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Development of relationship between crop coefficient and NDVI using geospatial technology

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ABSTRACT

In the present study, potential evapotranspiration (PET) is estimated using geographic information system (GIS) and remote sensing (RS) data. Linear imaging self-scanning sensor (LISS-III) satellite images of Tapi river basin area were used in the present study. The study area is classified into five different zones, namely forest land, agricultural land, barren land, urban land and water bodies by supervised classification. NDVI values for the respective zones (class) were used to estimate crop coefficient (Kc) using linear regression model. Reference evapotranspiration (ETo) was calculated from Penman–Monteith model and PET was calculated by multiplying the Kc and ETo. The results obtained by this methodology were validated using actual evapotranspiration. A new linear model was developed for the study area between NDVI and Kc. Developed methodology for the determination of Kc derived from RS data and NDVI-Kc model may be useful for irrigation scheduling and estimating water use efficiency.

Keywords: Normalized difference vegetation index (NDVI), reference evapotranspiration (ETo), potential evapotranspiration (PET), crop coefficient (Kc).

Efficient use of water resources in India has become important because of rapid depletion of water resources, industrial development, population increases, drought conditions, and degradation of ground and surface water quality in many regions. In the present study area of the lower Tapi Basin, India, there are many problems regarding irrigation scheduling, crop water requirement and water demand. But people are not much aware of optimum utilization of water for the irrigation. Because of over flooding of water in the field much of the water will be lost in the form of PET, that's why it is necessary to evaluate evapotranspiration. The combination of two separate processes whereby water is lost on the one hand from the soil surface as an evaporation and on the other hand, from the crop as a transpiration is called as evapotranspiration (ET). Due to the scarcity of water resources, the correct evaluation of water losses by the crops as ET is very important. Crop evapotranspiration (ETc) can be estimated using empirical methods (Doorenbos, *et al.,* 1979), field measurements (Allen, *et al.,* 2005) and RS techniques (Allen, *el al.,* 2002). However, the use of empirical methods and field measurements has been often sophisticated, expensive, time consuming. Further, these methods required proper knowledge and skills to apply the techniques. (Trezza, *et al.,* 2003) Traditionally PET from agricultural fields has been calculated by multiplying weather based reference PET by Kc determined according to crop type and crop growth stage. However, there are some concerns with regards to whether the crops grown compare with the conditions represented by the Kc values, especially in areas where water is limiting. In addition, it is difficult to predict the correct crop growth stage dates for large populations of crops and fields (Kamble, *et al.,* 2013; Tasumi, 2003).

RS technology is widely used in environmental and agricultural science. The NDVI, one of the most well-known vegetation indices derived from optical RS imageries, has been extensively used to estimate plant biomass, vegetation, (Prince, 1991), leaf area index (Asrar *et al.,* 1984), patterns of productivity (Goward and Dye, 1987), growth status and spatial density distribution (Purevdorj *et al.,* 1998), and plant phenology (Derrein *et al.,* 1992). It was first formulated by Rouse *et al.* (1973) as the difference between near-infrared (NIR) and red visible reflectance values received by the remote sensors normalized over the sum of the two. The value increases with the increasing high vegetation cover because leaf chlorophyll and other pigments absorb a large proportion of the red VIS radiation and the internal mesophyll cells of healthy green leaves strongly reflect NIR radiation (Tucker, 1979). Chlorophyll reflectance is about 20% in the red spectrum and 60% in the NIR spectrum and the contrast between the responses of both bands allows the quantitation of the energy absorbed by chlorophyll, thereby providing

Table 1: Land use classification showing area and NDVI

Class	Pixcel count	Area (Km2)	NDVI Range
Forest Area	104443	93.9987	0.64 - 0.35
Agriculture Area	604743	544.5887	0.32 - 0.25
Barren Land	2335882	2102.294	0.24 - 0.14
Urban Area	594646	535.1814	0.060 - 0.04
Water Bodies	645586	581.0274	-0.433 - -0.04

indicative levels of different vegetation surfaces (Tucker and Sellers, 1986). When an area is covered by vegetation, its NDVI value is a positive range.

The objective of the study is to develop the model by relating NDVI and Kc for different land uses determining the evapotranspiration using geospatial technology. Many previous authors have developed the relationship between NDVI and Kc for agriculture purpose and irrigation scheduling. But the problem in those models cannot determine the irrespective of land use. NDVI is obtained by using geospatial technology and Kc value is obtained by developed NDVI Kc model. Once Kc value is obtained ETo can be calculated.

MATERIAL AND METHODS

Study area

The Tapi Basin is the northern-most basin of the Deccan plateau. The basin extends over the States of Madhya Pradesh, Maharashtra and Gujarat have an area of 65,145 sq.km out of which nearly 80 percent area lies in Maharashtra State. It lies between 72°33' to 78°17' East longitudes and 20°9' to 21°50' North latitudes. The area of the lower Tapi basin is 3,837 sq.km.

For the study area meteorological data were collected from GSWDC of year 1990 to 2013 (Gujarat State Water Data Center), Gandhinagar. And LISS III (Linear Imaging Self Scanning Sensor) Resourcesat-1 satellite images are collected from bhuvan.nrsc.gov.in.

Image analysis

Linear Imaging Self Scanning Sensor (LISS-III) Resourcesat-1 satellite images of four different bands were used for the analysis. It covers a 141km-wide swath with a resolution of 23 meters in all spectral bands. Different composite images were used mosaic for the study area. After that study area was classified into five different zones, namely forest land, agricultural land, barren land, urban land and water bodies by supervised classification.

Estimation of normalized difference vegetation index (NDVI)

NDVI is calculated based on classification of images. The values of NDVI range from –1 to +1 with higher values corresponding to dense vegetation and low value indicates scare vegetation.

Estimation of reference evapotranspiration (ETo)

In order to calculate ETo, the Penman-Monteith model was used as it utilizes almost all meteorological parameters. Meteorological data comprising mean maximum and minimum temperature, relative humidity, total wind run, sunshine duration and wind speed were collected from weather stations. CROPWAT 8.0 (Allen, et al., 2000) is used to calculate ETo.

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

Where,

ETo reference evapotranspiration [mm day^{-1}]; Rn net radiation at the crop surface [MJ m^{-2} day^{-1}], G soil heat flux density [MJ m^{-2} day^{-1}]; T mean daily air temperature at 2 m height [°C]; u_2 wind speed at 2 m height [m s^{-1}]; es saturation vapour pressure [kPa]; ea actual vapour pressure [kPa]; es-ea saturation vapour pressure deficit [kPa]; Δ slope vapour pressure curve [kPa °C^{-1}]; g psychrometric constant [kPa °C^{-1}].

Estimation of potential evapotranspiration (PET)

In case of water bodies the pan evaporation is only considered. In case of urban land, barren land, agriculture land and forest land evapotranspiration is considered. The data is sorted according to its classification and then pan evaporation is converted in to evapotranspiration by referring procedure given in (Xiong, et al., 1999). Wherever evapotranspiration data required, ETo data is used and wherever evaporation data is required it is calculated using equation (1). Analysing experimental data from class A pan evaporimeter, evapotranspiration is calculated using relationship between evaporation and evapotranspiration given below in equation (1).

$$E(t) = EP(t) \times \tanh[P(t)/EP(t)] \quad (2)$$

Where, E(t) represents the actual annual evapotranspiration in mm,

EP(t) is the annual pan evaporation value in mm ,

P(t) is the annual rainfall in mm, and

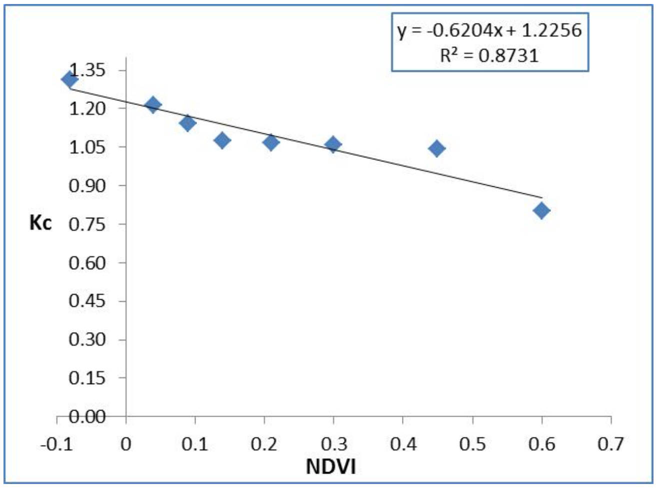

Fig. 1: Variation of Kc with NDVI

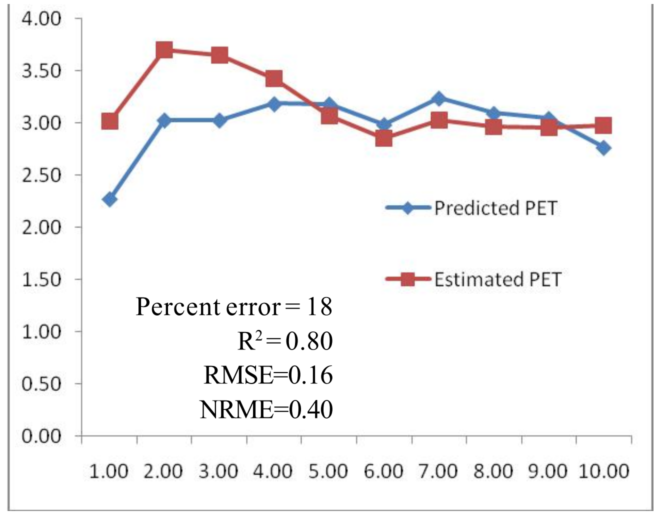

Fig. 2: Predicteded PET and estimated PET

tanh ( ) is the hyperbolic tangent function (Xiong, et al., 1999).

Estimation of crop coefficient (Kc)

Crop coefficients Kc is commonly used to determine actual water needs of a particular crop from estimates or measurements of potential or reference evapotranspiration ETo. The derivation and use of the crop coefficient is given by

$$Kc = PET/ETo \quad (3)$$

Where,

Kc is crop coefficient,

PET is potential evapotranspiration [mm day^{-1}] and

ETo is reference evapotranspiration.[mm day^{-1}]

RESULT AND DISCUSSION

Land use classification of Images and NDVI

Study area is classified into five different zones, namely forest land, agricultural land, barren land, urban land and water bodies by supervised classification. Maximum likelihood algorithm is used for classification (Table 1).

Development of model

A model is developed by considering all the ranges of NDVI values of different categories like forest land, agriculture land, barren land, urban land and water bodies. The range of NDVI values is given in Table 1. Kc value are indirectly obtained by dividing PET / ETo for the respective classes. Thus obtained Kc and NDVI from geospatial technology. As it can be seen from the Fig. 1, the negative correlation exists between NDVI and Kc are correlated. But earlier many authors have given the positive correlation. The reason behind getting the negative correlation is high evaporation in case of water bodies compared to evapotranspiration in other classes. Kc value mainly varies between 0 to 1 which is not true in the case for the equation given by (Kamble et al., 2013) because of exclusion of water bodies in their equation. The relationship is obtained in equation (4) shows strong correlation between Kc and NDVI with correlation coefficient 0.8731 developed regreesion model is given below.

$$Kc = -0.6204NDVI + 1.2256 \qquad R^2=0.8731 \quad (4)$$

Where, Kc is crop coefficient

Model performance

The developed model was validated using the independent data set of the study area. A graph is plotted between estimated PET and predicted PET. It can be seen from Fig. 2 that model predicts PET very well. The percentage average error is used to evaluate the model performance and it is less than 18%. Coefficient of correlation is found to be more than 0.8 between observed and predicted value. The root mean square error (RMSE) and normalised RMSE are also low (Fig. 2).

CONCLUSION

Present study concentrates on estimating NDVI and Kc values from field data like evaporation, evapotranspiration, climatic data and GIS data pertaining to lower Tapi basin (India). NDVI values range from -0.04 to +0.64 covering all the classes of land uses of study area viz. Forest land, agricultural land, barren land, urban land and water bodies and respective Kc values were evaluated. It is found that there is a strong correlation between Kc and NDVI.

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