

Advances in Determination Methods for Potential Soil Evaporation: Postprint

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Abstract

Based on research achievements in soil evaporation models from related fields and combined with the characteristics of evaporation processes in geotechnical engineering, this study introduces the development and current status of methods for determining potential soil evaporation, and analyzes the applicable conditions and parameter determination for each theoretical model. The following conclusions are drawn: (1) Under specific regional and climatic conditions, it is necessary to determine a relatively suitable theoretical model for estimating potential evaporation through comparative analysis of multiple theoretical models. (2) Meteorological parameters exhibit significant regional characteristics; even in small areas with similar climatic features, meteorological parameters retrieved from data provided by different weather stations are not identical. Therefore, meteorological parameters retrieved from meteorological data require correction. (3) The application of existing evaporation measurement techniques to evaporation measurement in geotechnical engineering requires further in-depth research and development. Future research directions for this topic in the field of geotechnical engineering are proposed, including the evaporation mechanism during the stable evaporation stage of soil, the hysteresis effect of evaporation, the influence of nocturnal soil moisture variation on evaporation, the establishment of a universal evaporation model, and the scale effect of measured evaporation.

Full Text

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Abstract

Based on research achievements in potential evaporation models for soil moisture across related disciplines, and combined with the characteristics of evaporation processes in the geotechnical engineering field, this paper summarizes advances in determining potential evaporation of soil moisture and analyzes application conditions and parameter determination methods for estimating potential evaporation. The key findings are: (1) Under specific climate conditions in particular regions, it is necessary to select relatively appropriate theoretical models to estimate potential evaporation by comparing various theoretical models. (2) Meteorological parameters are regionally variable; even in small regions with fairly similar climates, different inversion meteorological parameters could be drawn from data at different stations, so inversion meteorological parameters should be calibrated. (3) A thorough study should be performed on evaporation measurement technology in the geotechnical engineering field. Future research topics in geotechnical engineering are provided, including the evaporation mechanism of the stable stage, the hysteresis effect of evaporation, the effect of moisture change on evaporation at night, construction of universal soil moisture evaporation theoretical models, and the scale effect of evaporation measurement.

Keywords: potential evaporation; evaporation process; theoretical model; evaporation measurement

1 Introduction

The evaporation process of soil moisture is typically divided into three stages: the stable stage, the falling rate stage, and the dry stage. In the stable stage, the evaporation rate remains constant and is primarily controlled by atmospheric evaporation capacity. During the falling rate stage, the evaporation rate gradually decreases and is controlled by both atmospheric evaporation capacity and soil moisture conditions. In the dry stage, the evaporation rate approaches zero. Dalton's law forms the theoretical foundation for most evaporation models, which can be categorized into three types: water surface evaporation models, soil surface evaporation models, and comprehensive models. The Penman model, developed in 1948, combines energy balance and aerodynamic principles and has been widely applied. Various modified versions exist, including the FAO-24 Penman and FAO-56 Penman-Monteith methods.

2.3 Penman Model

The Penman model calculates potential evaporation as:

$$E_0 = c[W \cdot Rn + (1 - W) \cdot f(u) \cdot (e_s - e_a)]$$

where E_0 is potential evaporation ($\text{mm} \cdot \text{d}^{-1}$), W is a weighting factor, Rn is net radiation ($\text{MJ} \cdot \text{m}^{-2} \cdot \text{d}^{-1}$), $f(u)$ is the wind function, and $(e_s - e_a)$ is the vapor pressure deficit (hPa). The wind function is typically expressed as $f(u) = a + bu$, where u is wind speed ($\text{m} \cdot \text{s}^{-1}$) and a, b are empirical coefficients.

2.5 Hamon Model

The Hamon model, proposed in 1961, estimates potential evaporation using temperature and daylight hours:

$$E_0 = \frac{CD^2P_t}{100}$$

where E_0 is potential evaporation ($\text{mm} \cdot \text{d}^{-1}$), C is a coefficient (typically 0.55), D is daylight hours (12h), and P_t is saturated vapor pressure at mean temperature T_a . The FAO recommended a modified version with $C = 0.65$.

2.6 Turc Model

The Turc model (1961) is expressed as:

$$E_0 = c[W \cdot Rn + (1 - W) \cdot f(u) \cdot (e_s - e_a)]$$

where c is an empirical coefficient ranging from 0.56 to 0.34, and the wind function is:

$$f(u) = 0.27 \left(1 + \frac{u}{100} \right)$$

This model is particularly suitable for humid regions with relative humidity > 50%.

2.7 Penman-Monteith Model

Monteith combined the Penman equation with canopy resistance in 1965:

$$E_0 = \frac{\Delta(Rn - G) + \rho_a c_p \frac{(e_s - e_a)}{r_a}}{\Delta + \gamma \left(1 + \frac{r_s}{r_a}\right)}$$

where ρ_a is air density ($\text{kg} \cdot \text{m}^{-3}$), c_p is specific heat capacity ($\text{J} \cdot \text{kg}^{-1} \cdot \text{K}^{-1}$), r_a is aerodynamic resistance ($\text{s} \cdot \text{m}^{-1}$), r_s is surface resistance ($\text{s} \cdot \text{m}^{-1}$), and γ is the psychrometric constant.

In 1998, FAO proposed the FAO-56 Penman-Monteith equation for a reference crop:

$$E_0 = \frac{0.408\Delta(Rn - G) + \gamma \frac{900}{T+273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)}$$

where u_2 is wind speed at 2m height ($\text{m} \cdot \text{s}^{-1}$), and the surface resistance is $70 \text{ s} \cdot \text{m}^{-1}$ for a reference crop.

2.9 Hargreaves-Samani Model

The Hargreaves-Samani model (1985) estimates potential evaporation using temperature and solar radiation:

$$E_0 = 0.0135 \times KT \times (T_{av} + 17.8) \times (T_{max} - T_{min})^{0.5} \times \frac{R_a}{\lambda}$$

where KT is a coefficient (typically 0.17), T_{av} , T_{max} , and T_{min} are average, maximum, and minimum temperature ($^{\circ}\text{C}$), R_a is extraterrestrial radiation ($\text{MJ} \cdot \text{m}^{-2} \cdot \text{d}^{-1}$), and λ is latent heat of vaporization ($2.45 \text{ MJ} \cdot \text{kg}^{-1}$).

3.3 Parameter Inversion

Meteorological parameters show significant regional variability. Even within small areas with similar climates, different meteorological stations may yield different parameter values, necessitating local calibration. Parameter inversion methods include: (1) Using measured evaporation data to calibrate model parameters through optimization algorithms; (2) Employing remote sensing data to estimate regional parameters; (3) Applying machine learning techniques to establish relationships between parameters and environmental factors.

The S-SEBI (Simplified Surface Energy Balance Index) model and SEBS (Surface Energy Balance System) provide remote sensing-based approaches for regional parameter estimation. These methods use thermal infrared data to solve the energy balance equation and derive evaporation parameters without requiring detailed meteorological observations.

For geotechnical engineering applications, special consideration must be given to the scale effect. Lysimeter measurements represent point-scale evaporation, while numerical models require field-scale parameters. The scale conversion relationship can be expressed as:

$$E_{field} = k \cdot E_{point}$$

where k is a scale factor accounting for spatial heterogeneity in soil properties and atmospheric conditions.

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