

Development of the evaporation component for the physically-based distributed tank model

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Abstract In large river basins there may be considerable variation in both climate and land use across the region. The potential impact of these variations on the evapotranspiration is estimated for two study areas using a physically-based distributed model. Three kinds of models, the Penman-Kotoda, Morton and Brutsaert-Stricker models are validated. The ability of three models to estimate accurately the evaporation of basins with complex topography and land-use classifications is investigated by applying these models to two basins with different topographical and land-use features. Daily, monthly and annual variations for evaporation in the two basins are estimated. Comparison with the results obtained by the water balance method and others shows that the Penman-Kotoda model may underestimate the evaporation in some cases. The Morton and Brutsaert-Stricker models seem to be two kinds of available approaches for estimating the basinwide evaporation.

Key words basins; evaporation; evapotranspiration; land-use classification; hydrological data; meteorological data

INTRODUCTION

The advances in measurement and modelling have made it possible to accurately estimate evaporation at some points, which has a controlling influence on hydrological processes (Flerchinger *et al.*, 1996). However, the ability of a model to estimate the basin evaporation, which has received special attention by hydrologists with increasing interest in physically-based distributed hydrological models recently, has not been adequately examined. The evaporation from river basins is controlled by atmospheric and surface conditions. Numerical models of surface and soil water transport and energy balance should be used to describe this process (Yakirevich *et al.*, 1997). Unfortunately, data of soil and vegetation are usually scarce in practice. Therefore, models with only a few meteorological parameters and data being routinely obtainable at standard weather stations are more interesting for practitioners. The purpose of this study is to test the ability of several models to estimate the actual evaporation across basins with complex topography and land-use classifications. The data to be used

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include air temperature, wind speed, relative humidity, sunshine duration and precipitation.

MODEL DESCRIPTION

Penman was one of the first to describe evaporation in terms of the two main micro-meteorological components: energy for the conversion of water to a vapour and aerodynamic processes for the removal of saturated air away from the surface. The Penman equation is the most widely known combined approach for estimating evaporation. It was developed originally to estimate the potential evaporation of water and saturated land surfaces. In order to convert the potential evaporation from shallow open water to the actual evaporation in the area of interest, the coefficient f , a function of air temperature, wind speed and precipitation, was introduced by Kotoda (1986). The revised Penman approach is therefore defined herein as the Penman-Kotoda model.

By using the complementary relationship between potential evapotranspiration and the actual regional evapotranspiration, Morton (1978) derived a new equation to estimate actual evaporation. The disadvantage of this approach is that it cannot be conceptually used for short time intervals because of subsurface heat-storage changes and because of the lag times associated with the change in storage of heat and water vapour in the atmospheric boundary layer.

Based on the consideration of "advection-aridity", Brusaert & Stricker (1979) derived a similar kind of approach. Briefly, their approach is based on a conceptual model in which, with respect to a hypothetical nonadvective evaporative power of the air used as a reference, the excess in potential evaporation is equal to the deficit in actual evaporation. Both excess and deficit provide an index of the aridity of the atmosphere, and they are related to the regional advection. The approach gave good agreement with daily data of evaporation obtained by means of an energy budget method for a period of severe drought in a rural catchment in western Europe. One of the advantages is that no soil moisture data, no stomatal resistance properties of the vegetation, nor any other additional aridity parameters are further required to determine actual evaporation.

MODEL APPLICATION

The three models described above were used to estimate evaporation for two Japanese river basins. One is the Innbanuma basin, which is a typical closed catchment with an area of 541 km², centred around Innbanuma Lake with 11.55 km² of water surface. Elevation varies from 0 to 85 m a.s.l. The second basin is the Kasumigaura basin, which includes 51 tributaries with a basin area of 2080 km². The climate of this basin is temperate humid with an average annual precipitation of 1300 mm. The average elevation of the Kasumigaura basin ranges from 0 m at the outlet to 687.30 m a.s.l.

The physically-based distributed tank model has been developed using a resolution of 1 km² grid. The evaporation component takes a time series input of meteorological data. These data are combined with land-use data, defining the parameters of the

Table 1 Annual evaporation estimated for Innbanuma basin.

Year	Penman-Kotoda model	Morton model	Brutsaert-Stricker model	Mean value
1955	573	718	727	672
1979	472	652	734	619
1989	398	577	613	529
1996	382	546	576	501

evaporation model such as albedo, to calculate the evaporation rates day by day. Data from several meteorological stations were used. These data consist of daily observations of precipitation, air temperature, humidity, sun hours and wind speed. Land cover is represented by the land-use classification in the model. It consists of nine classes for Kasumigaura and seven classes for Innbanuma basin.

According to the development of urbanization and the data currently available in Innbanuma, the evaporation was estimated for the following years: 1955, 1979, 1989, and 1996. The daily evaporation was estimated by using the three models and was then aggregated to obtain monthly and annual evaporation. Part of those results are given in Table 1. The average evaporation for the four years is 580 mm.

With the combination of observed meteorological data at 11 observation stations in 1979, 1989 and 1995, the actual evaporation at Kasumigaura basin was estimated by using the three models. The average values of three estimations are 499, 525 and 541 mm for 1979, 1989 and 1995, respectively. Because of the large proportion of water surface (300 km²) in the study area, it is quite possible that the Penman-Kotoda model underestimates the evaporation due to the effect from the empirical coefficient *f*. If the result estimated by the Penman-Kotoda model is excluded, the average evaporation for the three years becomes 446, 588 and 619 mm, respectively, with a mean value of 551 mm.

ANALYSIS OF RESULTS

It is by no means an easy task to obtain data for observed basinwide evaporation. Fortunately, several related results with good quality have been obtained by others. As one of these examples, Kotoda (1986) estimated the evaporation for the Koise River basin, one of the sub-basins of Kasumigaura, as 582.8 mm. This is larger than the value (551 mm) computed in this study. Observed data are also available for the Yamaguchi River basin, which is adjacent to the Koise River basin, where the annual precipitation and discharge are 1396.0 and 778.0 mm, respectively, according to the observed records for 1970–1975. This means that if neither deep percolation nor change of storage in the areas occur, the potential evapotranspiration may be 618 mm (1396.0 – 778.0). For the entire Kasumigaura catchment, deep percolation or storage changes may happen; therefore the difference of 67 mm between the estimated actual evaporation and the potential evapotranspiration of 618 mm is reasonable. Figure 1 further shows the comparison between the annual evaporation values estimated using the different models for the Kasumigaura basin.

The results show that the Penman-Kotoda model underestimates the annual evaporation by approximately 15% below the average. The results obtained from the Morton and Brutsaert-Stricker models may be considered to be reasonable.

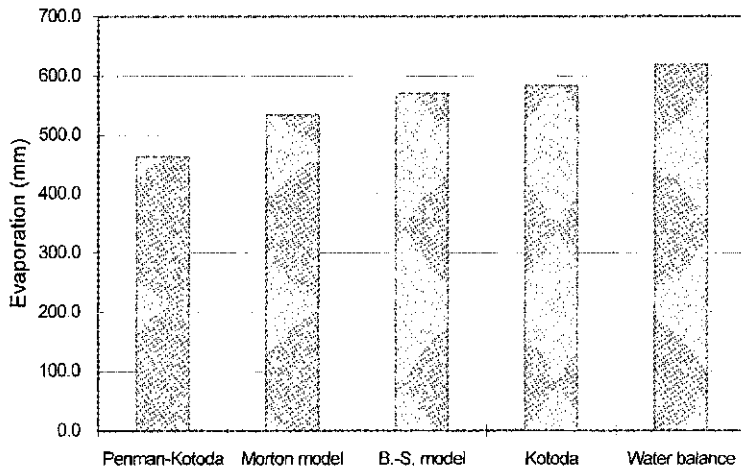


Fig. 1 Comparison of evaporation estimated using different models.

CONCLUSIONS

It should be noted that there are many factors which may affect the evaporation processes. In particular, the physical properties of the soils are important and have a strong influence on the nature of the basinwide evaporation. The results presented in this study are essentially an illustration of the effects that should be observed under various scenarios of climate and land use. Although a rather simple comparison among three models for only several years of data has been performed, the results may enable practitioners to select a more suitable evaporation model.

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