, 18]. Up to now, explanations for "evaporation paradox" mainly lie in: (1) declining global solar irradiance caused by changes in cloudiness or aerosol concentrations [18]; (2) "the complementary relationship" between actual evaporation and potential evaporation [15,19]; and (3) decreasing wind speed due to land use change [20] and monsoon changes [13, 21, 22, 23]. In this context, to explore the trends of pan evaporation will help to understand the response of pan evaporation to climate changes and to provide suitable water regulation in different regions of China. The objectives of this study are: (1) to explore the trends of pan evaporation; (2) to analyze the changes of pan evaporation in different basins; and (3) to investigate the causes for the changes of pan evaporation in different basins, China.

2. Study area and data processing

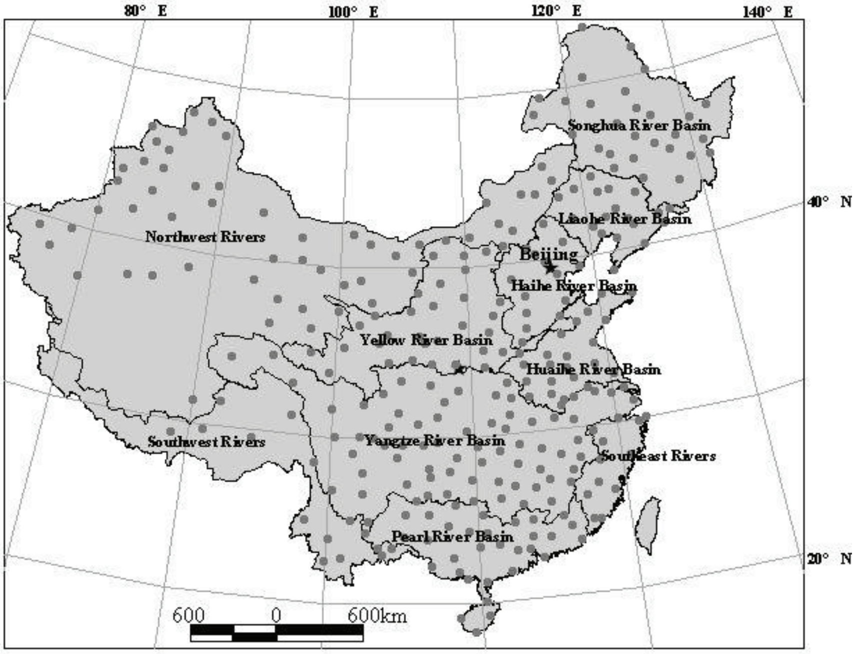

Fig. 1 the meteorological stations used in this study.

In this study, pan evaporation data were collected from 298 stations throughout whole China, which used to explore the temporal trends of pan evaporation in different basins of China. In order to maintain the data quality, data series were selected from 1959 to 2000. The pan evaporation measured with a diameter of 20 cm is used, which is one of the standard instruments at national meteorological stations in China. During the 42-year analysis period, the sites in Fig.1 provide a good spatial represent in the whole China. According to the watershed in China, ten basins were used to address the changes of pan evaporation in mainland of China, which is Songhuajiang River basin, Liaohe River Basin, Haihe River Basin, Huaihe River Basin, Yellow River Basin, Yangtze River Basin, Pearl River Basin, South Rivers region, Southwest Rivers region and Northwest Rivers region. The locations of the basins and meteorological stations were addressed in Fig. 1.

3. Methods description

3.1. Temporal trend analysis method

In order to reveal the temporal trend of pan evaporation, Kendall τ method and the linear fitted model were used in this study. The linear fitted model, which is tested against the hypothesis of null slope by means of a 2-tailed T-test at a confidence level of 95% [24], is most common technology of statistical diagnosis and forecast in modern climate. The Kendall τ method, which is a non-parametric method for testing the correlation [24, 25; 26], is used to test the trend for the pan evaporation.

3.2. Gray incidence analysis

Gray incidence analysis (GIA), provided by Liu and Lin (1998) [27] and Liu et al. (2004) [28] to estimate the degree of interaction among factors that govern system development, has been widely used to estimate the relationship between two factors in many subjects [29, 30]. If the trend of two factors is consistent, the degree of gray incident will be large; and vice verse, the degree of gray incidence will be small. While GIA is similar to the well-known cross-correlation analysis, it does not rely on any statistical concept [31].

A gray relation space is a binary set denoted by (X, C), where X is a collection composed of sequences including n entries, X_0 is called a mapping quantity of the system behavior (e.g., spring flow record), X_i are behavioral sequences of relevant factors to be compared (e.g., precipitation, evaportranspiration, groundwater level records, etc.), and C is a gray incidence map set (e.g., the relation between the spring flow and precipitation records). The system characteristic behavior sequence X_0 and relevant behavioral sequences X_s can be presented in a form of series as:

$$X_0 = (x_0(t)), t = 1,2,\cdots,n \tag{1}$$

$$X_\tau = (x(t-\tau)), \tau = 1,2,\cdots,m \tag{2}$$

where t is time and s is the time-lag between X_0 and X_s. During the GIA analysis, we use the normalized value of X_0 and X_s

$$X_0' = (x_0'(t) = \frac{X_0}{\bar{x}_0}, t = 1,2,\cdots,n \tag{3}$$

Where $\bar{x}_0 = \frac{1}{n}\sum_{t=1}^{n} x_0(t)$;

$$X_\tau' = (x_z'(t-\tau) = \frac{X_\tau}{\bar{x}_\tau}, t = 1,2,\cdots,n, \tau = 1,2,\cdots m \tag{4}$$

Where $\bar{x}_\tau = \frac{1}{n}\sum_{t=1}^{n} x_\tau(t-\tau)$.

The expression of the incidence coefficient of X_τ with respect to X_0 at the point t is defined as:

$$\gamma_{0\tau}(t)=\gamma(x_0'(t),x_\tau'(t-\tau))=\frac{\min_\tau\min_t\left|x_0'(t)-x_\tau'(t-\tau)\right|-\max_\tau\max_t\left|x_0'(t)-x_\tau'(t-\tau)\right|}{\left|x_0'(t)-x_\tau'(t-\tau)-\right|\max_\tau\max_t\left|x_0'(t)-x_\tau'(t-\tau)\right|} \tag{5}$$

Where the degree of gray incidence of Xτ with respect to X0 is defined as

$$\gamma(X_0,X_\tau)=\frac{1}{n}\sum_{t=1}^{n}\gamma(x_0'(t),x_\tau'(t-\tau)) \tag{6}$$

After the degree of gray incidence are determined, the gray incident order is determined through comparing $\gamma(X_0,X_\tau)$. The gray incidence order reflects the relative intimate grade between X_0 and X_τ.

4. Results and dicussions

4.1. The temporal trends for pan evaporation

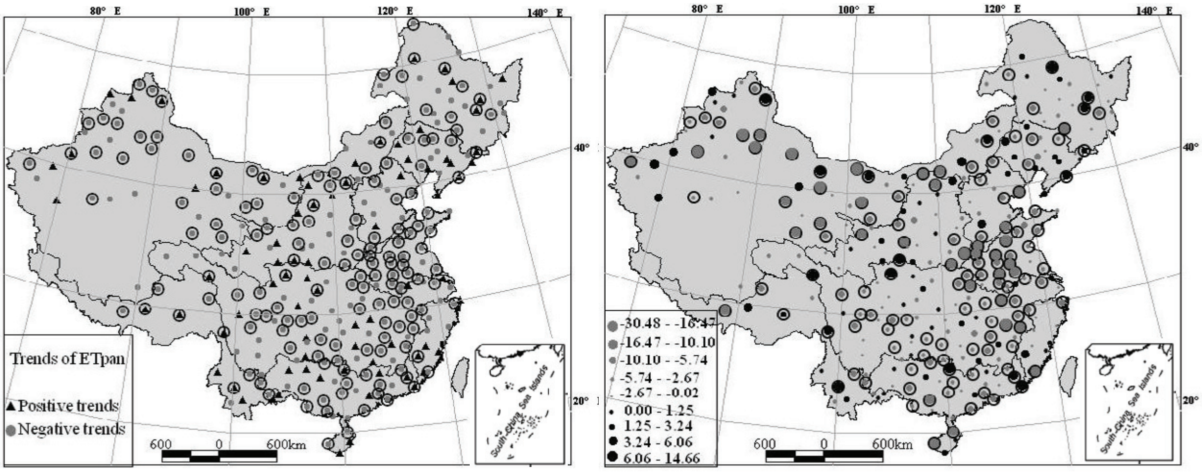

Fig. 2 the trends of pan evaporation in China.

According to Kendall τ method, most of the stations (219 among 298) showed negative trends for pan evaporation in China and 60% (131 among 219) negative stations presented significant decreasing trends at 99% confident level; conversely, only 26.5% (79 among 298) stations presented positive trends during 1959-2000 in China and 25 stations presented significant increasing trends. Our findings are consistent with the results presented by Liu et al. (2009) [32]. Generally, pan evaporation, influenced by the climate change, has decreased in most of regions of China.

In order to validate the results by the Kendall τ method, the linear fitted model used to address the trends of pan evaporation in China. The results, revealed by linear fitted model, showed that: 217 stations presented negative trends with an average slope of -5.88 mm a^{-2}, while only 81 stations showed positive trends with an average slope of 3.00 mm a^{-2}; especially, there were 132 stations showing significant trends at 95% confidence level with an average slope of -6.86 mm a^{-2}, most of them (114 among 132) presented negative trends with an average increase -8.97 mm a^{-2}, and only 18 stations showed significant positive trends at 95% confident level with an average slope of 6.48 mm a^{-2}. The magnitude of the decreasing trends for the negative stations is larger than that for the positive stations.

4.2. The trends of pan evaporation in different regions

In order to explore the changes of pan evaporation in different basins, the changes of pan evaporation in different basins were addressed in Table 1. The result addressed that: (1) most of the basins (except southwest rivers region) presented negative trends for pan evaporation; (ii) larger negative trends were located in the mid-latitude regions of China (e.g. the Northwest Rivers region, Huaihe River Basin, Haihe River basins, Yellow River basin), followed by the basin in south regions (e.g. Yangtze River basin, Pearl River basin and South Rivers regions), northeast regions (Songhuajiang River Basin and Liaohe River Basin) and Southwest Rivers region; (iii) the percentage of decreasing stations is larger than 70% in Songhua River Basin, Yellow River Basin, Yangtze River Basin, Pearl River Basin, Northwest Rivers region, Huaihe River and Haihe River Basin, and while the percentage of increasing trends stations is larger in Liaohe River Basin and Southwest Rivers region, which make up to 52.63% and 66.67%, respectively; and (v) most of significant increasing (P=0.05) stations located in Huaihe River Basin, Haihe River Basin, Northwest Rivers region, Yangtze River Basin, Pearl River Basin and Yellow River Basin, which make up to 78.76%, 46.15%, 42.59%, 43.06%, 43.33% and 25.81%, respectively.

Table 1 The trends of pan evaporation in different basins of China.

		SRB	LRB	YRB	YTB	PRB	SWB	NWB	SRB	HuaiRB	HaiR
Increasing Trends	Percentage of increasing station (%)	21.43	52.63	29.03	22.22	23.33	66.67	25.93	33.33	—	15.
	Average slope (mm a^{-2})	3.39	2.78	2.80	1.98	3.23	3.39	4.89	1.87	—	3.
Significant Increasing Trends at 95 % confident level	Percentage of increasing station	10.71	10.53	3.23	2.78	10.00	25.00	7.41	0.00	0.00	0.
	Average slope (mm a^{-2})	5.30	4.19	8.39	8.26	6.17	5.58	8.06	—	—	—
Decreasing Trends	Percentage of increasing station	78.57	47.37	70.97	77.78	76.67	33.33	74.07	66.67	100.00	84.
	Average slope (mm a^{-2})	-2.60	-6.25	-5.69	-4.65	-4.71	-6.74	-8.79	-4.06	-7.89	-6.
Significant Decreasing Trends at 95 confident level	Percentage of increasing station	14.29	21.05	25.81	43.06	43.33	16.67	42.59	16.67	78.26	46.
	Average slope (mm a^{-2})	-7.44	-4.58	-12.02	-6.49	-6.42	-9.73	-12.93	-10.32	-9.33	-8.
Trends in the whole basin		-1.32	-0.71	-3.23	-3.18	-2.86	0.01	-5.24	-2.09	-7.89	-4.

Note: Songhuajiang River basin, SRB; Liaohe River Basin, LRB; Yellow River Basin, YRB, Pearl River Basin, PRB, Southwest rivers region, SRB; Northwest rivers region, NWB; South rivers region, SRB; Huaihe River Basin; HuaiRB and Haihe River Basin, HaiRB.

4.3. The causes for the temporal trends of pan evaporation

According to gray incidence analysis, the influences of different meteorological variables on pan evaporation were showed in Table 2. The results indicated that: (i) the sunshine hours and maximum air temperature are the most important meteorological variables that influence the changes of pan evaporations, followed by relative humidity, wind speed, average air temperature and minimum air temperature in the whole China; (ii) the changes of sunshine hours, influence the energy conditions, which is the key factors to influence the changes of pan evaporation in

Songhuajiang River Basin, Liaohe River Basin, Huaihe River Basin, Haihe River Basin, Yellow River Basin, Yangtze River Basin and northwest rivers region, respectively; (ii) while the maximum air temperature made up to the key factor to influence the changes of pan evaporation in Pearl River Basin, South rivers region and Southwest rivers region; and (iii) wind speed, reflecting the aerodynamic variables to influence the changes of pan evaporation, contributed a larger magnitude to the changes of pan evaporation in Songhua River Basin, Huaihe River Basin, Yellow River Basin and Northwest rivers region.

Table 2 The correlation coefficient revealed by the gray incidence analysis in different basins, China.

	Sunshine hours	Wind speed	Relative humidity	Air temperature	Max air temperature	Min air temperature
SongHua River Basin	0.95	0.90	0.91	0.64	0.88	0.77
Liaohe River Basin	0.94	0.89	0.89	0.88	0.92	0.64
Huaihe River Basin	0.82	0.76	0.67	0.69	0.72	0.64
Haihe River Basin	0.89	0.79	0.81	0.79	0.84	0.67
Yellow River Basin	0.93	0.89	0.85	0.86	0.90	0.66
Yangtze River Basin	0.71	0.60	0.63	0.64	0.68	0.59
Pearl River Basin	0.73	0.68	0.72	0.75	0.78	0.72
South Rivers region	0.63	0.64	0.64	0.69	0.70	0.67
Southwest Rivers region	0.80	0.63	0.73	0.75	0.80	0.62
Northwest Rivers region	1.00	0.99	0.99	0.99	0.99	0.64

In order to identify the dominant variables associated with the change in pan evaporation, stepwise regression was applied between pan evaporation and the various meteorological parameters which control evaporation: relative humidity, wind speed, sunshine hours, and maximum and minimum air temperature.

5. Conclusions

Pan evaporation, influenced by water and energy conditions, reflects the combined effects of different meteorological variables. In this study, the temporal trends of pan evaporation were explored by Kendall τ method and linear fitted model, and the causes for the changes of pan evaporation were discussed in different basins of China. The conclusion can be drawn as follows:
(1) the trends of pan evaporation presented that most of stations showed negative trends and only few stations demonstrated positive trends during 1959-2000 in China, the significant increasing and decreasing trends have been detected in 18 and 114 stations with an average slope of 6.48 mm a^{-2} and -8.97 mm a^{-2}, respectively;
(2) the spatial distribution of trends for pan evaporation indicated that larger negative trends were detected in mid-latitude regions, followed by Northeast regions, south regions and southwest regions in China;
(3) the causes of tends in pan evaporation presented that changes of energy, resulted from the changes of sunshine hours, can be the key factors to influence the pan evaporation; changes of maximum air temperature also influenced the changes pan evaporation in some basins.

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