# A SIMPLE APPROACH FOR ESTIMATING ANNUAL EVAPOTRANSPIRATION WITH CLIMATE DATA IN KOREA

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**Abstract:** Estimates of annual actual evapotranspiration are needed in water balance studies, water resources management projects, and many different types of hydrologic studies. This study validated a set of 5 empirical equations of estimating annual actual evapotranspiration with climate data on 11 watersheds, and evaluated the further applicability of these forms in estimating annual runoff on watershed level. Five empirical equations generally overestimated annual evapotranspiration, with relative errors ranging 3.3% to 47.2%. The results show that Schreiber formula can be applicable in determining annual evapotranspiration in sub-humid region that is classified by aridity index, while Zhang equation gave better results than the remaining methods in humid region. The mean differences for annual evapotranspiration bias over 11 watersheds are Zhang, Schreiber, Budyko, Pike, and Ol'dekop formula from lowest to highest. The empirical equations provide a practical tool to help water resources managers in estimating regional water resources on ungauged large watershed.

**Keywords**: Annual runoff, Actual evapotranspiration, Empirical evapotranspiration equation

## 1. INTRODUCTION

Freshwater has been recognized as the important natural resources, as well as the fundamental element of socio-economic progress. In the last two decades the reliable assessment of available water has played a major role in providing key hydrological information for water resource planners and designers in Korea. Many streamflow records are too short or unavailable to permit a valid analysis, but in most watersheds rainfall records extend back over much longer period. Thus a tool of estimating the water yield or a streamflow from climate data is needed.

Runoff is a physical process that is dependent on precipitation, climate, and watershed characteristics such as geology, soil, and land use. Statistical approaches of estimating annual runoff have attempted to develop empirical relationships between annual streamflow collected at many watersheds and available information (Vogel et al., 1999; Duell, 1994; Risbey and Entekhabi, 1996; KICT, 1989). These studies indicated rainfall amount and drainage area are strongly related to annual runoff volume, but estimates of annual runoff are very dependent on the form of proposed statistical model. Other studies have used a simple water balance model (Arnell, 1999;

Yates, 1997; Zhang et al., 2001). Assuming no spatial and temporal variations of watershed characteristics, annual runoff is considered to be a function of precipitation amount and climate data in the water balance approach. Eagleson (1978) and Milly (1994) have developed process oriented annual runoff models with both theoretical and empirical analysis. In addition, a conceptual watershed model can be used to estimate annual streamflow in the United States (Sankarasubramanian and Vogel, 2002; Sankarasubramanian et al., 2001).

Of the approaches mentioned above, the water balance approach may be easily implemented in simulating annual streamflow at the watershed of interest. However, estimation of actual evapotranspiration is a difficult procedure that is affected by potential evapotranspiration, soil moisture, soil and vegetation types. A number of attempts have been made to develop empirical equations relating annual evapotranspiration to climate data (Brutsaert, 1982; Pike, 1964; Zhang et al., 2001). However, the applicability of these empirical equations to complex land use, large-scale watersheds in Korea has not been evaluated.

The purposes of this study are to apply the different empirical equations to 11 watersheds in Korea, and to evaluate the applicability in estimating annual actual evapotranspiration. The performance of the empirical equations was evaluated using a unique database of precipitation, potential evapotranspiration, and streamflow on annual basis for the selected watersheds.

## 2. ANNUAL EVAPOTRANSPIRATION ESTIMATION

The simplest water balance model is the lumped form of the continuity equation applied to a watershed:

$$\frac{dS}{dt} = P - Q - E - G \tag{1}$$

Where $P$ , $Q$ and $E$ are the annual amounts of precipitation, runoff, and actual evapotranspiration, respectively. $G$ is the net amount of groundwater that leaves aquifer storage, and $dS$ represents the change in groundwater storage over the time interval $dt$. Assuming negligible the changes in groundwater and aquifer storage over the long-term period leads to (Pike, 1964; Sankarasubramanian and Vogel, 2002)

$$Q = P - E \tag{2}$$

The key in water balance equation (2) is the value of annual $E$, which is dependent on the long-term average of climate factors, vegetation, and soil moisture condition. Since few methods of measuring $E$ value directly are available, a number of attempts have been made to indirectly calculate an annual value of $E$ using existing climate data.

On the basis of annul values of rainfall, potential evapotranspiration, and runoff measured in a number of watersheds in central Europe, Schreiber (1904) developed a simple relationship (Brutsaert, 1982).

$$E = p[1 - \exp(-E_P / P)] \tag{3}$$

where $E_P$ is a potential evapotranspiration on annual basis.

A few years later, Ol'dekop (1911) suggested the formula for Russian river basins, which is a similar relationship to that of Schreiber (1904) but used a hyperbolic tangent relationship (Budyko, 1974; Brutsaert, 1982).

$$E = E_P \cdot \tanh(P / E_P) \tag{4}$$

Budyko (1958) found that the following equation was derived as the geometric mean of empirical equations proposed by Schreiber (1904) and Ol'dekop (1911) (Budyko, 1974), and further applied this relationship to 29 European river basins larger than 10,000 ㎢ (Arona, 2002; Choudhury, 1999).

$$E = [\{P(1 - \exp(-E_P / P))\} \cdot \{E_P \cdot \tanh(P / E_P)\}]^{0.5} \tag{5}$$

Pike (1964) modified Turc's (1954) relationship to represent a long-term actual evapotranspiration as a function of rainfall and potential evapotranspiration, and applied to four large watersheds in Malawi.

$$E = P[1 + (P / E_P)^2]^{0.5} \tag{6}$$

Zhang et al. (2001) developed a simple function (hereafter abbreviated a Zhang equation) to quantify the long-term impact of vegetation change on annual mean evapotranspiration at a regional scale. The equation can be written as

$$E = P\left[\frac{1 + wE_P / P}{1 + wE_P / P + (E_P / P)^{-1}}\right] \tag{7}$$

where $w$ is the plant-available water coefficient, and has a range from 0.1 to 2.0 (Zhang et al., 1999).

## 3. DESCRIPTION OF DATABASE

### 3.1 Streamflow data

Streamflow data have been collected by different agencies such as Korea Water Resources Corporation (KOWACO), Ministry of Construction and Transportation (MOCT), and Korea Electric Power Corporation (KEPCO) for their purposes. Kim (2001) compiled these data from MOCT et al. (1999) and discussed the details of these. In this study the daily streamflow records were collected at large watersheds (> 100 ㎢). This resulted in a total of 11 gauged watersheds around Korea as shown in Table 1. Their locations are also presented in Figure 1.

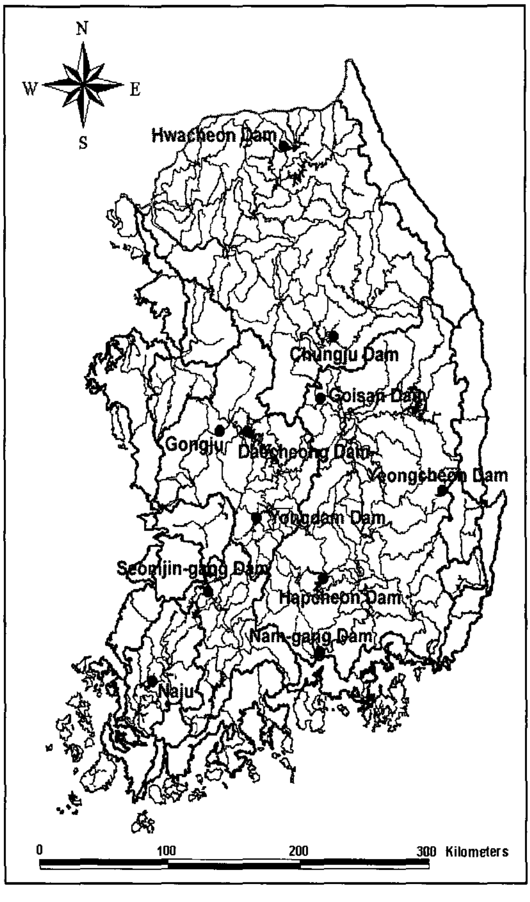


**Figure 1. Location of selected watersheds**

**Table 1. Watershed characteristics and data used**

| Watershed | Area (㎢) | Location | | Data period | Remarks |
|---|---|---|---|---|---|
| | | Lat. | Lon. | | |
| Hwacheon Dam | 3,901 | 38°06'30" | 127°47'41" | 1967-1990 | KEPCO |
| Chungju Dam | 6,648 | 37°00'13" | 127°59'44" | 1986-1996 | KOWACO |
| Goisan Dam | 671 | 36°45'24" | 127°50'47" | 1976-1995 | KEPCO |
| Daecheong Dam | 4,134 | 36°29'50" | 127°28'01" | 1981-1996 | KOWACO |
| Gongju | 7,126 | 36°27'52" | 127°07'38" | 1967-1976 | MOCT |
| Yeongcheon Dam | 235 | 36°03'47" | 129°00'59" | 1983-1996 | KOWACO |
| Yongdam | 937 | 35°57'44" | 127°36'47" | 1970-1976 | MOCT |
| Hapcheon Dam | 925 | 35°33'18" | 128°02'42" | 1989-1996 | KOWACO |
| Seomjin-gang Dam | 763 | 35°32'27" | 127°07'33" | 1975-1996 | KOWACO |
| Nam-gang Dam | 2,285 | 35°09'44" | 128°02'06" | 1976-1996 | KOWACO |
| Naju | 2,060 | 35°01'55" | 126°44'07" | 1966-1981 | MOCT |

KOWACO: Korea Water Resources Corporation
KEPCO: Korea Electric Power Corporation
MOCT: Ministry of Construction and Transportation

### 3.2 Precipitation data

Precipitation is one of the important parameters in the water balance estimation, and varies temporally and spatially. Korea Meteorological Administration (KMA) has operated a number of meteorological stations around Korea. MOCT has also operated rainfall gauges for the purpose of measuring precipitation amount and forecasting flash flooding. The number of rainfall gauges located in the selected watersheds varies from one to fifty three, according to monitoring purpose (Kim, 2001). In this study, annual value of precipitation was obtained using arithmetic mean of precipitation amounts measured at rainfall gauges within the watershed.

### 3.3 Estimation of Potential Evapotranspiration

Potential evapotranspiration can be recognized as a precursor for estimating the actual evapotranspiration and commonly employed in the long-term water balance model. Numerous models for estimating potential evapotranspiration are available and in use. The Penman-Monteith equation is relatively high data demanding, but is the most popular model that can be used to estimate potential evapotranspiration over large area with resonable degree of accuracy (Allen et al., 1998) The Penman-Monteith equation (Allen et al., 1998) is;

$$\lambda ET = \frac{\Delta(R_n - G) + \rho_a c_p \dfrac{(e_s - e_a)}{r_a}}{\Delta + \gamma\left(1 + \dfrac{r_s}{r_a}\right)} \tag{8}$$

where $R_n$ is the net radiation, $G$ is the soil heat flux, $(e_s - e_a)$ represents the vapour pressure deficit of the air, $\rho_a$ is the mean air density at constant pressure, $c_p$ is the specific heat of the air, $\Delta$ represents the slope of the saturation vapour pressure temperature relationship, $\gamma$ is the psychrometric constant, and $r_s$ and $r_a$ are the (bulk) surface and aerodynamic resistances, respectively.

From the equation (8), the FAO Penman-Monteith method to estimate reference evapotranspiration, $ET_0$ for the hypothetical crop with an assumed height of 0.12 m, with a surface resistance of 70 s/m and albedo of 0.23, can be written as (Allen et al., 1998)

$$ET_0 = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T+273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)} \quad (9)$$

where $T$ is mean daily air temperature at 2 m height, and $u_2$ is wind speed at 2 m height.

In this paper, $ET_0$ in equation (9) was used to calculate the potential daily evapotranspiration, and climatic data such as maximum and minimum temperature, relative humidity, wind speed, and sunshine hour, needed to calculate the daily $ET_0$, were taken from meteorological stations operated by KMA. To estimate annual potential evapotranspiration used in equations (3)~(7), daily potential evapotranspiration calculated by equation (9) was compiled on annual basis.

## 4. RESULTS AND DISCUSSION

### 4.1 Estimate of Actual Evapotranspiration

Estimated annual actual evapotranspiration by different empirical equations were compared with observed values on 11 watersheds. As described in equation (2), over an area with no change of water stored within the watershed in the long-term, the difference between precipitation and streamflow can be equal to evapotranspiration. Thus, actual evapotranspiration for each selected watershed was calculated as precipitation minus streamflow volume in units of millimeter per year. Its value can be used in making comparison with estimated evapotranspiration by 5 empirical equations. Table 2 presents the mean values of annual precipitation, actual and estimated evapotranspiration during the computation periods.

Annual mean precipitation ranged from 1,014 mm/yr (Yeongcheon Dam) to 1,330 mm/yr (Naju) with a average of 1,175 mm/yr. It yielded a range in actual evapotranspiration from 409 mm/yr (Hwacheon Dam) to 628 mm/yr (Naju). Approximately 44% of precipitation evaporated from soil and vegetation surfaces over the watersheds. Table 2 also shows that all empirical formulas overestimated annual evapotranspiration, compared with the difference between precipitation and runoff for the corresponding watershed. Bias between actual and estimated evapotranspiration varied somewhat by the applied equation. Annual mean evapotranspiration estimated by Schreiber equation ranged 555 mm/yr (Chungju Dam) to 647 mm/yr (Naju) with an overestimate of evapotranspiration by 18%. Budyko formula tended to overpredict annual evapotranspiration, with bias ranging 68 mm/yr (Yeongcheon Dam) to 252 mm/yr (Hwacheon Dam). Ol'dekop and Pike equations gave the mean bias of 241 mm/yr and 168 mm/yr, respectively. The relationship introduced by Zhang et al. (2001) has a parameter ( $w$ ) to be adjusted with soil and vegetation types. For the collected data from 11 watersheds, it was found that the best fit value of $w$ was 0.2. A comparison of actual and estimated evapotranspiration from Zhang

**Table 2. Actual and estimated annual evapotranspiration on the selected watershed**

| Watershed | P (㎜/yr) | Actual ET (㎜/yr) | Estimated ET (㎜/yr) | | | | |
|---|---|---|---|---|---|---|---|
| | | | Schreiber | Ol'dekop | Pike | Budyko | Zhang |
| Hwacheon Dam | 1,214 | 409 | 594 | 729 | 674 | 661 | 524 |
| Chungju Dam | 1,091 | 433 | 555 | 683 | 630 | 616 | 489 |
| Goisan Dam | 1,079 | 454 | 578 | 708 | 653 | 639 | 506 |
| Daecheong Dam | 1,136 | 517 | 603 | 737 | 681 | 667 | 529 |
| Gongju | 1,219 | 561 | 600 | 739 | 682 | 666 | 530 |
| Yeongcheon Dam | 1,014 | 586 | 596 | 718 | 666 | 654 | 518 |
| Yongdam | 1,205 | 434 | 598 | 738 | 680 | 664 | 528 |
| Hapcheon Dam | 1,099 | 511 | 601 | 726 | 674 | 661 | 525 |
| Seomjin-gang Dam | 1,214 | 557 | 602 | 738 | 682 | 667 | 531 |
| Nam-gang Dam | 1,320 | 537 | 639 | 781 | 723 | 706 | 564 |
| Naju | 1,330 | 628 | 647 | 791 | 732 | 715 | 570 |
| Average | 1,175 | 512 | 601 | 735 | 680 | 665 | 528 |

equation is also listed in Table 2. The differences between observed and estimated evapotranspiration vary from 11 mm/yr at the Daecheong Dam watershed to 116 mm/yr at the Hwachoen Dam watershed. Based on the results summarized in Table 2, Zhang equation was found to be in good agreement with the data collected at 11 watersheds. The mean differences for annual evapotranspiration bias over 11 watersheds are Zhang, Schreiber, Budyko, Pike, and Ol'dekop equation from lowest to highest.

Figure 2 illustrates observations of the evapotranspiration ratio ($E/P$, the ratio of annual evapotranspiration to precipitation) as a function of the aridity index ($E_p/P$), which is the ratio of potential evapotranspiration to precipitation and is the reciprocal of the humidity index (Arona, 2002). The figure also plots the curves derived from the empirical equations (3)~(7). Many of the observations shown in Figure 2 depart significantly from any of the empirical equations. Schreiber formula can be applicable in determining annual evaporanspiration in case of sub-humid region, which is defined as $0.75 \le E_P/P < 2$ by Ponce et al. (2000). In humid region ($0.375 \le E_P/P < 0.75$), the Zhang empirical equation gave generally better result than the remaining methods.

### 4.2 Estimated annual runoff

Long-term water balance at large watershed level can be evaluated using equation (2). A scatter plot of observed and estimated annual runoff from the selected watersheds is shown in Figure 3. Ol'dekop equation yielded large underestimates relative to observed annual runoff volumes. Schreiber, Pike, and Budyko equations also showed large differences in runoff for the selected watersheds. However, the mean error between observed and estimated annual runoff by Zhang equation was 17 mm/yr

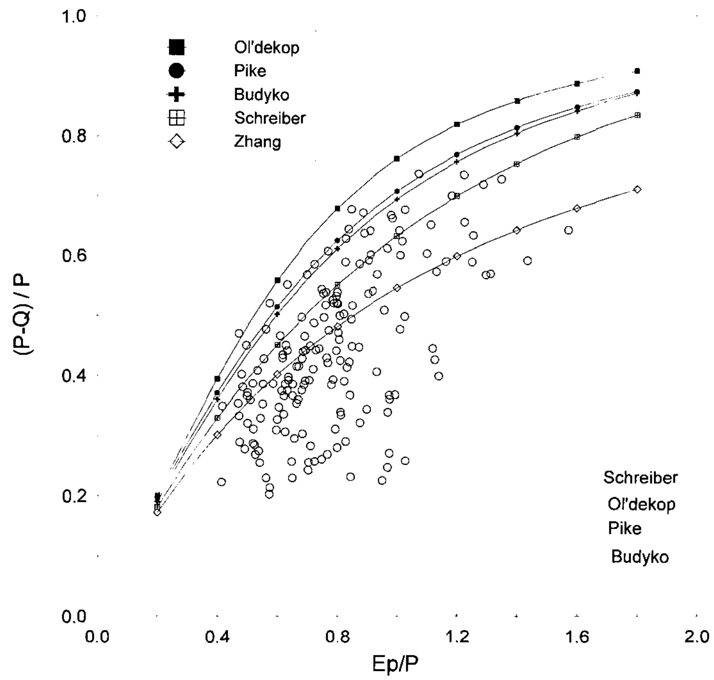


**Figure 2. Comparison of observations with 5 empirical equations on 11 watersheds**

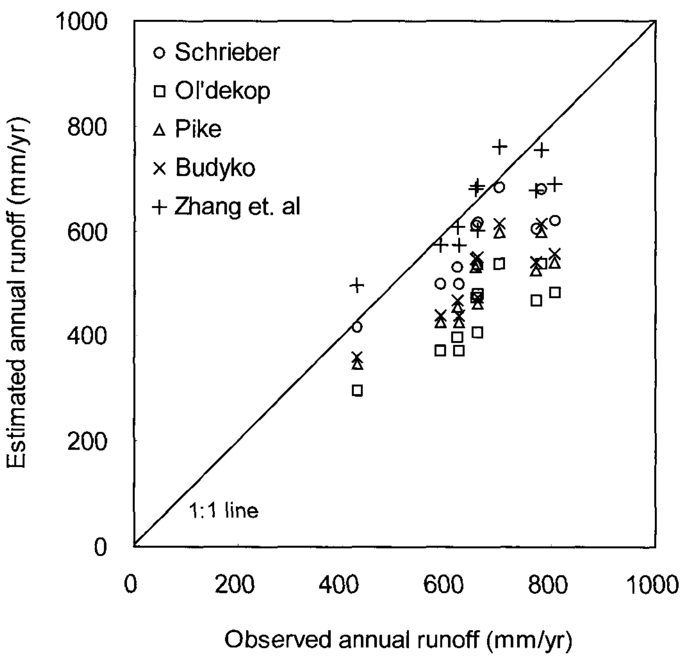


**Figure 3. Scatterplot of observed and estimated annual runoff on 11 watersheds**

or 3%. The results indicated that in spite of its simplicity, Zhang equation produced resonable estimates of annual runoff volume over a broad geographic domain.

## 5. CONCLUSIONS

The most difficult parameter in the long-term water balance estimation is actual evapotranspiration, which is a function of precipitation, water in the soil, vegetation type, and climatic variables. Five empirical-based approaches in this study were attempted to estimate annual actual evapotranspiration from annual precipitation and climate data. Long-term series of precipitation and runoff data collected from 11 watersheds with the area of 235~6,648 ㎢ can be used in evaluating empirical equations by comparing observed and estimated annual evapotranspiration.

Annual mean precipitation ranged from 1,014 mm/yr (Yeongcheon Dam) to 1,330 mm/yr (Naju) with a average of 1,175 mm/yr, and the average of actual evapotranspiration for 11 watersheds was 512 mm/yr. Five empirical equations were generally overestimated annual evapotranspiration, with relative errors ranging 3% to 47%. Schreiber formula considered to be applicable in determining annual evapotranspiration in sub-humid region, which is defined as $0.75 \le E_P / P < 2$ . In humid region ( $0.375 \le E_p / P < 0.75$ ), the Zhang equation gave generally better result than the other methods. Of the 5 empirical equations for estimating annual actual evapotranspiration, we found a consistent ordering in the difference from lowest to highest of Zhang, Schreiber, Budyko, Pike, and Ol'dekop equation.

The empirical approaches used in this study assume that actual evapotranspiration is principally determined by the climate conditions, and do not explicitly represent the effects of vegetation and soil types. However, it provides a practical tool to help water resources managers estimate regional water resources on ungauged large watershed, and has potential use in taking into account the long-term variability of runoff to climate changes at watershed level.

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