Nature Environment and Pollution Technology
An International Quarterly Scientific Journal

ISSN: 0972-6268	Vol. 13	No. 2	pp. 289-296	2014

Original Research Paper

Applicability of Different Models of Reference Crops Evapotranspiration in China

Xi Wang*, Honglei Wang, Fangfang Jia* and Xiuru Wang***
*School of Soil and Water Conservation, Beijing Forestry University, Beijing 100083, China
**Key Laboratory of Water and Sediment Sciences, Ministry of Education, Department of Environmental Engineering, Peking University, Beijing 100871, China
Corresponding author: Xiuru Wang

Nat. Env. & Poll. Tech.
Website: www.neptjournal.com
Received: 6-3-2014
Accepted: 4-5-2014

Key Words:
Reference crops
Evapotranspiration
Empirical methods
Weather stations

ABSTRACT

Measuring and counting reference crops evapotranspiration (ET_0) accurately is of great importance for water resources evaluation and efficient utilization of agricultural water resources. In order to evaluate the applicability of the six formulas in China, this paper selected eight weather stations. They were Erlianhaote, Jiexiu, Yuncheng and Yichang stations which are on the same longitude but in different climatic conditions, and Tieganlike, Huailai, Jinzhou and Dandong weather stations which are on the same latitude but in different climatic conditions. By taking the daily meteorological data of 1960-2012 as the original data, the paper adopted Penman-Monteith method, Makkink, Penman, Kimberly Penman, Hargreaves-Samani, Priestley Taylor and Irmark-Allen to calculate the daily reference crops evapotranspiration. And the other 6 methods were contrastively analysed by using the Penman-Monteith method proposed by United Nations Food and Agriculture Organization. The results show that in the same longitude and latitude, score sequence of Makkink, Pemman and Kimberly Penman is: humid area>sub-arid areas>sub-humid areas>arid areas. Irmark-Allen's entropy score sequence was sub-humid area>sub-arid areas>arid zone>humid area. But in the two cases, the order of Hargreaves-Samani and Priestley Taylor is different. The suitability of Hargreaves-Samani and Priestley Taylor is the best in China, followed by Irmark-Allen and Makkink, but the applicability of Penman and Kimberly Penman is poorer. This paper provides theoretical basis and reference by using different types of the formulas to calculate reference crops evapotranspiration in different regions of China.

INTRODUCTION

Reference crops evapotranspiration (ET_0) reflects the influence of meteorological factors on the plant transpiration. It is both an important parameter to calculate crop water requirement and an important basis of reasonable farmland water management and irrigation engineering design. There are dozens of empirical formulas for computing ET_0. The United Nations Food and Agriculture Organization (FAO) has recommended the FAO-56 Penman-Monteith formula (P-M) as a standard formula for computing the reference crop water requirement (Allen et al. 1998), because that it considers comprehensively the factors affecting evapotranspiration including maximum temperature, minimum temperature, relative humidity, wind speed, sunshine time and so on, and it has universal applicability (Pereira & Pruitt 2004, Gavilan et al. 2007). But this method needs more input parameters, so it could not be applied if a certain data are deficient. In this case, some formulas which need less entering of data can be chosen to calculate ET_0, such as Hargreaves method based on temperature (Hargreaves & Allen 1994, Hargreaves & Allen 2003), and Priestley Taylor method based on radiation (Pereira 2004, Suleiman & Hoogenboom 2007, Liu & Lin 2005). As these simple methods have been established in the specific climatic conditions, they should be corrected when applied to other areas (Helge 2011, Jensen et al. 1990).

In recent years, experts and scholars have done a lot of research (Ali et al. 2012, Al-Ghobari 2000, Sabziparvar et al. 2010, Li 2012, Fan et al. 2012, Gundekar et al. 2008) on ET_0 in formula application at home and abroad. Hu Shunjun and other people compared ET_0 computed by P-M formula with that computed by modified Penman formal, found that they had a significant linear correlation (Hu et al. 2005). Wang Xinhua used the Hargreaves and P-M formula respectively to calculate ET_0 in the northwest arid areas, then put forward the formula which was suitable for that area (Wang et al. 2006). Tabari evaluated the application of four models to calculate ET_0 in four climate types of Iran, including Makkink, Turc, Priestley Taylor and Hargreaves (Tabari 2010). The results showed that the Turc model was the most suitable for cold-humid and dry climate, while Hargreaves was the most accurate in warm-humid and sub-arid climate.

Khoob (Ali 2008) contrasted Hargreaves and artificial neural network in a sub-arid environment, and the results showed artificial neural network could be substitute for P-M to calculate ET_0 when it lacks meteorological data. To assess the applicability of Hargreaves, Thornthwaite, Turc, Priestley Taylor and Jensen-Haise in the humid regions, Trajkovic analysed computed results finding in the humid climate, and Turc was the most appropriate (Trajkovic & Kolakovic 2009).

According to the above research, those models may have feasibility of different degrees. Based on dry and wet climates in China, including arid, sub-arid, sub-humid and humid, this paper chose Erlianhaote station, Jiexiu station, Yuncheng station and Yichang station which are on the same longitude but in different climate conditions. Meanwhile, Tieganlike station, Huailai station, Jinzhou station and Dandong station which are on the same latitude but in different climate conditions were selected with the goal to evaluate the applicability of different models in different regions of China. By taking the daily meteorological data of 1960-2012 as the original data, the paper adopted Penman-Monteith method, Makkink, Penman, Kimberly Penman, Hargreaves-Samani, Priestley Taylor and Irmark-Allen to calculate the daily reference crops evapotranspiration. And the other 6 methods were contrastively analysed by using the Penman-Monteith method proposed by United Nations Food and Agriculture Organization (FAO). The result can provide basis and reference for the calculation of reference crops evapotranspiration by different formulas in different areas of China.

MATERIALS AND METHODS

Study area: In order to explore the applicability of different formulas to calculate ET_0 in China, according to the four climate zones divided by China's meteorological administration (cma) from the northwest to the southeast which are arid areas, sub-arid areas, sub-humid areas and humid area (Jiang 2010), Erlianhaote, Jiexiu, Yuncheng and Yichang station which are on the same longitude but in different climate conditions and Tieganlike, Huailai, Jinzhou and Dandong weather stations which are on the same latitude but in different climate conditions were selected to analyse the variation regularity of ET_0 with different meteorological factors. Basic conditions of weather stations are given in Table 1.

Data sources: The raw meteorological data come from China ground weather material international exchange station data set offered by China Meteorological Data Sharing Service System. This article uses the daily meteorological data of 8 stations from 1960 to June, 2012 to compute daily ET_0, including 20-20 o'clock average precipitation, air pressure, average wind speed, average temperature, average relative humidity, sunshine duration, daily minimum temperature and daily maximum temperature.

Empirical methods: Based on P-M formula's results, the applicability of the 6 empirical ET_0 calculation methods were assessed. They respectively were MK, PA, KP, HS, PT and IA. The reason of assessing these methods was that the application was very broad. Few meteorological factors were demanded and the calculation was more simple than the P-M formula.

$$ET_{0(\mathrm{P-M})} = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T+273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)} \quad ...(1)$$

$$ET_{0(\mathrm{MK})} = 0.61 \frac{\Delta}{\Delta+\gamma} \frac{R_s}{2.45} \text{-} 0.12 \quad ...(2)$$

$$ET_{0(\mathrm{PA})} = \frac{\frac{\Delta}{\Delta+\gamma}(R_n - G) + 6.43 \frac{\gamma}{\Delta+\gamma}(1 + 0.537u_2)(e_s - e_a)}{\lambda} \quad ...(3)$$

$$ET_{0(\mathrm{KP})} = \frac{\frac{\Delta}{\Delta+\gamma}(R_n - G) + 6.43 \frac{\gamma}{\Delta+\gamma}(0.75 + 0.993u_2)(e_s - e_a)}{\lambda} \quad ...(4)$$

$$ET_{0(\mathrm{HS})} = \alpha R_a (\mathrm{T_{max}} \text{-} \mathrm{T_{min}})^{1/2} (T + 17.8) \quad ...(5)$$

$$ET_{0(\mathrm{PT})} = 1.26 \frac{\Delta}{\Delta+\gamma} \frac{R_n \text{-} G}{\lambda} \quad ...(6)$$

$$ET_0(\mathrm{IA}) = 0.489 + 0.289 R_n + 0.023T \quad ...(7)$$

Where, ET_0 is reference crop evapotranspiration (mm/day), R_n is net radiation at crop surface (MJ m^{-2} day^{-1}), G is the daily soil heat flux (MJ m^{-2} day^{-1}), T is mean daily air temperature at a height of 2m (°C), u_2 is wind speed at 2m height (m s^{-1}), e_s is saturation vapour pressure (kPa), e_a is the actual vapor pressure (kPa), Δ is the slope of saturation vapor pressure curve (kPa °C^{-1}), y is the psychrometric constant (kPa °C^{-1}), R_s is solar radiation (MJ m^{-2} day^{-1}), 5λ is the latent heat of vaporization (MJ kg^{-1}), T_{max} is the daily maximum temperature (°C) and T_{min} is daily minimum temperature (°C).

Statistical parameters: Statistical parameters such as mean variation *MBE*, root mean square error *RMSE*, consistency coefficient *d* and correlation coefficient *R* were used to evaluate the error between calculated result and the measured result. Calculation methods of statistical parameters are as follows.

$$MBE = \frac{\sum_{i=1}^{n} P_i - Q_i}{n} \quad ...(8)$$

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n} (P_i - Q_i)^2}{n}} \quad ...(9)$$

$$d = 1 - \frac{\sum_{i=1}^{n}(P_i - Q_i)^2}{\sum_{i=1}^{n}(|P_i - \bar{Q}| + |Q_i - \bar{Q}|)^2} \quad ...(10)$$

$$R = \frac{\sum_{i=1}^{n}(P_i - \bar{P})(Q_i - \bar{Q})}{\sqrt{\sum_{i=1}^{n}(P_i - \bar{P})^2}\sqrt{\sum_{i=1}^{n}(Q_i - \bar{Q})^2}} \quad ...(11)$$

Among them, P_i was the calculated value of each method and Q_i was the calculated value of the measured value. $\bar{P}$ $\bar{Q}$ and correspond to the average. *n* was sample number. The smaller the mean deviation *MBE* and root mean square error *RMSE* of the calculation results are, the better the computing method performs; the bigger the consistency coefficient *d* and correlation coefficient *R* of the calculation results are, the greater the computing method is. In this paper, entropy weight method was used for comprehensive evaluation of the above indicators.

Entropy weight method: Four indicators were selected to build the applicability evaluation index system. If there are *n* samples with *m* indicators to be evaluated, evaluation index characteristic value matrix are:

$$X_{m\times n} = \begin{pmatrix} x_{11} & \cdots & x_{1n} \\ \vdots & \ddots & \vdots \\ x_{m1} & \cdots & x_{mn} \end{pmatrix} \quad (i = 1, 2, ..., m;\ j = 1, 2, ..., n) \quad ...(12)$$

Indicators participated in the evaluation were divided into two types: the bigger the better one and the smaller the better one, and this is why characteristic value of matrix (12) should be normalized processed as follows:

For indicators which are the bigger the better type:

$$X'_{ij} = \frac{X_{ij}}{\max X_{ij}} \quad ...(13)$$

For indicators which are the smaller the better type:

$$X'_{ij} = \frac{\min X_{ij}}{X_{ij}} \quad ...(14)$$

Accordingly, normalized matrix X' is gotten as:

$$X'_{m\times n} = \begin{pmatrix} x'_{11} & \cdots & x'_{1n} \\ \vdots & \ddots & \vdots \\ x'_{m1} & \cdots & x'_{mn} \end{pmatrix} \quad ...(15)$$

The evaluation index characteristic values proportion of the NO.j evaluation sample of the NO.i index was as follows:

$$p_{ij} = \frac{x_{ij}}{\sum_{i=1}^{m} x_{ij}} \quad ...(16)$$

Entropy of the NO.i evaluation index was as follows:

$$e_i = -\frac{1}{mn}\sum_{i=1}^{n} p_{ij} \ln p_{ij} \quad ...(17)$$

The weight of the NO.i evaluation index was as follows:

$$a_i = \frac{1 - e_i}{\sum_{i=1}^{n}(1 - e_i)} \quad ...(18)$$

The comprehensive evaluation value of each sample was as follows:

$$W_j = \sum_{i=1}^{m} a_i p_{ij} \quad ...(19)$$

Samples were sorted according to the W_j from big to small.

RESULTS AND DISCUSSION

Applicability of the formulas under different kinds of climate: Based on the results of the P-M formula, mean variation *MBE*, root mean square error *RMSE*, consistency coefficient *d* and correlation coefficient *R* of the ET_0 calculated by 6 kinds of methods were quantized. Quantitative results of each indicator of the four sites in the same longitude are given in Table 2.

In the arid Erlianhaote station, daily mean value of ET_0 was from 1960 to June 2012 was 3.25 mm, but the results of the six methods were between 2.18mm and 4.62mm. Average deviation was between 1.07mm and 1.37mm, and PA and KP overestimated ET_0 value, while the other 4 methods underestimated it. In terms of MBE and RMSE, PA got the best effect with the MBE 0.52 mm, followed by IA, HS and PT. R values among 6 methods and P-M formula were 0.897-0.996 and all of them were greater than 0.900 except IA's, which showed good correlation with P-M formula. In terms of *d*, *d* of PA, HS and KP were greater than 0.900, which were better than the other three models. According to the comprehensive score calculated by entropy weight method, it could be thought that in the arid Erlianhaote station, PA and IA's results were the best, HS and PT were the second while MK and KP performed poorer.

In sub-arid Jiexiu station, MK and PT underestimated the ET_0 value, while the other 4 methods overestimated it; PA had high correlation with P-M formula, but as a result of MBE and RMSE, PT and IA performed best, followed by HS and PA.

In sub-humid Yuncheng station, MK and PT underestimated ET_0, nevertheless the other 4 methods overestimated it; MBE of IA was minimum, which was only 0.05. R of PA was extremely high reaching 0.998. But from perspective of entropy score, PT and PA had best effect while IA and MK took second place. At the same time, KP and HS were poorer.

Table 1: Basic situation of meteorological stations.

Station Designator	Station Name	Climate Type	Longitude	Latitude	Elevation /m	Average Annual Rainfall/mm	Average Annual ET_0/mm
51765	Tieganlike	arid	87°42′E	40°38′N	84.6	346.2	1213.4
54405	Huailai	sub-arid	115°30′E	40°24′N	53.68	381	1111.3
54337	Jinzhou	sub-humid	121°07′E	41°08′N	6.59	575.6	1030.6
54497	Dandong	humid	124°20′E	40°03′N	1.38	976.9	836.1
53068	Erlianhaote	arid	111°58′E	43°39′N	96.47	134.9	1184.8
53863	Jiexiu	sub-arid	111°55′E	37°02′N	74.39	461.5	1005
53959	Yuncheng	sub-humid	111°01′E	35°02′N	11.04	530.2	1135.5
57461	Yichang	humid	111°18′E	30°42′N	13.31	1150	928.6

Table 2: Statistical characteristics of the ET_0 calculated by each method in the same longitude.

Station	Formula	Mean Value/mm	MBE	RMSE	d	R	Score
Erlianhaote	MK	2.18	-1.07	1.59	0.863	0.927	0.013
	PA	3.77	0.52	0.64	0.986	0.996	0.028
	KP	4.62	1.37	1.78	0.918	0.983	0.010
	HS	2.63	-0.62	1.06	0.951	0.942	0.022
	PT	2.27	-0.98	1.47	0.897	0.910	0.014
	IA	2.70	-0.55	1.36	0.896	0.897	0.023
Jiexiu	MK	2.21	-0.54	0.82	0.933	0.941	0.026
	PA	3.23	0.48	0.53	0.979	0.998	0.031
	KP	3.57	0.82	0.98	0.938	0.985	0.018
	HS	3.10	0.34	0.94	0.935	0.903	0.037
	PT	2.58	-0.17	0.78	0.951	0.915	0.071
	IA	3.01	0.26	0.77	0.942	0.908	0.049
Yuncheng	MK	2.29	-0.82	1.20	0.889	0.924	0.017
	PA	3.62	0.51	0.56	0.983	0.998	0.029
	KP	4.08	0.97	1.18	0.939	0.989	0.015
	HS	3.21	0.10	0.93	0.945	0.895	0.120
	PT	2.78	-0.33	0.85	0.954	0.924	0.039
	IA	3.16	0.05	0.90	0.933	0.914	0.250
Yichang	MK	2.13	-0.41	0.56	0.964	0.974	0.034
	PA	2.98	0.44	0.49	0.979	0.998	0.034
	KP	3.08	0.54	0.61	0.968	0.996	0.027
	HS	3.04	0.50	0.77	0.943	0.937	0.028
	PT	2.85	0.31	0.53	0.976	0.983	0.044
	IA	3.23	0.69	0.77	0.936	0.980	0.021

In humid Yichang station, MK underestimated ET_0 value but the other 5 ways overestimated it; The RMSE and R of PA were doing very well, from the perspective of entropy score, the best was PT, followed by PA, MK and HS.

In general, in arid areas, the majority of formulas' score was smaller than in other climate zones, which showed that the formula is not suitable for arid areas. Among them, MK, PA, KP formulas' entropy score sequence were: humid area >sub-arid areas>sub-humid areas>arid areas. HS entropy

Table 3: Statistical characteristics of the ET_0 calculated by each method in the same latitude.

Station	Formula	Mean Value/mm	MBE	RMSE	d	R	Score
Tieganlike	MK	2.48	-0.84	1.53	0.861	0.880	0.009
	PA	3.90	0.58	0.66	0.983	0.996	0.014
	KP	4.38	1.06	1.33	0.945	0.993	0.007
	HS	3.56	0.24	1.13	0.944	0.898	0.028
	PT	2.65	-0.67	1.31	0.913	0.890	0.011
	IA	2.97	-0.35	1.28	0.897	0.888	0.019
Huailai	MK	2.34	-0.71	0.99	0.918	0.938	0.011
	PA	3.60	0.55	0.62	0.976	0.997	0.014
	KP	4.14	1.09	1.30	0.912	0.973	0.007
	HS	2.89	-0.16	0.91	0.944	0.899	0.040
	PT	2.57	-0.48	0.99	0.935	0.907	0.015
	IA	2.97	-0.08	0.80	0.947	0.903	0.085
Jinzhou	MK	2.11	-0.71	1.01	0.905	0.929	0.011
	PA	3.37	0.55	0.65	0.973	0.995	0.014
	KP	3.96	1.15	1.42	0.897	0.972	0.007
	HS	2.54	-0.28	0.86	0.938	0.894	0.024
	PT	2.39	-0.43	0.97	0.931	0.895	0.016
	IA	2.86	0.05	0.79	0.944	0.898	0.137
Dandong	MK	1.96	-0.33	0.55	0.959	0.950	0.022
	PA	2.75	0.46	0.53	0.969	0.996	0.017
	KP	3.08	0.79	0.96	0.911	0.969	0.01
	HS	2.31	0.02	0.69	0.942	0.892	0.299
	PT	2.33	0.04	0.76	0.941	0.919	0.173
	IA	2.88	0.59	0.87	0.914	0.913	0.013

score order was sub-humid area>sub-arid areas>humid area >arid zone; PT's entropy score order was sub-arid zone> humid area>sub-humid area>arid zone; IA's entropy score sequence was sub-humid area>sub-arid areas>arid zone> humid area.

Table 3 reveals statistical characteristics of the ET_0 calculated by each method in the same latitude. In the arid Tieganlike station, daily average ET_0 from 1960 to June 2012 was 3.32 mm, but the results of the six methods were between 2.48mm and 4.38mm. KP, PA and HS overestimated ET_0 values, while the other three methods underestimate the ET_0 values. For MBE and RMSE, HS was the best with its MBE 0.24 mm, followed by IA and PA. R of 6 methods was from 0.880 to 0.996, and PA and KP's was greater than 0.900. This indicated that there was good correlation to P-M formula. As for consistency coefficient, all was bigger than 0.900 except MK and IA, which means the performance was good. According to the comprehensive score of the entropy weight method, it can be thought that in the arid Tieganlike station, HS and IA's result were greatest, PA and PT's were greater, and MK and KP's result performed weaker.

In sub-arid Huailai station, PA and KP overestimated ET_0 values, and the other 4 methods underestimate the ET_0 value. There was high correlation between PA and P-M formula, but owing to MBE and RMSE, IA and HS had the best effect followed by PT and PA, and MK and KP's were poorest.

In sub-humid Jinzhou station, KP, PA and IA overestimated ET_0 values, meanwhile the other three methods underestimate the ET_0 value. MBE of IA was minimal with only 0.05. But from the perspective of entropy score, IA and HS were greatest, and then PT and PA, MK and KP performed the weakest.

In humid Dandong station, MK underestimated ET_0 values, but the other 5 ways overestimated ET_0 values. RMSE of PA was minimal at 0.53. From the perspective of entropy score, the best were HS and PT, and then MK and PA.

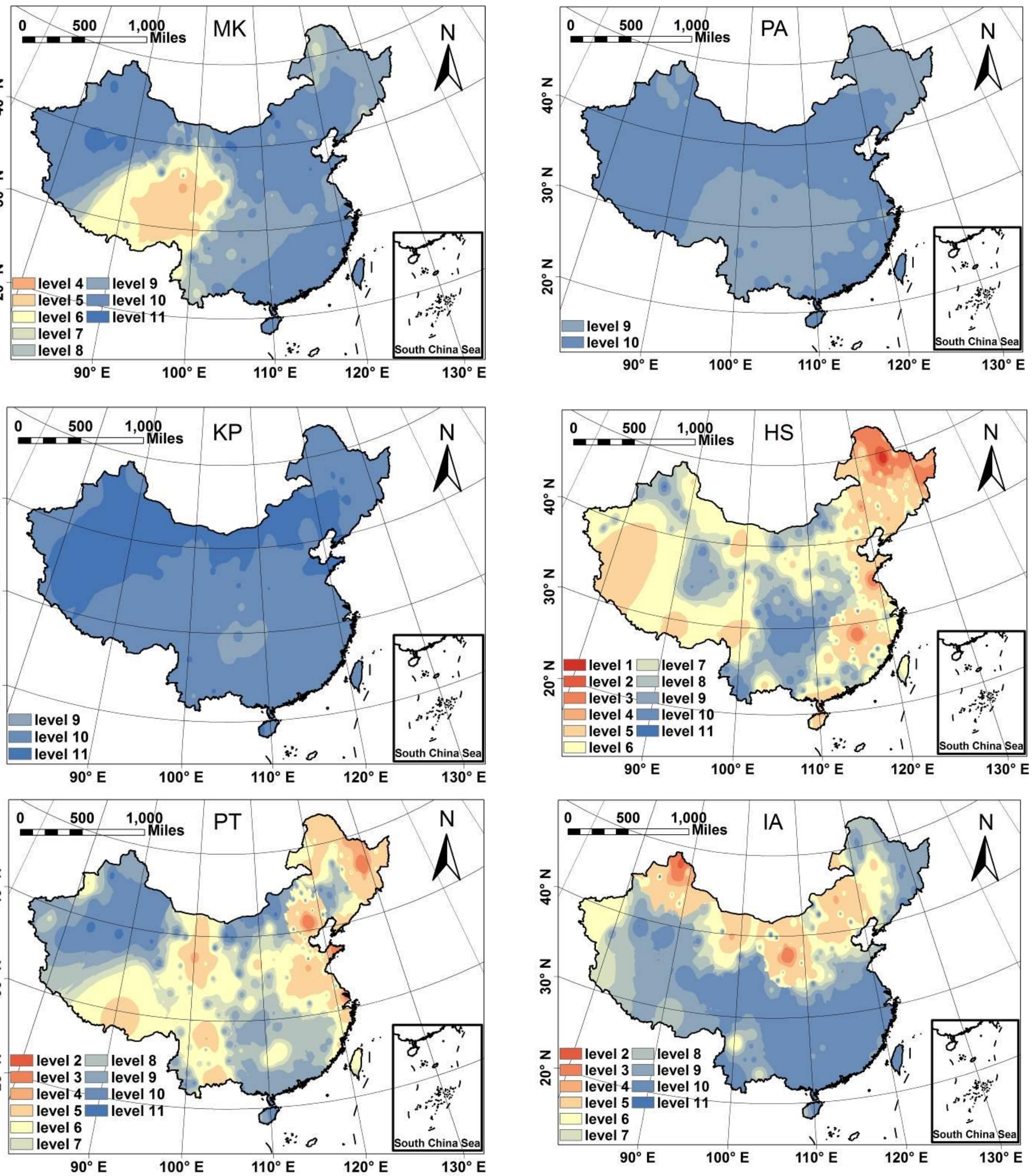

Fig. 1: Suitability classification of 6 empirical methods.

In a word, when the latitude was consistent, score sequence of MK, PA, KP and IA was consistent with that in the same longitude. The scores level of HS of descending order was that humid area>subarid area>arid area> subhumid area; PT's score sequence was humid area>subhumid area >subarid area>arid area.

Spatial distribution of the formulas' applicability in China: Results of 6 empirical methods at 194 stations of China were evaluated and graded from 1-11 according to >0.1, 0.05-0.1, 0.01-0.05, 0.005-0.01, 0.001-0.005, 0.0005-0.001, 0.0004-0.0005, 0.0003-0.0004, 0.0002-0.0003, 0.0001-0.0002 and 0-0.0001. Then spatial interpolation was done for each formula's score respectively in China to analyse the spatial difference of 6 formulas' suitability in China.

Fig. 1 shows that evaluation result of MK was between level 4 and level 11, taking up eight grades in total. More than three-quarters of the area were under level 8. The effect was better in Qinghai, most areas of Xinjiang, Gansu,

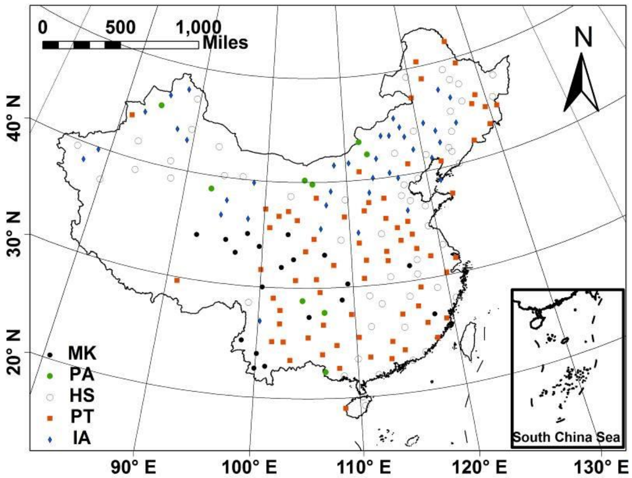

Fig. 2: The most appropriate models in 194 stations of China.

Sichuan and western area of Yunnan.

Evaluation value of PA and KP were generally low in China. PA formula's results were level 9 and level 10, namely all the scores were less than 0.0003, which means the effect was weaker. The value of KP was between level 9 and level 11, which means the effect was worse. So KP was not recommended in China.

HS formula had good performance in most parts of China, especially in the northeast. There were 4.84 hm^2 area whose value was higher than 0.5 in the junction of Inner Mongolia and Heilongjiang. The area under level 8 accounted for only less than 15% of the total area, most of which was in western Qinghai province, southern Gansu, east of Sichuan, southern Shaanxi, southern Henan, west of Hubei and northwestern Hunan, Chongqing, Guizhou, western Guangxi, central and southern Yunnan. There were patches performing poorer in Xinjiang, Inner Mongolia and Guangdong.

Both PT and IA made up ten levels. Result of PT was only next to HS formula. It was better in northeast of China and Shandong peninsula, and the area which was equal or greater than level 6 is about 46%. The total area which was under level 8 was less than 30%, mainly distributing in Xinjiang, northern Tibet, northwest of Qinghai, central Inner Mongolia, southwest of Hubei, northwest of Hunan, southern Chongqing, northeast of Guizhou, south of Guangdong and Guangxi, and Hainan provinces. IA's value became smaller from north to south. The area which is on level 6 or above accounted for 30 percent of total area, mainly distributing in northern and western Xinjiang, most area of Inner Mongolia, northwest and the east of Gansu, north of Qinghai, Ningxia, most area of Shaanxi and Shanxi, Hebei, Beijing, Tianjin, west of Heilongjiang-Jilin-Liaoning. In southern region it appeared only in Lijiang, Zhongdian, JianChuan, Eryuan, Heqing, Yongsheng, Ninglang yi autonomous county in Yunnan. The best results appeared in ALeTai city on the edge of northern Xinjiang uygur autonomous region. Area under level 8 occupied nearly 50% of the total area.

In conclusion, the performance of HS and PT were the most applicable in China, followed by IA and MK, but PA and KP performed weakly.

Selection of methods in areas without enough data: Fig. 2 shows the preferred ET_0 calculation formula in the 194 weather stations. MK were suitable for 19 stations, all of them located in the south of 40°N; there were 9 stations prior to PA, only taking up 5%, namely PA was applicable in minority areas of China. KP was appropriate for no stations, that was to say this formula was not suitable in China. HS was appropriate at 56 weather stations, the distribution of those stations was uniform, so HS was suitable in most parts of China. Seventy two stations that evenly distributed preferred to use PT, this formula had extensive applicability in China; IA was optimum at 38 stations and they were mostly in the north of China. When choosing formula to calculate ET_0, the climate could be compared with above 194 weather stations and then the formula which is appropriate in the station with similar climatic condition could be selected.

CONCLUSION

1. When the longitude is consistent, in the arid Erlianhaote station, PA and IA have the best results, HS and PT take the second place, MK and KP have the worse effect. In sub-arid Jiexiu station, the effects of PT and IA are the best, followed by HS and PA; in sub-humid Yuncheng station, PT and PA perform greatly, IA and MK perform a little poorly, and KP and HS are the worst. In the humid Yichang station, the best is PT, followed by PA, MK, and HS. Scores of MK, PA and KP are in order humid area>sub-arid area>sub-humid area>arid areas. HS's score order is sub-humid area>subarid area>humid area>arid area; PT's sequence is sub-arid zone>humid area>sub-humid area>arid zone. The order of appropriateness of IA is sub-humid area>subarid area>arid area>humid regions.
2. When the latitude is consistent, in the arid Tieganlike station, HS and IA have the best results, PA and PT are the second, and MK and KP are the weakest. In sub-arid Huailai station, IA and HS are the best, followed by PT and PA, and MK and KP perform poorly. In sub-humid Jinzhou station, IA and HS perform best, PT and PA take the second place, and MK and KP are worst; in humid Dandong station, the effects of HS and PT are the best,

followed by MK and PA. The order of appropriateness of MK, PA, KP and IA is consistent with that in the same longitude. HS's score is in order humid area>sub-arid area>arid area>sub-humid area; PT's sequence is humid area>sub-humid area>sub-arid area>arid area.

3. From the perspective of spatial distribution of entropy evaluation score, MK performs well in Qinghai, most area of Xinjiang, west of Gansu-Sichuan-Yunnan; PA and KP generally get a lower value in China; HS has good performance in most parts of China, especially in the northeast; result of PT is a little worse than HS, which has a good effect in northeast of China and Shandong peninsula. IA's result gradually becomes poor roughly from north to south.
4. According to the comparison of evaluation score of 194 weather stations in China, MK is the most suitable for 19 stations located in the south of 40°N; PA is appropriate for 9 stations, taking up 5%, namely it is proper in minority areas of China. KP is appropriate for no station, namely that this formula is not suitable in China; 56 weather stations are appropriate with HS, these stations distribute evenly, so it could be explained that it is applicable in many parts of the country. There are 72 stations distributing evenly suitable for PT, this formula has extensive applicability in China; IA is fit to 38 stations, most of which are in the north of China. When choosing ET_0 calculation formula, we can compare climate in the 194 weather stations and select formula according to stations in which the climate is alike.

This research focuses on the calculation of ET_0. Variation and influential mechanism of actual evapotranspiration are still to be researched.

ACKNOWLEDGMENTS

The authors would like to thank the anonymous reviewers for their valuable comments and suggestions which improved the quality and level of the article. The authors would like to thank China Meteorological Data Sharing Service System for offering raw meteorological data. This study was done in Key Laboratory of Soil and Water Conservation and Desertification Combating, School of Soil and Water Conservation, Beijing Forestry University.

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