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Estimation of water requirement of wheat using multispectral vegetation indices

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ABSTRCT

Estimation of crop coefficient (Kc) and crop evapotranspiration (ETc) using remote sensing data is essential for planning irrigation water use in arid and semiarid regions. The study was conducted to test the suitability of remotely sensed Vegetation Indices (VIs) for modeling spatial crop coefficient, choosing most appropriate vegetation index among them for modeling and applying this model to estimate water requirement of wheat. The study area consisted of wheat growing five districts situated in central Maharashtra. Images of IRS-P6, AWiFS sensor were used to generate multi temporal vegetation indices RVI, NDVI, TNDVI, SAVI and MSAVI2. The week-wise VIs were correlated with week-wise recommended wheat crop coefficients which resulted in linear relationships/models. Simple linear regression analysis showed NDVI as a superior index for predicting crop coefficients of wheat. NDVI-Kc model showed highest R^2 and D values of 0.895 and 0.980 respectively with lowest values of SE, RMSE and PD of 0.120, 0.113 and 4.64 respectively. The crop coefficients (Kc), obtained by this NDVI-Kc model and reference evapotranspiration (ETo), estimated by Penman- Monteith equation, were used to compute wheat crop evapotranspiration (ETc) which represents the water requirement of wheat and found varying from 378.34 mm to 439.10 mm in the study area.

Keywords: Wheat, vegetation indices, evapotranspiration, water requirement, AWiFS, Maharashtra

Wheat (*Triticum aestivum* L.) is the most important food crop of the world. It is grown under different soil and climatic conditions. In India it is second most important food crop. Since wheat is grown mostly in irrigated conditions, comprehensive knowledge of water requirement (crop evapotranspiration, ETc) of the wheat crop is necessary for appropriate irrigation scheduling. Crop water requirement is the amount of water required to compensate the evapotranspiration loss from the cropped field. Food and Agricultural Organization (FAO) in its publication FAO-56 have suggested to use the single crop coefficient approach with the relation , ETc = ETo x Kc where ETo is refrence evapotranspiration and Kc is crop coefficient (Allen *et al.* 1998). This approach have suggested to use tabulated Kc values of crops developed in standard conditions. Since the Kc curves used with FAO procedures are time-based, they often lack the flexibility required to capture a typical crop development and water use patterns caused by weather anomalies.

Satellite remote sensing offers a means to overcome some of the shortcomings of time-based Kc curves by providing real-time and/or near real time spatial information on Kc and ETc use as influenced by the actual cropping patterns. Remote sensing based multispectral vegetation indices (VIs) have been acclaimed to be closely related with several crop growth parameters (Moran *et al.*, 1995). The potential for using multispectral VIs as near real-time surrogates for crop coefficients was proposed by Jackson *et al.* (1980) who pointed out the similarity between the seasonal pattern of VI for crops and that of the crop coefficient. The concept was eventually established by Bausch and Neale (1989) who derived Kc for corn based on several VIs. They incorporated VI-based crop coefficients with existing scheduling algorithms and reported improvements in corn irrigation scheduling due to better estimation of water use and more appropriate timing of irrigations. Gontia and Tiwari (2010), Farg *et al.* (2012) and Ozcan *et al.* (2014) correlated the remotely sensed vegetation indices to estimate Kc and estimated wheat crop evapotranspiration based on these vegetation indices and calculated spatial water requirement of wheat. Thus crop coefficient (Kc) can be derived from spectral vegetation indices(VIs) since both are related to leaf area index and fractional ground cover. Therefore, techniques are needed to estimate Kc weekly or biweekly for the purpose of water requirement calculations at the field level.

Keeping this in mind, this study was conducted to test the suitability of remotely sensed Vegetation Indices

Table 1: Vegetation indices (VIs) used for study

S.No.	Indices	Equation	Reference
1.	RVI	NIR/RED	Jordan (1969)
2.	NDVI	(NIR-R) / (NIR+R)	Rouse *et al.* (1973)
3.	TNDVI	[(NIR - RED)/ (NIR + RED) + 0.5]^(1/2)	Tucker (1979)
4.	SAVI	[(NIR - RED) / (NIR + RED + L)] * (1 + L)	Huete (1988)
5.	MSAVI2	$[2*NIR+1-\sqrt{(2*NIR+1)^2-8*(NIR-R)}]/2$	Qi *et al.* (1994)

(VIs) derived from AWiFS sensor of Indian remote sensing satellite IRS P-6, for predicting spatial crop coefficient, choosing most appropriate vegetation index among them and applying this relationship to estimate weekly crop evapotranspiration i.e. water requirement of wheat.

MATERIAL AND METHODS

Study area

The study area consists of five districts situated in central part of Maharashtra *i.e*. Pune, Solapur, Ahmednagar, Beed and Osmanabad wherein spatially, extensive and contiguous sites contribute to wheat production. It is located between 73°17'19"E to 76°47'42"E longitudes and 19°58'57" N to 17°03'56"N latitudes.

Remotely sensed data

Multi-date, multispectral satellite images of IRS- P6, AWiFS (Advanced Wide Field Sensor) for five consecutive months of rabi season (19 October 2012, 11 and 29 November 2012, 11 and 27 December 2012, 11 and 23 January 2013 and 4 February 2013) with path-row of 097-058 for the year 2012-13 were used for this study. Rectangular subset images covering the study area were obtained and processed in ERDAS Imagine to generate five most commonly used vegetation indices (VIs) i.e. Ratio Vegetation Index (RVI), Normalized Difference Vegetation Index (NDVI), Transformed Normalized Difference Vegetation Index (TNDVI), Soil Adjusted Vegetation Index (SAVI) and Modified Soil Adjusted Vegetation Index (MSAVI2) on all the dates of satellite pass (Table 1).

Ground truth data

Ground truth work was carried out in December 2012, coinciding with with the season of wheat crop in the study area. Field data were collected from 17 sites using handheld GPS, geotagged camera and a mobile with LOCATE software to obtain the locations and elevations of the sites.

Image processing

Wheat polygon vector layer was prepared based on the ground truth data in ArcGIS. Images of all the vegetation indices (VIs) on all the dates of pass were generated. Pure wheat polygon multidate VIs were extracted using ERDAS Imagine software. These VI values were arranged weekwise considering the age of wheat crop at different locations in terms of week.

Establishment of VI-Kc models

The empirical relationships between weekly wheat crop coefficients (Kc) recommended by Mahatma Phule Krishi Vidyapeeth Rahuri (MPKV, 2012) and vegetation indices (VIs) were obtained by using linear regression analysis. The relations (Models) obtained were evaluated by means of statistical parameters such as coefficient of determination (R^2), root mean square error (RMSE), Willmott Index of agreement (D) and percent deviation (PD). Based on the results of statistical analysis best performing model was selected.

Estimation of water requirement

FAO Penman Monteith method was adopted to estimate reference evapotranspitaion (ETo) by using weekly data of maximum temperature, minimum temperature, wind speed, relative humidity-I and relative humidity-II of the stations Rahuri (Dist Ahmednagar), Pune, Solapur, Beed and Osmanabad obtained from MPKV Rahuri and MAU Parbhani. The weekwise crop coefficients were obtained by utilizing the developed the best performing VI-Kc model. The weekwise water requirements (ETc) of the wheat crops were obtained by FAO suggested relation, ETc = ETo X Kc.

RESULTS AND DISCSSION

VI-Kc models

The average weekly values of vegetation indices for i.e. RVI, NDVI, TNDVI, SAVI and MSAVI2 for wheat (Table 2) were plotted against weekly crop coefficients (Kc) recommended by MPKV Rahuri (based on Penman-Monteith method of calculation of reference evapotranspiration, ETo). Simple linear regression analysis was carried out to investigate the relation between the vegetation indices and crop coefficients. It was observed that fairly good linear

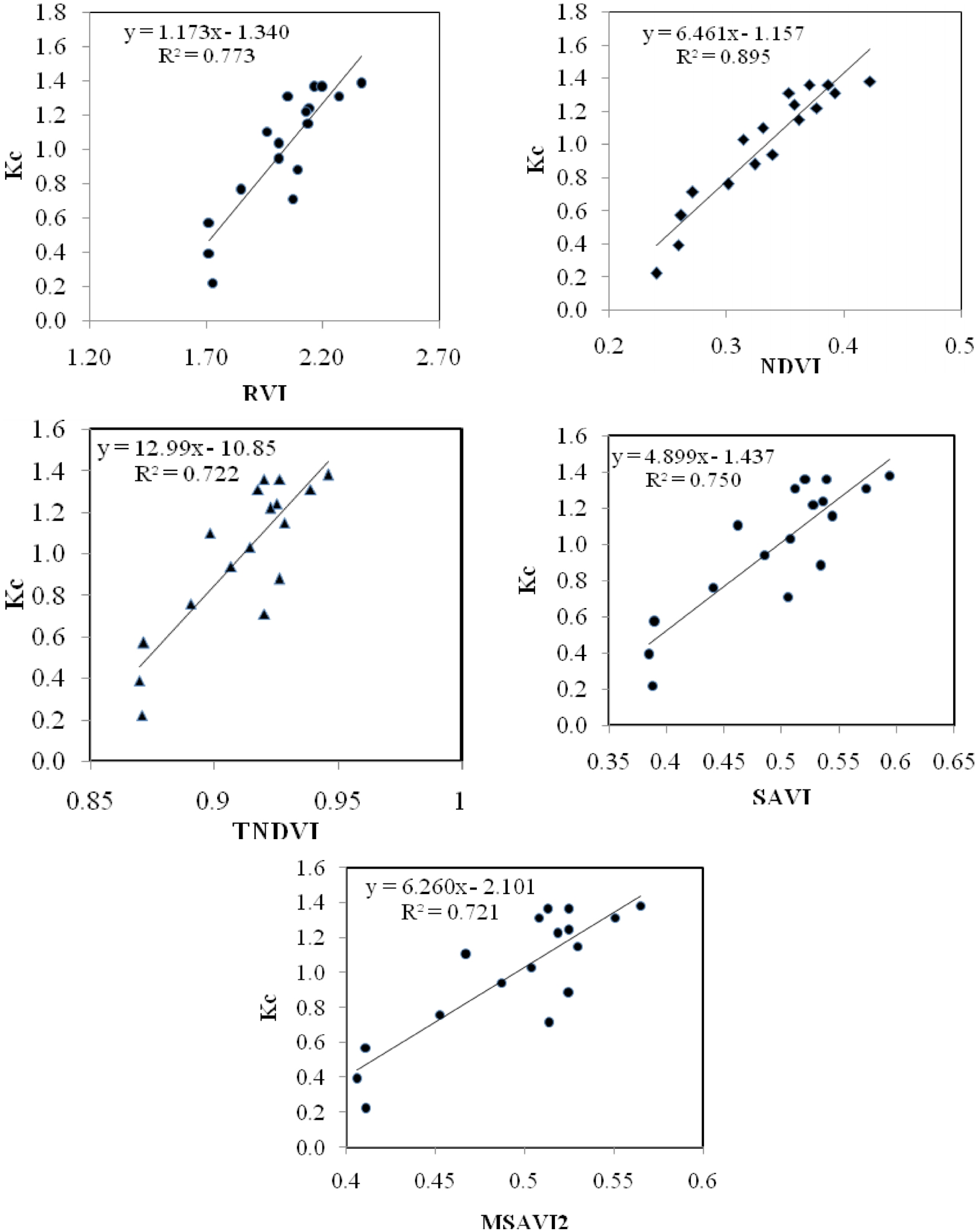

Fig. 1 : Relationship of crop coefficients(Kc) with vegetation indices (VIs) for wheat

Table 2: Week-wise averaged values of vegetation indices of wheat

WAS	RVI	NDVI	TNDVI	SAVI	MSAVI2
1	2.0727	0.2714	0.9204	0.5053	0.5136
2	2.0937	0.3241	0.9263	0.5338	0.525
3	2.0117	0.3142	0.9147	0.5077	0.5035
4	2.1404	0.3620	0.9285	0.5442	0.5297
5	2.1463	0.3576	0.9255	0.5362	0.5248
6	2.2692	0.3926	0.9391	0.5733	0.5506
7	2.1620	0.3705	0.9203	0.5213	0.5130
8	2.3654	0.4224	0.9463	0.5937	0.5649
9	2.2019	0.3871	0.9266	0.5391	0.5246
10	2.0547	0.3533	0.9178	0.5117	0.5080
11	2.1289	0.3770	0.9228	0.5284	0.5185
12	1.9619	0.3311	0.8984	0.4617	0.4674
13	1.9232	0.3394	0.9070	0.4850	0.4868
14	1.8506	0.3014	0.8908	0.4404	0.4524
15	1.7160	0.2615	0.8718	0.3903	0.4113
16	1.7150	0.2590	0.8700	0.3850	0.4060
17	1.7270	0.2400	0.8710	0.388	0.4110

Where WAS : Week after sowing

relationship exists between these vegetation indices with crop coefficients (Fig. 1). From the regression analysis linear relations (prediction models) were obtained and were evaluated by most frequently used statistical parameters such as R^2, SE RMSE, PD and D.

It is found that all the vegetation indices have reasonably good correlation with wheat crop coefficients with reasonably high R^2 values. However, NDVI-Kc model showed highest R^2 and D values of 0.895 and 0.980 respectively with lowest values of SE, RMSE and PD of 0.120, 0.113 and 4.64 respectively. This confirms the excellent performance of NDVI-Kc model. On the other hand RVI –Kc model showed poor performance as compared to other four models indicating less accuracy for forming linear relationship. The vegetation indices are function of greenness and leaf area index. Wheat crop is mostly grown in irrigated conditions having dense plant population. As a result canopy always covers maximum surface of soil very fast after crop emergence. Therefore soil background does not significantly affect the vegetation indices. Study conducted by Gontia and Tiwari (2010) in TSMC command, West Bengal for comparison of NDVI and SAVI showed higher significance (R^2) in case of SAVI. This may be due to use of coarse spatial and low temporal resolution data. However the study indicated usefulness of both the vegetation indices in calculating ET for wheat crop. The findings showing superiority of NDVI for predicting wheat crop coefficients were obtained by Calera and Gonzalez (2007) in Spain as well as Lei and Yang (2014) in China.

Table 3: Estimated water requirement (mm) of wheat in different districts

WAS	Ahmednagar	Pune	Solapur	Beed	Osmanabad
1	15.0	14.6	14.3	14.1	17.1
2	23.2	20.9	25.0	22.0	24.9
3	19.1	18.1	19.0	23.2	23.2
4	23.6	23.8	23.7	26.5	28.0
5	26.8	25.5	23.0	27.9	31.3
6	29.7	30.1	31.7	31.3	29.7
7	25.8	25.9	33.4	30.1	29.4
8	32.8	30.0	38.1	35.1	35.1
9	26.1	32.4	29.0	29.8	30.6
10	23.8	22.9	24.4	25.0	25.9
11	31.1	26.8	32.9	29.8	32.8
12	23.0	22.1	25.5	26.7	24.5
13	26.8	22.5	27.9	26.3	31.5
14	22.3	19.9	23.8	22.9	23.8
15	16.4	15.0	16.3	14.9	16.8
16	16.1	15.6	16.8	15.8	18.8
17	13.6	12.1	13.8	14.8	15.4
Total	395.2	378.2	418.6	416.2	438.8

Water requirement

Best performing NDVI-Kc Model was used to estimate week-wise crop coefficients and the estimated crop coefficients when multiplied with corresponding reference evapotranspiration resulted to give evapotranspiration (ETc) which represents the water requirement of wheat crop. The estimated water requirements of wheat are presented in Table 3. The water requirement was found lowest (378.2 mm) in Pune district and highest (438.8 mm) in Osmanabad district. This difference in ETc of wheat crop at different places is because of variation in reference evapotranspiration which depends on conditions of weather and physiography of the area.

CONCLUSIONS

The study demonstrated the ability of remotely sensed vegetation indices to predict spatial and temporal crop coefficients of wheat crop. The study revealed that NDVI-Kc model gives more accurate results than other VI-Kc models. Utilization of this methodology can be successfully made to estimate temporal and spatial water requirement of wheat crop which can help in proper planning of available water. This will save considerable amount of water.

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