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Research Article

RELATIONSHIP OF NDVI WITH CROP COEFFICIENTS OF WHEAT OBTAINED BY CONSIDERING DIFFERENT METHODS OF ESTIMATING REFERENCE EVAPOTRANSPIRATION

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Abstract: It has been observed by many research workers worldwide that the vegetation indices of crops derived from satellite data may have close correlation with the crop coefficients. It is also seen that Normalized Difference Vegetation Index (NDVI) plays an important role in prediction of crop coefficients and other parameters also. The present study was carried out in wheat growing districts of central Maharashtra. Multidate 8 images of satellite IRS P-6, AWiFS sensor of the rabi season of 2012-13, were used for the study. Necessary ground truth work was carried out. By necessary processing of image data NDVI of wheat fields was obtained. It was found that NDVI has close relation with crop coefficients of wheat obtained by all the three methods of reference eapotranspiration. NDVI-Kc PM linear regression showed highest R_2 value (0.895) indicating superiority over other methods of calculating crop coefficients. The relation is given by linear equation Kc PM = 6.461NDVI - 1.157 The results demonstrate that this approach may prove a very useful method for large scale estimation of crop evapotranspiration using crop coefficient estimated by this approach.

Keywords: *Crop coefficient, vegetation indices, NDVI, wheat, AWiFS, evapotranspiration*

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Introduction

Wheat is important food crop of India as well as world. It has major share in human diet. For achieving higher yields of wheat, it is of utmost importance to apply appropriate amount of irrigation water at appropriate time. So, it is required to have the knowledge of accurate water requirement, at different stages of crop development. Crop water requirement refers to the quantity of water which should be added to overcome the water loss from cropped field in the form of evapotranspiration (ETc). Crop water requirement numerically equal to crop evapotranspiration. The crop evapotranspiration (ETc) at different stages of crop development is estimated as product of crop coefficient (Kc) and reference evapotranspiration (ETo) [1]. The crop coefficients are tabulated in FAO 24 publication [2]. However, for more accuracy it is required to find out crop coefficients by local lysimeter studies. The local crop coefficients (Kc) are computed by lysimeter experiments as

Kc = ETc / ETo (1)

Depending upon the availability of weather data there are different methods of estimating reference evaotranspiration. If sufficient weather data is available the standard FAO Penman–Monteith formula can be used for calculations of daily ETo. Reference evapotranspiration (ETo) can also be estimated by other methods such as Pan Evaporation method and Hargeaves-Samani method. Lysimeter studies on wheat crop at Mahatma Phule Krishi Vidyapeeth Rahuri, Maharashtra, India (2013) [3] have recommended such Kc values for wheat crop week wise based on the above three methods of estimating reference evapotranspiration.

However, there are variations of crop growth stages at different fields. Thus, accounting for spatial and temporal variations in water use with present crop coefficient procedures is extremely difficult. Remote sensing technology can help to a great extent to obtain spatial and temporal crop coefficients of the same crop based on vegetation indices (VI). Normalised difference vegetation Index (NDVI) is a major vegetation index. Jackson *et al.* (1980) [4] observed the similarity between the seasonal pattern of vegetation indices (VIs) of crop fields obtained from satellite data and that of the crop coefficient. Bausch and Neale (1989) [5] derived Kc for corn in Colorado based on several VIs. Glenn *et al.* (2008) [6] remarked that numerous studies have shown a high correlation between NDVI and biophysical characteristics of plants. Limited research on this aspect has been done so far to expand the development of VI-based crop coefficients for field crops in India. Therefore, a study was undertaken in 5 dominant wheat growing districts of central Maharashtra to test the feasibility of vegetation index NDVI for estimating crop coefficients and finding out the most suitable method.

Materials and Methods

The Study area

The study area comprises of centrally located five districts of Maharashtra *i.e.* Pune, Solapur, Ahmednagar, Beed and Osmanabad. In the study area dominant crops are grown in rabi season are sorghum, wheat and chickpea. The study area lies between 73° 15' 57" to 76° 47' 36" E longitude and 19° 59'40" to 17° 04'50" N latitude. Total area of 65,716 Km^2 is covered under this study. The average annual rainfall varies between 500-700 mm with uncertain and uneven distribution. Dry spells occur oftenly. The climate is hot and dry. General topography is having slope between 1-2 %. Most soils are vertisol.

Remotely Sensed data

Multi-date images of satellite IRS- P6, AWiFS (Advanced Wide Field Sensor) Sensor for five consecutive months of wheat season (October / November / December / January / February) of 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 Normalized Difference Vegetation Index (NDVI) images on all the dates of satellite pass.

Ground Truth data

The fields having large areas under wheat were visited at different dates coinciding with the season of wheat crop in the study area in the rabi season of 2012-13. The data of actual crop growth stages was obtained by visiting total 105 locations of wheat and other crops in the study area. Stages of wheat crop at different locations were decided by visual observations referring Feekes scale of wheat development [7] and discussion with farmers about the date of sowing. The rough sketch of fields and photos with geotagged camera and a mobile with LOCATE software were taken and then located on the point map. Handheld GPS was also used.

Normalized Difference Vegetation Index (NDVI)

Normalized difference vegetation index (NDVI) has been used in numerous studies. So, it was selected for this study. The NDVI was calculated using spectral reflectance from visible and near infrared bands referring the relationship given by Rouse *et al*. 1973.[8]

Analysis of satellite data

The AWiFS image data was obtained. Digital image processing and digital analysis was carried out using ArcGIS and ERDAS Imagine software's. This analysis involved importing bandwise data and layer staking the satellite data, digitization of study area, georeferencing the AWiFS images, clipping/subseting the area of interest from larger image and radiometric normalization. Point and polygon vector layers were obtained by utilizing the data of ground truth work. Non crop mask, road network layer and toposheet layer were also utilized for precise interpretation. The NDVI of each pure wheat crop polygon was extracted by using signature editor. The mean values of wheat polygon NDVI at different dates were considered for further analysis. Considering the age of wheat crop (in weeks) of each polygon the values of NDVI extracted were assigned to week that week and average week wise NDVI values were obtained.

Crop Coefficients of wheat Crop (Kc)

The week wise crop coefficients of wheat crop obtained from lysimeter studies recommended by Mahatma Phule Krishi Vidyapeeth Rahuri, Maharashtra, India [3] were used for the study [Table-1].

Table-1 *Recommended crop coefficients for wheat*

Week past sowing	Kc for wheat based on method of calculating reference ET		
	Penman-Monteith (KcPM)	Pan Evaporation (KcPE)	Hargeaves-Samani (KcHS)
1	0.71	0.84	0.70
2	0.88	1.11	0.86
3	1.03	1.29	0.98
4	1.15	1.40	1.08
5	1.24	1.46	1.17
6	1.31	1.50	1.24
7	1.36	1.51	1.28
8	1.38	1.51	1.31
9	1.36	1.47	1.31
10	1.31	1.41	1.27
11	1.22	1.31	1.20
12	1.10	1.17	1.10
13	0.94	1.00	0.95
14	0.76	0.79	0.78
15	0.57	0.58	0.59
16	0.39	0.37	0.40
17	0.22	0.20	0.22

Results

NDVI profile of wheat

The Model Builder function in ERDAS Imagine was applied to get Normalized Difference Vegetation Index (NDVI) of each pixel of the subset image and NDVI image of the subset was obtained for each of the 8 dates of pass. A layer stack of the 8 NDVI images was prepared. Vector layers (point and polygon) of crops and non-crop mask were added. Pure crop pixels of wheat already marked by polygons were selected as AOI and added in signature editor of ERDAS Imagine to get statistics of NDVI of the 105 wheat crop polygons for each date. The statistics consisted of maximum value, minimum value, mean and standard deviation. This statistic corresponding to NDVI of each wheat polygon was obtained. The mean values of the wheat crop polygon NDVI were used for further study. The NDVI values were distributed for different weeks after sowing of the crop with consideration of ground truth date and ground truth information. [Table-2] shows the week wise distribution of average values of NDVI for pure wheat crop pixels.

Table-2 *Week wise distribution of average wheat NDVI*

Weeks past sowing	Avg. NDVI
1	0.2714
2	0.3241
3	0.3142
4	0.3620
5	0.3576
6	0.3926
7	0.3705
8	0.4224
9	0.3871
10	0.3533
11	0.3770
12	0.3311
13	0.3394
14	0.3014
15	0.2615
16	0.2590
17	0.2400

NDVI–Kc Pattern

MPKV Rahuri has recommended wheat crop coefficients based on methods of calculating reference evapotranspiration (ETo) *i.e.* Penman-Monteith Method, Pan evaporation method and Hargreaves–Samani method. In this study these are denoted as KcPM, KcPE and KcHS respectively. The NDVI and Kc values of the three types were plotted against the number of weeks after sowing and are shown in [Fig-1]. It is observed that the temporal variations of NDVI is similar to that of crop coefficients. The trend of these curves looks exactly similar in initial and crop development stage. During the late season stage all the three types of Kc values decrease fast whereas this rate of NDVI is comparatively slow. However overall similarity of these curves with NDVI curve exhibits the possibility of modelling Kc of wheat in terms of NDVI. Therefore, the relation of NDVI can be utilized as a surrogate of the Kc by adopting the related models.

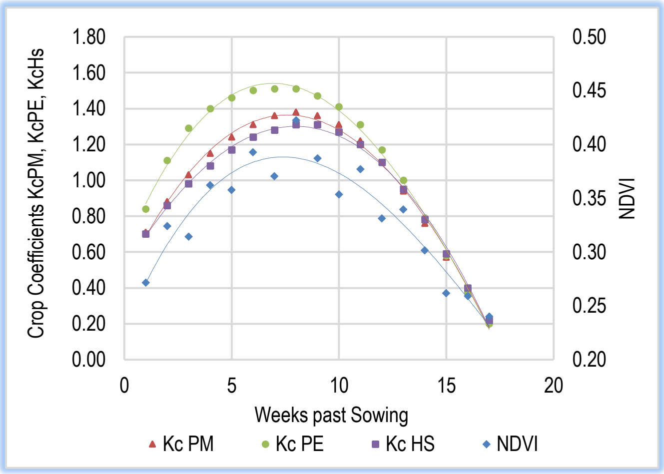

Fig-1 Comparison of trend of NDVI and Crop coefficient patterns of wheat

Relation between NDVI and Kc

The average weekly NDVI values of the selected sites were determined through the satellite images and arranged week wise and correlated with the weekly crop coefficients recommended by MPKV Rahuri to develop regression equations.

The Kc values are recommended by considering the three methods of calculating reference evapotranspiration *i.e.* Penman–Monteith method, Pan Evaporation method and Hargeaves-Samani method. When weekly NDVI values were plotted against Kc_{PM} is was observed that NDVI is closely related with Kc_{PM} by linear model with R^2 value of 0.895 [Fig-2]. The model is expressed as

KcPM = 6.461 NDVI-1.157 (2)

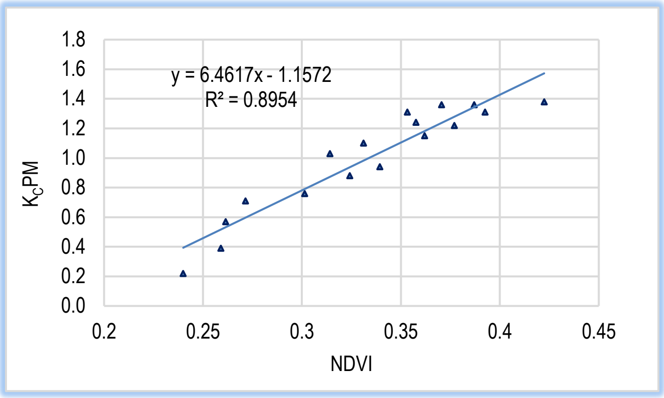

Fig-2 Relationship of crop coefficient Kc PM of wheat with NDVI

The plot of NDVI versus KcPE have also shown linear relation [Fig-3]. The linear relation is given as

KcPE = 7.361 NDVI-1.339 (3)

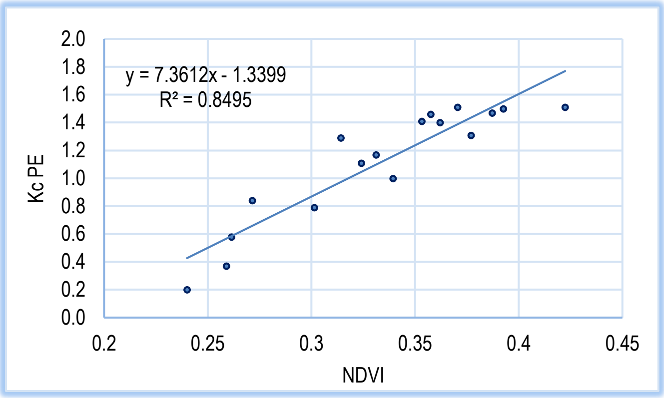

Fig-3 Relationship of crop coefficient Kc PE of wheat with NDVI

The R^2 value obtained was 0.849. This also indicates that this correlation can also be utilized for getting crop coefficients KcPE of wheat in terms of NDVI. Similarly, when wheat NDVI values were plotted against KcHS, it was observed linear relation KcHS-NDVI exists with high value of R^2= 0.886 [Fig-4].

KcHS = 5.950 NDVI – 1.010 (4)

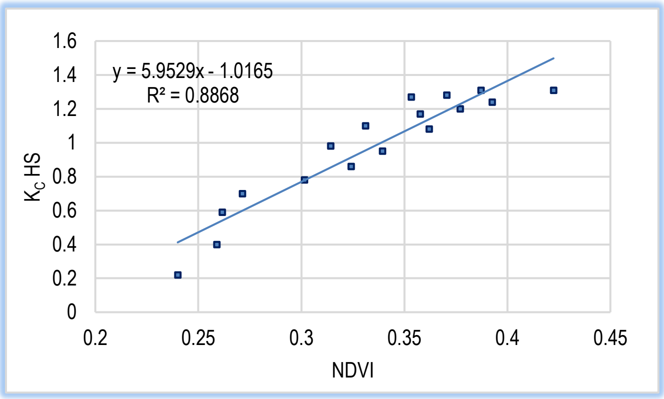

Fig-4 Relationship of crop coefficient Kc HS of wheat with NDVI

All the three equations show good linear relation indicating the correlation of wheat crop Kc with NDVI. It is clear that recommended Kc obtained with lysimeter studies using Penman–Monteith method for ETo have shown highest correlation with NDVI followed by Hargeaves-Samani method and Pan Evaporation method. This shows that the NDVI is highly correlated with wheat crop Kc in linear relation considering all the methods of calculation of reference evapotranspiration. As per the availability of weather data suitable method for reference evapotranspiration can be utilized. The results obtained are supporting the similar study conducted by Misra *et al.* (2005) [9] for paddy crop (West Bengal), Duchemin *et al.* (2006) [10] for wheat in Central Morocco, Suifan *et al.* (2007) [11] for irrigated vegetable crops, Calera and Gonzalez (2007) [12] and Gontia and Tiwari (2010) [13] for wheat crop in Tarafeni South Main canal irrigation command, Kamble *et al.* (2013) [14] at Nebraska USA. for irrigated crops, Lei and Yang (2014) [15] for wheat in China.

Conclusion

Satellite remote sensing data and GIS techniques were applied to estimate wheat crop coefficients. The multispectral vegetation index NDVI was obtained and its relation with Kcs obtained by lysimeter experiments was tested. The relations of NDVI with KcPM, KcPE and Kc HS obtained are as follows.

KcPM = 6.461 NDVI – 1.157, R^2 = 0.895

KcPE = 7.361 NDVI – 1.339, R^2 = 0.849

KcHS = 5.950 NDVI – 1.010, R^2 = 0.886

This indicates that NDVI can be used as a surrogate of wheat crop coefficients. For this purpose, these models may be used. This can help to calculate accurate and spatial water demand of wheat crop. Therefore, the information generated can be used to schedule right amount of water at right time for higher production of wheat.

Application of research: The present investigation can pave an innovative approach for optimizing irrigation water scheduling. These models can also be used in the areas of similar climatic conditions.

Research Category: Remote sensing

Abbreviations: NDVI, AWiFS

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Author Contributions: All authors equally contributed

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Study area / Sample Collection: Pune, Solapur, Ahmednagar, Beed and Osmanabad, Maharashtra

Cultivar / Variety / Breed name: Wheat

Conflict of Interest: None declared

Ethical approval: This article does not contain any studies with human participants or animals performed by any of the authors.

Ethical Committee Approval Number: Nil

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