Sensitivity analysis of climate factors impacted on evapotranspiration in forested mountainous watersheds

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1. Introduction

Of all the components of the hydrological cycle, evapotranspiration (ET) is the key component and its estimation is the prior task of researchers and practitioners working in the fields of land, crop, water, and atmosphere studies. As climate seems to be changed to some degree everywhere, it is important to understand the relative importance of climatic variables to the variation of reference evapotranspiration.

In this study, a non-dimensional relative sensitivity coefficient was employed to predict responses of ET_0 to perturbations of six climatic variables in two forested mountainous watersheds. We first assessed parameter sensitivity to the estimated evapotranspiration based on FAO 56 Penman-Monteith method and then evaluated the impact of the change of the measured meteorological variables to the estimated reference evapotranspiration. Finally, we compare the relative influence of each meteorological parameter to reference evapotranspiration.

2. Study Area and Climate Data:

For this study, Enbara and Futatsumori watersheds located respectively in Yamagata city and Nakatsugawa city of Gifu Prefecture, represented with Tarumi and Kurakawa climatic stations of the JMA (Fig. 1). The daily data of maximum and minimum temperatures (*T*max and *T*min) at a height of 2 m, wind speed (u_z) at a height of 10 m, maximum and minimum relative humidity (*RH*max and *RH*min), and sunshine duration (*n*) of 39-year (1979–2017) period for the selected stations were obtained from the AMeDAS. Since the data of relative humidity has not been observed in the mentioned stations, distance-based interpolation approach was applied to use neighbor stations's *RH* data and estimate *RH* at selected stations. In this regard, Fukui, Gifu and Takayama data were used to estimate *RH* at Enbara and *RH* data for Futatsumori were estimated using the relative humidity data of Iida, Gifu and Takayama stations.

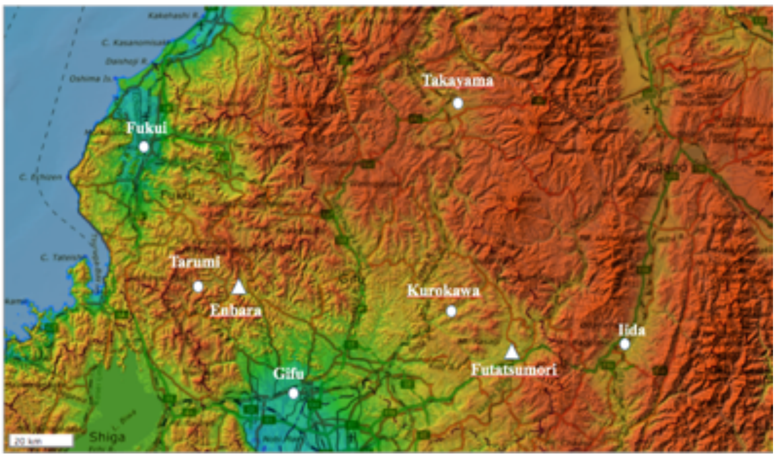

Figure1. Location of stations. AMeDAS stations: Circle; Watersheds: Triangle. (copyright from https://maps.gsi.go.jp)

3.Methodology

3.1. Reference evapotranspiration

Among a group of methods, the Penman–Monteith has been commonly applied to calculate reference evapotranspiration as this method has been also recommended by the Food and Agriculture Organization of the U.N. (FAO). This method takes into account both meteorological and physiological crop variables (Allen et al., 1998). For 24-hour calculations of ET_0, from daily data the FAO 56 Penman-Monteith is given by:

$$ET_o = \frac{0.408\Delta\,(R_n - G) + \gamma \frac{900}{T+273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34\,u_2)}$$

where ET_0 is the reference evapotranspiration (mm), *Rn* is the net Radiation (MJ m^{-2} d^{-1}), Δ is the slope of saturation vapour pressure curve (kPa °K^{-1}), e_s is the mean saturation vapour pressure (kPa), e_a is the actual vapour pressure (kPa), u_2 is the mean wind speed at height 2m (m s^{-1}), *T* is the mean daily temperature (°C), γ is the psychrometric constant (kPa °K^{-1}), and *G* is the soil heat flux (MJ m^{-2} d^{-1}).

3.2. Sensitivity analysis

Sensitivity analysis is required to gain a better understanding of the meteorological systems; particularly to indicate the physical meaning of each meteorological parameter used in the estimation of the reference evapotranspiration. Several dimensionless sensitivity coefficients have been proposed, based on the partial derivative of the dependent variable (reference evapotranspiration) to the independent variables (meteorological variables). To evaluate the sensitivity of ET_0 related to climatic factors a mathematically defined sensitivity coefficient was used(McCuen, 1974).

$$S(x_i) = \lim_{\Delta x_i \to 0}\left(\frac{\Delta \mathrm{ET}_0/\mathrm{ET}_0}{\Delta x_i/x_i}\right) = \frac{\partial \mathrm{ET}_0}{\partial x_i}\cdot\frac{x_i}{\mathrm{ET}_0}$$

where x_i is the ith climatic factor and $S(x_i)$ is the sensitivity coefficient of ET_0 related to x_i. A positive (or negative) sensitivity coefficient of a climatic variable indicates that ET_0 will increase (or decrease) as the climatic variable increases (or decreases). The larger the sensitivity coefficient, the larger effect a given variable has on ET_0.
For this purpose, the parameters were changed within a range of −30 to +30 % at an interval of ±5 % (twelve scenarios) and then the percent change of ET_0 was calculated(Goyal, 2004) . Finally, the percent changes of the mentioned climatic parameters against percent changes of the output ET_0 were plotted as a sensitivity curve.

4. Result and Discussion:

Right-hand corner of the Figure 2 shows the curves of the sensitivity analysis of ET_0 obtained by FAO-56 PM model for each of the weather parameters in the selected stations in annual time scale. Sensitivity curves of ET_0 to climatic variables are generally linear. Also, the slope of lines for sensitivity of ET_0 to RH is negative for all stations. According to Fig. 2, at both stations the most controlling factors to ET_0 is first Tmax and then n. On the other hand, Tmin is the less sensitive variable on ET_0. In response to the increase climate variables by +30 %, the larger and less value of percent change in ET_0 are about 11 % (Tmax) and 2.5 % (Tmin), respectively.
Left-hand corner of the Figure 3, compares annual relative influence of climate variables on ET_0 at two stations. As shown, sunshine duration has more influence on ET_0 in Futatsumori rather than Enbara. This might come from the topographical differences which two watersheds located in. Enbara watershed is located in the boundary of plain and mountain areas which changes the heat transfer processes comparing Futatsumori watershed with the characteristics of uniform mountainous area. That caused non matching patterns of n and Tmax at Enbara (Fig.2 left). Right-hand corner of the Figure 3 compares seasonal differences in sensitivity coefficient at two watersheds. As seen during hot seasons, Tmax and n have more effects on ET_0 while for the cold seasons, RH effect is dominant.
We conclude that changes in temperature due to the global warming will lead to considerable change in ET_0. Since increasing the value of ET_0 would affect water budget, the results of this work can be used as a theoretical basis for future research on the response of hydrological process to climate change.

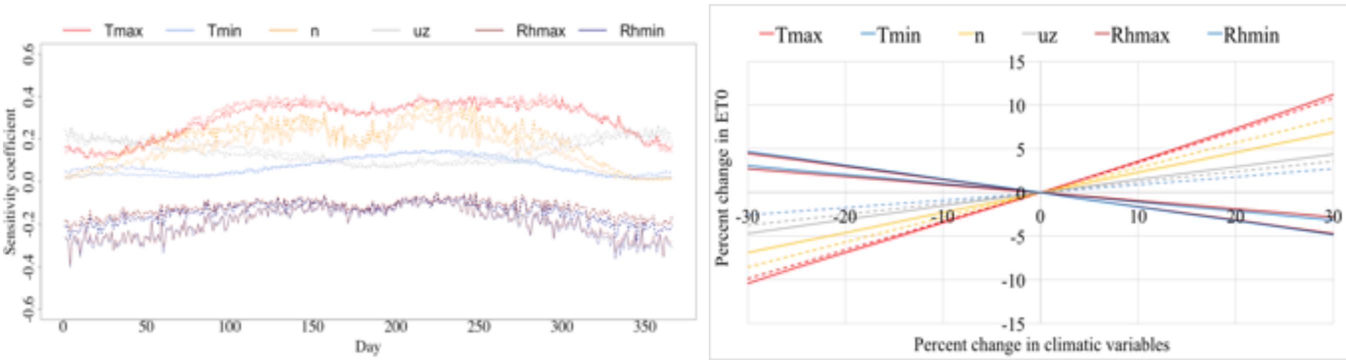

Figure 2. left: Mean daily sensitivity coefficient, right: Percent changes in ET_0 with respect to changes in climatic variables in annual time scale. Enbara (soild) and Futatsumori (dashed).

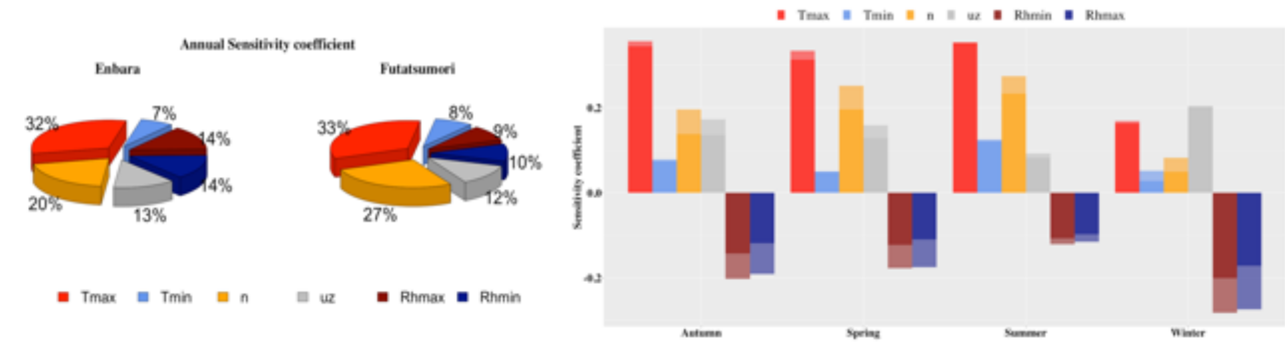

Figure 3. left: Comparison of annual relative influence of climate variables on ET_0, right: Mean seasonal sensitivity coefficients of two watersheds; Enbara (light colors) and Futatsumori (dark colors).

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