

## Evapotranspiration estimation using remote sensing data

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**सार** – पृथ्वी की सतह और वायुमंडल के बीच वाष्पोत्सर्जन एक महत्वपूर्ण जल-वैज्ञानिक संपर्क है। अतः जलवायु, जलवायु परिवर्तन और पारिस्थितिक तंत्र प्रतिक्रिया के बहुत से पहलुओं में यह मुख्य विषय होता है। यह भली-भाँति पता है कि वाष्पोत्सर्जन की प्रक्रिया के कारण मृदा और वानस्पतिक सतह से वायुमंडल में नमी का अंतरण होता है। वाष्पोत्सर्जन में परिवर्तन का स्थलीय वनस्पति पर अधिक प्रभाव पड़ने की संभावना रहती है। वनस्पति के प्रकार के वितरण और बाहुल्य को काफी हद तक नमी की मात्रा और मौसमी प्रभाव नियंत्रित करते हैं। जब जलसंतुलन में परिवर्तन महत्वपूर्ण होता है तब वनस्पति प्ररूपों और परिस्थितियों में अधिकांश बदलाव जलवायु परिवर्तन के कारण हो सकता है। इसी तरह वाष्पोत्सर्जन में परिवर्तन हरित ग्रह गैसों की वायुमंडलीय संरचना और जलवायु को प्रभावित कर सकते हैं चूँकि उष्ण से जल-वैज्ञानिक चक्र की तीव्रता में वृद्धि होती है। अतः इस शोध पत्र में, राष्ट्रीय महासागरीय और वायुमंडलीय प्रशासन (एन.ओ.ए.ए.)/सामान्यीकृत वनस्पति सूची (एन.डी.वी.आई.) के कार्य के रूप में 1.1 कि.मी. के स्थूल स्थानिक विभेदन पर आधुनिक अति उच्च विभेदन रेडियोमीटर (ए.वी.एच.आर.आर.) से प्राप्त आँकड़ों और सामि-आनुभविक पद्धति का उपयोग करके वनस्पति और खाली पड़ी भूमि में वाष्पोत्सर्जन का आकलन लगाने का प्रयास किया गया है। बहु समाश्रयण विश्लेषण द्वारा एन.डी.वी.आई.-सतही तापमान पर वाष्पोत्सर्जन की निर्भरता की जाँच की गई और एन.डी.वी.आई.-सतही तापमान पर वाष्पोत्सर्जन की निर्भरता की अच्छी प्रतिशतता पाई गई। इस प्रकार का आकलन जलवायु निदर्शकार, जलवायु वैज्ञानिकों, पारिस्थितिक तंत्र निदर्शकार और क्षेत्रीय नियोजक के लिए सहायक होगा।

**ABSTRACT.** Evapotranspiration (ET) is a critical hydrological link between the earth surface and the atmosphere. It is therefore important point of issues involving many aspects of climate, climate change, and ecosystem response. It is well known that ET is the process responsible for the transfer of the moisture from soil and vegetated surface to the atmosphere. Changes in ET are likely to have large impacts on terrestrial vegetation. Since the distribution and abundance of plant communities are controlled to a large extent by the quantity and seasonality of moisture. If the changes in water balance are significant, major shifts in vegetative patterns and condition are a likely result of climate change. Equally changes in ET are likely to impact atmospheric composition of green house gases, and climate, as the hydrological cycle increases in intensity with warming. Therefore, in this paper, it is attempted to estimate the ET over vegetative and bare field using National Oceanic and Atmospheric Administration (NOAA)/ Advanced Very High Resolution Radiometer (AVHRR) data at coarse spatial resolution of 1.1 km as a function of Normalized Difference Vegetation Index (NDVI) and with semi-empirical approach. For this purpose, a model has been proposed to estimate the ET over vegetative and bare field. The dependence of ET on NDVI-Surface temperature has been checked by multiple regression analysis and quite good percentage of dependence of ET on NDVI-Surface temperature has been observed. This type of estimation will be helpful for climate modeler, climatologists, ecosystem modeler and regional planner.

**Key words** – Evapotranspiration, Surface temperature, Normalized difference vegetation index, Radiometer, Remote sensing.

### 1. Introduction

Apart from the precipitation the most significant component of the hydrologic and climatic budget is evapotranspiration (ET). ET varies regionally and seasonally; during a drought it varies according to weather and wind conditions. Because of these variabilities, water managers who are responsible for planning and adjudicating the distribution of water resources need to

have a thorough understanding of the evapotranspiration process and knowledge about the spatial temporal rates of ET.

ET is a process where water evaporating from the ground and transpiration by the plants. It is also the way by which water vapor re-enters the atmosphere. It occurs when radiant energy from the sun heats water causing the water molecules become so active that some of them rise

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into the atmosphere as vapor. Transpiration occurs when plants take water through the roots and release it through the leaves, a process that can clean water by removing contaminants and pollution. The seasonal trend of ET within given climate region follows the seasonal trend of solar radiation and air temperature. Minimum ET rates generally occur during the coldest month in the year and maximum rates, which generally coincide with the summer season, when water may be in short supply, also depend on the availability of soil moisture and plant moisture. ET is one of the most important climate parameter. It is also a key variable in the circulation of soil water balance, the detection of water stress or modeling of crop yield (Thunnisses and Nienwnhrs, 1989, Brisson *et al.*, 1992). Remotely sensed thermal infrared data have been widely used to estimate ET (Jackson *et al.*, 1983, Caselles *et al.*, 1992).

Estimation of ET by ground based is very cumbersome and time consuming. Therefore, it is the point of research to estimate the ET using the remote sensing data. In this paper, we have attempted to estimate ET using satellite NOAA/AVHRR data which is freely available on the daily basis in five channels (0.58-0.68 $\mu\text{m}$ , 0.725-1.0 $\mu\text{m}$ , 1.58-3.93 $\mu\text{m}$ , 10.30-11.30 $\mu\text{m}$ , 11.50-12.50 $\mu\text{m}$ ) with horizontal resolution of  $\sim 1$  km at Nadir. For estimating ET using NOAA/AVHRR data, we have applied two approaches; (i) Semi-empirical approach and (ii) NDVI as modulating factor approach. In which, we have proposed NDVI as modulating factor approach. We have taken NDVI as modulating factor because, one of the most common applications of remote sensing is monitoring and evaluating vegetation over the land surface, and important mechanism for assessing vegetation condition is the Normalized Vegetation Index (Liping, *et al.*, 1994). Researchers have demonstrated that NDVI is related to a variety of pertinent vegetative parameters including percentage land cover, leaf area index (LAI), green biomass, and absorbed photo synthetically active radiation (Fung *et al.*, 1987, Goward *et al.*, 1985, Box *et al.*, 1989). The transpiration in ET depends upon these vegetative parameters and on the other hand, soil moisture is the major contributor for the evaporation in ET as well as for vegetation growth. Because, NDVI can be linked to general vegetation condition, which in turn, is related to soil moisture, it seems worthwhile to examine NDVI in relation to soil moisture availability. In fact, NDVI may be a useful indicator of soil moisture and vegetation. Therefore, it will be also a useful indicator for ET. The paper is divided in five sections. In which section 2 presents the theoretical approach to estimate the ET using NOAA/AVHRR data. Section 3 describes the methodology and available data. The results and discussions are presented in section 4 followed by conclusions.

## 2. Theoretical approach to estimate the ET

### 2.1. Semi empirical approach

From the energy balance equation, the application of a single layer model to the convective heat exchange yields the following equation (Jackson *et al.*, 1977)

$$ET_a - R_{nd}^* = \beta (T_{air} - T_{soil})_d \quad (1)$$

Where  $ET_a$  is the actual evapotranspiration expressed in millimeter per day of water,  $R_n^* = R_n / L$  is net radiation expressed in millimeter per day of water,  $L$  is the latent heat flux,  $(T_{air} - T_{soil})$  is the temperature difference between air and crop surface, the daily values are denoted by subscripts "d",  $\beta$  is the semi-empirical coefficients whose value is given by (Hurtado *et al.*, 1995)

$$\beta = \left( \frac{R_{nd}}{R_{nl}} \right) \left\langle \frac{\rho C_p}{L(r_a + r_o)} \right\rangle \quad (2)$$

where,  $\rho$  is the air density ( $\text{kg m}^{-3}$ ),  $C_p$  is the specific heat of air at constant pressure ( $\text{J kg}^{-1} \text{K}^{-1}$ ), and  $r_a$  and  $r_o$  are the aerodynamic and crop resistance respectively ( $\text{sm}^{-1}$ ). The average value over the growing season of the crop is denoted by symbol  $\langle \rangle$ .

We can also use equation (1) in semi-empirical ways for computing the ET, as, (Jackson *et al.*, 1977)

$$ET = A + B (T_{surface} - T_{air}) \quad (3)$$

Where, A and B are empirical coefficients,  $T_{surface}$  can be estimated from data given by satellite channels, and  $T_{air}$  can only be obtained with meteorological stations.

### 2.2. Land surface temperature by satellite data

At a coarse scale (1.1 km) land surface temperature ( $T_{surface}$ ) is directly obtained from the NOAA/AVHRR thermal channels (channel 4 and 5) using split window method (Price, 1984)

$$T_{surface} = T_4 + a^* (T_4 - T_5) + b \quad (4)$$

Parameters a and b are adopted to the test site using field measurements collected in Mkomazi, South Africa (Lahoche *et al.*, 2000)

$$T_{surface} = T_4 - 5.23^* (T_4 - T_5) + 30.73 \quad (5)$$

Equation (3) and (5) allow the computation of ET on NOAA acquisition area.

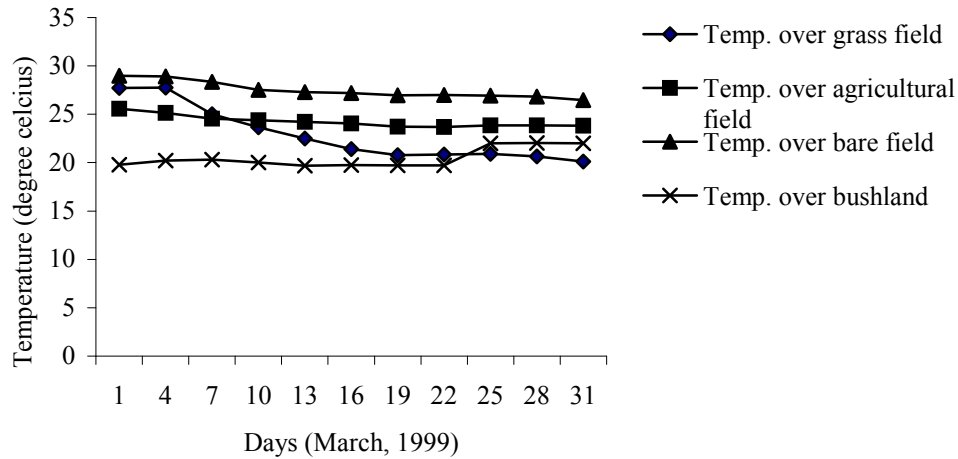


Fig. 1. Variation of surface temperature over various land cover

Nevertheless, due to the coarse resolution of this sensor (1.1 km), it is not possible to characterize ET behavior according to land cover. In fact, each pixel contains more than one land cover type. So, individual ET temporal profiles to the different land cover types, have to be computed.

This can be obtained by applying equation (3) for each date  $t$  and each land cover type  $j$

$$ET_j(t) = A + B [(T_{\text{surface}})_j(t) - (T_{\text{air}})_j(t)] \quad (6)$$

Where  $(T_{\text{surface}})_j(t)$  is the individual surface temperature for land cover  $j$  at date  $t$ .

### 2.3. Estimation of ET by NDVI as modulating factor

To assess the ET over various land covers, we have proposed a model in which we used NDVI as modulating factor. The normalized difference vegetation index (NDVI) is defined as

$$NDVI = \frac{R_2 - R_1}{R_2 + R_1} \quad (7)$$

where  $R_1$  and  $R_2$  are the reflectance in channel 1 and 2 in NOAA/AVHRR.

To account for the fractional crop coverage contribution to total evapotranspiration  $(ET)_T$ , NDVI may be used as modulating factor. When interpreting NDVI as a modulating parameter of the function vegetation cover,  $(ET)_T$  represents the composite ET of soil  $(ET)_s$  and

vegetation  $(ET)_v$ , which is often regarded as simple additive measure

$$(ET)_T = (NDVI_n) (ET)_v + (1 - NDVI_n) (ET)_s \quad (8)$$

where  $NDVI_n$  is the normalized NDVI

$$NDVI_n = (NDVI - NDVI_{\text{soil}}) / (NDVI_{\text{veg}} - NDVI_{\text{soil}}) \quad (9)$$

Here, NDVI is referred to the pixel for which  $(ET)_T$  is computed.

If, we have more than one type of land cover in one pixel then, we can write eq. (8) as

$$(ET)_T = \sum_{i=1}^N (NDVI_n)_i (ET_v)_i + \left[ 1 - \sum_{i=1}^N (NDVI_n)_i \right] (ET_s) \quad (10)$$

where  $i$  is the type of land cover and  $N$  is the number of type of land cover in one NOAA/AVHRR pixel. Using least square method, we have solved the eqn. (10) for neighboring pixels and get the values of ET over various land cover and soil.

### 2.4. Individual temporal profiles

For calculating the  $NDVI_n$ , we must know the individual profiles (*i.e.*, reflectance in channel 1 and 2 for each land cover). So, in this section, we have to explain how to infer individual temporal profiles from NOAA/AVHRR acquisitions by modeling the information

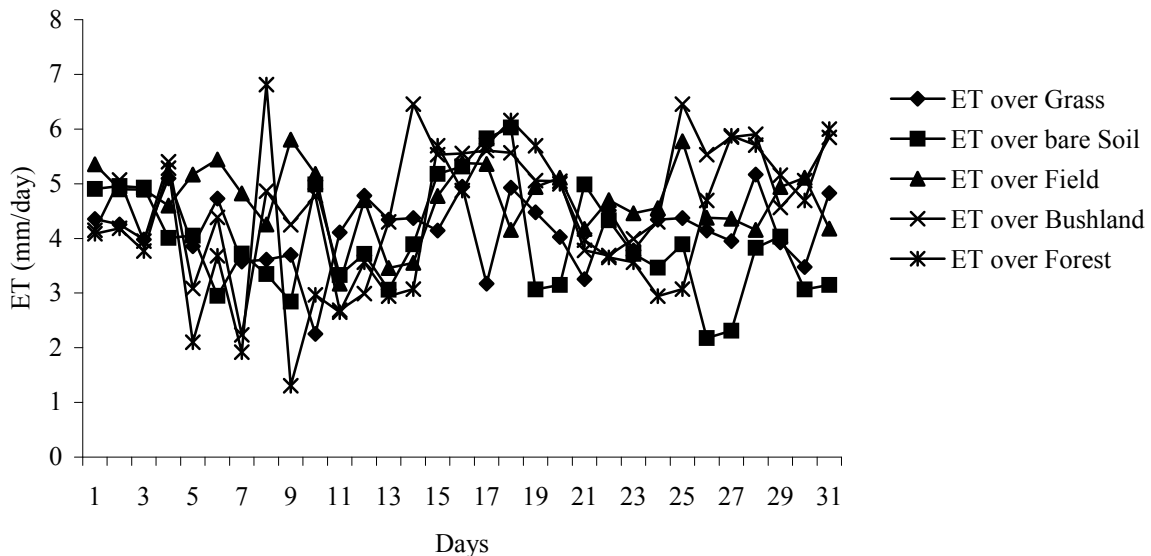


Fig. 2. Variation of estimated ET over various land cover in March 1999

contained within a pixel. On the small test area, the land cover classification gives proportion  $\alpha_{ij}$  of land cover  $j$  within each NOAA pixel  $i$ . For calculation of individual reflectance of each land cover in one pixel, here, we assumed a linear mixture model for reflectance in visible (channel 1) and near infrared (channel 2) channel (Bouzidi, 1998)

$$R_i^k = \sum_{j=1}^N \alpha_{ij} R_j^k \quad (11)$$

Where,  $k$  is the number of channel (either 1 or 2),  $R_i$  is the reflectance of NOAA pixel  $i$ ,  $R_j$  is the reflectance of land cover  $j$ ,  $\alpha_{ij}$  is the proportion of land cover  $j$  in the pixel  $i$ ,  $N$  is the number of land cover. On the same learning area, knowing proportions  $\alpha_{ij}$  is, the inversion of the linear mixture model (eqn.11) gives individual reflectance  $R_j^k$ .

### 3. Methodology/Available data

The studied area is the Mkomazi river catchment located in South Africa. The available data are (1) a daily NOAA/ AVHRR sequence of month March 1999 with 5 channels, (2) A supervised land cover classification derived from Landsat TM data (Fiegel 1998). After a preprocessing of the NOAA/AVHRR data and matching of NOAA and Landsat data (Berroir *et al.*, 1998), a test

area is chosen for which we have simultaneously both (*i.e.*, ground truth and satellite) data. The split window algorithm (eqn. 4), ET semi empirical model eqn. (6) are calibrated using field measurements (Jackson *et al.*, 1977 and Price, 1984). The process described in the section 2.4 is applied and individual temporal profiles of temperature and NDVI are obtained. Results of surface temperature over bare soil, bush land, agricultural field and grassland are represented in Fig. 1.

### 4. Results and discussion

Temporal profiles of evapotranspiration are computed using semi empirical model eqn. (6) and NDVI as modulating factor model eqn. (10) for month March 1999 of the test area Mkomazi in South Africa. The estimated ET over various land covers has been shown in Fig. 2, using NDVI as modulating factor. In these figures, we can easily discriminate the ET values over different land cover. If, we compare the ET over different land cover in the month March, 1999, then it is observed that the variation in ET during March is 2.1 to 6 mm/day over the bare soil, 2.2-5.1 mm/day over the grassland, 3.4-5.8 mm/day for agricultural field, 2-6.5 mm/day for bushland and 1.2-7 mm/day over the forest. The maximum variation or dynamic range in ET is found over the forestland cover in the March 1999. This will help to predict that which type of land cover is maximum affecting ET as well as to the climate in the particular season or month.

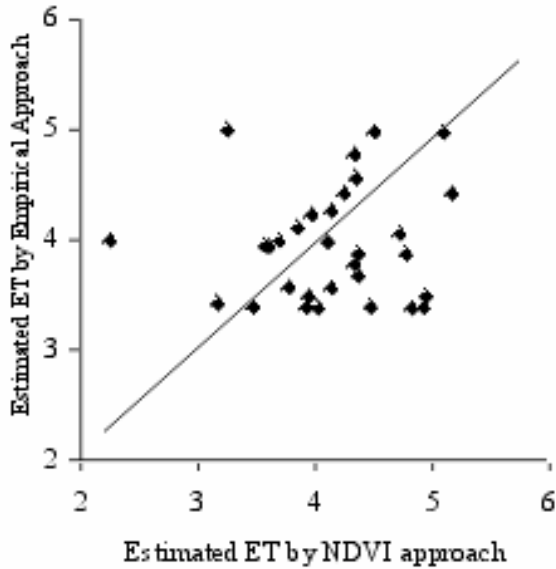


Fig. 3. Comparison between estimated ET by empirical and NDVI approach over grass field

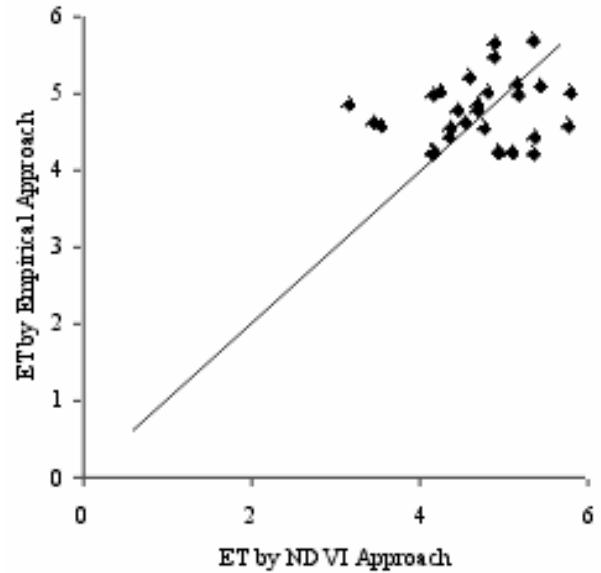


Fig. 5. Comparison between estimated ET by empirical and NDVI approach over agricultural field

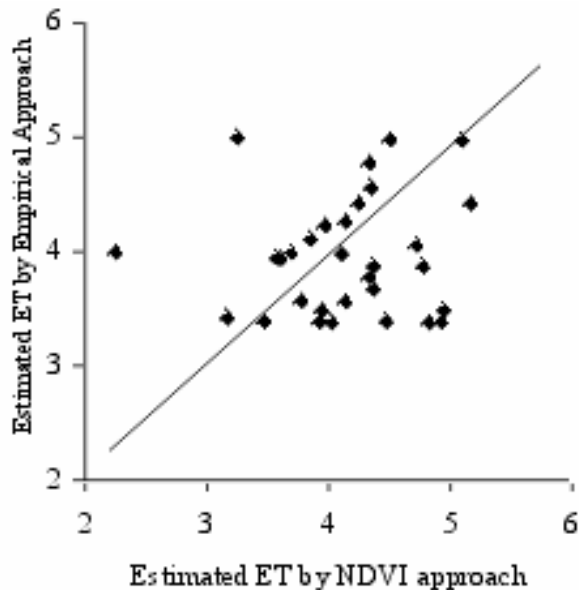


Fig. 4. Comparison between estimated ET by empirical and NDVI approach over bare soil field

The ET estimated over the various land covers that by semi empirical method is compared with the NDVI as modulating factor method. The results are shown in the [Figs. (3-5)]. It is observed that ET computed by the semi-empirical approach over the agricultural field over estimates the ET computed by NDVI as modulating factor, while we observed the reverse thing over the grass field and bare field.

TABLE 1

The values of coefficient of determination ( $r^2$ ) and standard error (SE) over various lands cover by multiple regression analysis between ET and NDVI-Surface Temperature (Over different land cover)

Land Cover	$r^2$	SE
Bare soil	0.50	0.65
Grass	0.64	0.48
Bushland	0.58	0.56
Agricultural field	0.62	0.52

A multiple regression analysis has been carried out for observing the dependence of ET on NDVI and surface temperature. We found a significant relationship among the ET, NDVI and surface temperature ( $T_s$ ) for the Mkomazi area. The coefficient of determination and standard error of estimate over various areas is given in Table 1. However, difference in land cover over the test site has some effect on the relationship between ET and NDVI-  $T_s$  (Table 1). In the Mkomazi area, we found that the percentage of dependence of ET on NDVI and grass surface temperature is higher in comparison to the other land cover ( $r^2=0.64$ ) and standard error of estimate is also less in comparison to other land cover. Although, the dependence of ET on NDVI and surface temperature depends upon a various factor (*i.e.*, green biomass of crop/grass, wind speed, etc). The maximum value of coefficient of determination over the grassland has been

observed. It may be due to the fact that the grass was dense and greener in the month March 1999, in comparison to other land cover. This type of analysis helps us to know the effect of each land cover on the climate as well as for hydrological modeling.

## 5. Conclusions

We have estimated the ET by two methods. Despite the some differences among all estimation of ET. The NDVI as modulating factor approach seems to be a good approach for estimating ET over various land covers at regional scale. This approach may be an important tool for solving the gap between local and regional monitoring of climate. ET over the grass field is highly dependent on the NDVI and surface temperature of the grass in comparison to the other land cover. The results presented strengthen the possibility of developing the most needed operation product, ET to monitor the climate and water balance.

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