Spatial distribution of reference crop evapotranspiration in Hangjiahu Area

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Abstract. The reference crop evapotranspiration ($ET_0$) is an important parameter for calculating crop water requirement. Based on meteorological data of nearly 50 years from 6 meteorological stations in Hangjiahu area, the reference crop evapotranspiration is calculated by using the Penman-Monteith method recommended by Food and Agriculture Organization of United Nations (FAO). By using Geographical Information System (GIS) spatial analysis function, the maps of reference crop evapotranspiration with meteorological parameters used in the analysis are obtained by inverse distance weighted interpolation method. The results show that the mean values of $ET_0$ range from 811.2 to 1039.9 mm, and it decreases from eastern to western of the study area. $ET_0$ values of the plain area are higher than that of the mountain area, which shows the same pattern as the spatial distribution trend of temperature trend.

1. Introduction

Affected by climate change, the global temperature increases significantly, and other meteorological parameters also show the global or regional changes trend, and have brought far-reaching impact to the development of natural ecosystems and agricultural production. Reference evapotranspiration ($ET_0$) is a meteorological parameter which expresses atmosphere evaporation capacity, and basic data of designing and researching irrigation and water conservancy. Studying the space distribution characteristics of reference crop evapotranspiration of Hangjiahu area under climate change has an important guiding significance to estimate crop water requirement of coastal plains, to research the rule of water cycle, to evaluate water resources, and irrigation planning and management.

Several methods are available to calculate the reference crop evapotranspiration ($ET_0$). Among them, Penman-Montieth formula recommended by FAO-56 is more accurate and the widely used [1,2]. Daifei et al. studied the change trends of reference crop evapotranspiration in Bengbu area for more than 50 years, and the analysis showed $ET_0$ increase significantly due to the impact of climate change, and temperature and relative humidity are main influencing factors [3]. Goyal analyzed the sensitivity of $ET_0$ under global warming, and the analysis showed $ET_0$ increase 15 mm when temperature increases 1 centigrade in humid regions [4]. Ni et al analyzed change trends of reference crop evapotranspiration over the years and the relationship with meteorological factors based on daily meteorological data obtained from more than 200 meteorological stations, and the analysis shows that due to the decrease of wind speed and the increase of air temperature, $ET_0$ is decreasing in arid area, semi-arid area and semi-humid area, nevertheless humid area is relatively stable [5]. Kang et al analyzed the effects of climate and non-climate factors on evapotranspiration through experiments, and thought the sensitivity of $ET_0$ to climate change was related to the local climate conditions [6]. Hu et al also researched the variation characteristics, influence factors and correlation analysis [7-9].
Previous studies analyzed change trend of reference crop evapotranspiration in-depth, but most of these analysis are biased towards the inland areas, few people researched spatial distribution and main meteorological factors of $ET_0$ in the coastal plain. This paper uses the statistical methods and GIS to analyze spatial distribution of $ET_0$ in Hangjiahu area under climate change according to the meteorological stations data.

2. Data and methods

2.1. General situation of study area

Hangjiahu area is located in the northern part of Zhejiang Province, including Hangzhou City, Jiaxing City and Huzhou City, north by Jiangsu Province and Shanghai City, East by Ningshao area. Its geographical location is very special. Close to the Taihu territory, has numerous lakes and developed river systems. Northeast is a part of the Plain of Yangtze River Delta, southwest is the mountainous terrain. It has Mild and humid climate, adequate light, and is a subtropical monsoon climate zone. It is rainy in spring and summer (May to July) and frequent typhoon occurs in summer (August to October), average annual precipitation is about 1100 mm, known as "land of fish and rice, silk of the house". Six meteorological stations are selected in Hangjiahu area for the study. Locations of the stations are shown in figure 1.

![Figure 1. Location of Hangjiahu area and the meteorological stations.](image)

2.2. Data

Several sources such as the National Oceanic and Atmospheric Administration (http://data.cma.gov.cn/) and China's meteorological data network (http://gis.ncdc.noaa.gov/) provide the historical meteorological data, The data include daily average temperature, maximum and minimum temperature, average wind speed, sunshine duration, and relative humidity data. Coordinates, elevation and record length of each station are given in table 1.
Table 1. Information for the meteorological observatory stations used in this study.

| Number | Station            | Length of record | Latitude (°N) | Longitude (°E) | Altitude (m) |
|--------|--------------------|------------------|---------------|----------------|--------------|
| 1      | Hangzhou           | 1951~2014        | 30.23         | 120.17         | 41.7         |
| 2      | Tianmu Mountain    | 1956~1997        | 30.35         | 119.42         | 1505.9       |
| 3      | Chunan             | 1998~2014        | 29.62         | 119.02         | 171.4        |
| 4      | Linan              | 2009~2014        | 30.22         | 119.71         | 42.6         |
| 5      | Huzhou             | 2009~2014        | 30.87         | 120.06         | 4.1          |
| 6      | Pinghu             | 1956~2014        | 30.62         | 121.08         | 5.4          |

2.3. Methods

2.3.1. Estimation of reference crop evapotranspiration ($ET_0$). $ET_0$ is evapotranspiration which occur from a standard "reference surface". FAO defines the reference surface is grassland that is highly uniform, vigorous growth, completely covering the soil surface and well-watered. Its height is 0.12 meters, the surface resistance is 70 s m$^{-1}$, and the reflectivity is 0.23. According to the reference surface, FAO proposed Penman-Monteith formula of calculating reference crop evapotranspiration:

$$ET_0 = \frac{0.408 \Delta (R_n - G) + \gamma \frac{900}{t + 273} u (e_s - e_a)}{\Delta + \gamma (1 + 0.34u)}$$  \hspace{1cm} (1)

Where $ET_0$ is the reference crop evapotranspiration, mm d$^{-1}$; $R_n$ is net radiation of canopy surface, MJ m$^{-2}$ d$^{-1}$; $G$ is soil heat flux, MJ m$^{-2}$ d$^{-1}$, ignored in the daily calculation; $t$ is the daily average temperature, °C; $u$ is the wind speed at 2 meters above the surface of the earth, m s$^{-1}$; $e_s$ is the saturation vapor pressure kPa; $e_a$ is actual water vapor pressure kPa; $e_s - e_a$ is saturated with water vapor pressure kPa; $\Delta$ is water vapor pressure curve slope, kPa °C$^{-1}$; $\gamma$ is constant hygrometer, kPa °C$^{-1}$.

2.3.2. Spatial analysis. Inverse distance weighted (IDW) interpolation function of ArcGIS is used for the spatial distribution of $ET_0$. IDW interpolation method is based on the similar principle: the closer the distance between the two objects, the more similar the nature; conversely, the farther the distance, the smaller the similarity. The weighted average by the distance is between the interpolation point and the sample points. The IDW interpolation formula can be expressed as:

$$\hat{Z}(s_0) = \sum_{i=1}^{n} \lambda_i Z(s_i)$$  \hspace{1cm} (2)

Where $\hat{Z}(s_0)$ is predictive value of $s_0$; $n$ is the number of points around the predicted point to be used in the prediction calculation; $\lambda_i$ is to the weights of various points used in the forecast calculation process, the value decreases with the increase of the distance between the sample and the prediction point; $Z(s_i)$ is measured value obtained in $s_i$.

The formula to determine the weights:

$$\lambda_i = \frac{d_i^{-p}}{\sum_{i=1}^{n} d_i^{-p}}$$  \hspace{1cm} (3)

Where $p$ is an index value; $d_{io}$ is the distance between the predicted point and the known sample point $s_i$.

3. Results and discussion
Figure 2 shows the spatial distribution of meteorological parameters for many years in the Hangjiahu area. As can be seen from the figures 2(a)-2(c) the distributions of average temperature, maximum temperature and minimum temperature in the Hangjiahu area show high in the east and low in the west, and the minimum values of them were distributed in Tianmu Mountain area. (d) The average value of relative humidity for many years shows a decreasing trend from the north to the south, and Tianmu Mountain area is relatively higher, but Huzhou close to Taihu Lake is lower. (e) The average value of wind speed for many years shows an increasing trend from the north to the south, and the highest value is mainly distributed in Tianmu Mountain area. (f) The average value of sunshine hours for many years shows a decreasing trend from the north to the south, and the high value is mainly distributed in Jiaxing.

Figure 3 shows the average value of $ET_0$ for many years decreases from east to west, the value in the northern and southern areas is high and middle is low. The value of plains is higher than mountains, and the highest value is distributed in the Huzhou area near Taihu. The results of the study of Luo et al in 2014 showed that the average value of $ET_0$ for many years of Taihu area in Jiangsu Province is also the highest value [10].
4. Conclusions
The average value of \( ET_0 \) in Hangjiahu Area is found between 811.2~1039.9 mm, \( ET_0 \) shows a decreasing trend from east to west. Higher values are seen in the south and north, whereas lower values in the middle. \( ET_0 \) values of the plain area are higher than that of the mountain area.

The spatial distribution of \( ET_0 \) in Hangjiahu Area has roughly the same pattern as temperature (mean temperature, maximum temperature, and minimum temperature). However, it is different from relative humidity, average wind speed, and sunshine hours.

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