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Estimation of Crop Evapotranspiration of Wheat using Vegetation Index-Based Crop Coefficient

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ABSTRACT

Due to climate change and dwindling water supplies, precise irrigation methods are essential. Remote Sensing is a tool that can be used to determine crop coefficients indirectly. The research area included three wheat-growing districts in North Maharashtra. The purpose of present work was to assess the applicability of remotely sensed Vegetation Indices (VIs) for modelling spatial crop coefficients, choose the most relevant vegetation index among them for modelling and apply this model to predict wheat water requirements. Sentinel 2A, MIS sensor images were employed to produce NDVI, NDWI, SAVI, MSAVI2 and RVI multi temporal vegetation indices. The week-wise VIs was linked with the week-wise crop coefficients of wheat suggested by MPKV, Rahuri and establishing linear models. All of the vegetative indices have a relatively good correlation with wheat crop coefficients with considerably high R^2 values. However, the NDWI-Kc model has the highest R^2 value of 0.954 and the lowest SE, RMSE, and PD values of 0.0796, 0.0748, and 3.14.The RVI-Kc model performed poorly with R^2 value of 0.703.Estimated total crop evapotranspiration of wheat for Dhule was found 449.65 mm whereas for Jalgaon it was 440.92 mm and total crop evapotranspiration of wheat for Nashik was found 429.16 mm.

Introduction

Crop water requirement refers to the quantity of water required to make up for evapotranspiration loss from a planted area. The amount of water needed varies significantly from crop to crop and even during the growth season of each specific crop. An essential component of agricultural planning is the precise estimation of crop water requirements. Water use efficiency, which is primarily determined by crop evapotranspiration (ETc) may be enhanced on a regional scale by adequate irrigation planning, scheduling, and decision making based on expected ETc, which is dependent on crop coefficient (Kc). Crop coefficients of different crops given by FAO may give a useful guideline for scheduling irrigation, but they are subject to significant inaccuracy in calculating crop water requirements due to their empirical aspect (Jagtap and Jones, 1989). Hence, crop coefficient values must be adjusted based on local conditions. Gontia and Tiwari (2010); Farg *et al.,* (2012) linked remotely sensed vegetation indices to estimate Kc and computed wheat crop evapotranspiration based on these vegetation indices. Crop coefficient (Kc) may therefore be calculated from spectral vegetation indices (VIs) as both are connected to leaf area index and fractional ground cover. Therefore, approaches for estimating Kc weekly or biweekly are required for water need estimations at the field level. Satellite remote sensing solves some of the shortcomings of time-based Kc curves by providing real-time and/or near real-time spatial data on Kc and ETc use as influenced by actual cropping patterns. Many polar orbiting satellites offer continuous observations of the earth's surface in the red, NIR, and SWIR wavelength regions as well as allow estimate of major vegetation parameters such as canopy cover, vegetation water content, biomass, and so on. Sentinel 2A data consists of 13 bands of spectral responses ranging from visible to short wave infrared with spatial resolutions of 10 m, 20 m and 60 m. It has swath path of 294 km and its revisiting time is 5 days. The data is freely available for download at the Sentinel Scientific Data Hub website (https://scihub.copernicus.eu/dhus/#/home).

Wheat (*Triticum aestivum L*.) is the second-most significant grain crop after rice in India. Numerous elements including proteins, carbohydrates and vitamins are added to it. Wheat is grown in a range of soil types in India but clay loams and well-drained loams are ideal for growing wheat. A cold environment and irrigation are required for wheat growing.

It takes between 450 and 650 mm of water to grow wheat. Growth stages affect the real-time water requirement for the wheat crop. With the satellite-derived crop data along with ground truth data, it is feasible to estimate evapotranspiration from meteorological data and extract crop phenological phases from satellite images. With these considerations in mind, the primary objective of this study is to estimate the amount of crop water needed for wheat cropping system using satellite data.

Materials and Methods

Study area

The study area including Dhule, Jalgaon and Nashik districts of Maharashtra, which are growing wheat consistently. The research region is located between 73° 78' 98" to 75° 52' 77" E longitude and 19° 99' 75" to 21° 03' 96" N latitude. The average annual rainfall in the study region is between 600 and 1000 mm.

Remote Sensing Data used

Multispectral and multidate satellite images of Sentinel 2A satellite (MSI sensor) was acquired during the *rabi* season of 2020-21. Images of Sentinel 2A satellite has 13 spectral bands out of which 5 bands are used for the study.

Ten cloud free images were taken and analysed using ERDAS software to obtain NDVI, NDWI, SAVI, MSAVI2 and RVI images for each day a satellite passed over the research region. The date of pass of satellites over study area was 15th Dec 2020, 25thDec 2020, 19th Jan 2021, 29th Jan 2021, 13th Feb 2021, 28th Feb 2021, 15th Mar 2021, 25thMar 2021, 09th Apr 2021 and 19th Apr 2021 respectively.

Ground Truth Data

The ground truth was carried out between 24th to 30th January 2021, collecting information of 28 sites of wheat growing during *rabi* season of 2020-21. Handheld GPS, Android mobile for taking photos of sites and ground truth proform a sheet was used for collecting the data.

Meteorological Data

Weekly mean data including Maximum and Minimum Temperature, Relative Humidity, Solar radiation and Wind speed was obtained from website of NASA Power system for Dhule, Jalgaon and Nashik district separately.

Image Processing

In ArcGIS 10.2 software, a wheat polygon vector layer was generated using ground truth data. ERDAS Imagine software was used to extract pure wheat polygon multidate vegetation indices. These vegetation indices values were organised week by week, taking into account the age of the wheat crop at various sites.

Establishment of VI-Kc models

Using linear regression analysis, the empirical correlations between weekly wheat crop coefficients (Kc) proposed by Mahatma Phule Krishi Vidyapeeth Rahuri (MPKV, 2021) and VIs were discovered.VI-Kc model was assessed using statistical criteria such as Coefficient of determination (R^2), Root Mean Square Error (RMSE), Willmott Index of agreement (D) and percent deviation (PD).

Estimation of water requirement

Using weekly meteorological data, FAO Penman Monteith technique was used to determine reference evapotranspiration (ETo). The week-wise crop coefficients were calculated using the best performing VI-Kc model. The week-wise water requirements (ETc) of the wheat crops were obtained by product of reference evapotranspiration and vegetation index-based crop coefficient.

Results and Discussion

Developed VI-Kc model

The weekly crop coefficients (Kc) suggested by MPKV Rahuri were plotted against the average weekly values of vegetation indices for wheat as given in Table 2.The relationship between the vegetative indices and crop coefficients was investigated using simple linear regression analysis. All of the vegetative indices were shown to have a relatively excellent association with wheat crop coefficients with significantly high R^2 values as shown in Fig 1.However, the NDWI-Kc model has the greatest R^2 value of 0.954and it has lowest values of SE, RMSE and PD of 0.0796, 0.0748 and 3.14.RVI-Kc model showcased comparatively poor performance with an R^2 value of 0.703. This might be because RVI is just a simple ratio and doesn't entirely account for the greenness of vegetation. NDWI measures water content of crop as well as soil. Therefore, when crop is in development stage NDWI is maximum due to higher water content and decreases in maturity stage as water content of crop reduced.

Water requirement of wheat

The reference crop evapotranspiration (ETo) of Dhule, Jalgaon and Nashik district were calculated by using FAO Penman Monteith method by using meteorological data collected from NASA power website and are presented in Table 3. The crop evapotranspiration (ETc) of wheat was estimated by multiplying the reference evapotranspiration (ETo) by Kcs obtained by NDWI-Kc model and shown in Table 4.

Similarly, Pimpale *et al.,* (2015) evaluated water needs of wheat using multispectral vegetation indices for five wheat-growing areas in central Maharashtra using remote sensing approach. They discovered wheat ETc ranging from 378.34 mm to 439.10 mm in the study region. Kivrak *et al.,* (2019) used plant phenology and Landsat-8 satellite data to quantify water usage by onion crops in the Mesilla Valley, New Mexico. Water demand was predicted to be 973 mm in 2015 and 975 mm in 2016.

Kosale *et al.,* (2021) in their M.Tech studies observed that the estimated total crop evapotranspiration (ETc) of wheat was 405.74 mm. The study revealed the potential of remotely sensed vegetation indices to predict spatial and temporal crop coefficients of wheat crop. The study found that the NDWI-Kc model produces more accurate findings than other VI-Kc models. This technology may be effectively used to predict the temporal and spatial water requirements of a wheat crop, which can aid in efficient water planning.

Table.1 Average weekly values of VIs of wheat

WPS	NDVI	NDWI	SAVI	MSAVI2	RVI
1	0.189	0.117	0.273	0.286	1.244
2	0.239	0.128	0.308	0.316	1.428
3	0.256	0.138	0.369	0.378	1.617
4	0.297	0.195	0.401	0.400	1.983
5	0.327	0.235	0.471	0.495	2.269
6	0.408	0.269	0.576	0.553	3.099
7	0.418	0.294	0.637	0.597	3.327
8	0.440	0.299	0.694	0.634	3.409
9	0.425	0.283	0.654	0.605	3.142
10	0.420	0.285	0.643	0.594	2.869
11	0.406	0.244	0.615	0.573	2.636
12	0.352	0.199	0.524	0.514	2.290
13	0.298	0.106	0.445	0.453	1.902
14	0.250	0.059	0.354	0.385	1.765
15	0.234	-0.001	0.347	0.361	1.650
16	0.201	-0.016	0.266	0.299	1.535
17	0.156	-0.043	0.203	0.237	1.367

Table.2 Reference evapotranspiration of various districts of study area.

Met. Week	Reference evapotranspiration (ETo) (mm)		
	Dhule	**Jalgaon**	**Nashik**
45	3.56	3.29	3.51
46	3.47	3.25	3.16
47	3.31	3.16	3.07
48	3.48	3.31	3.22
49	3.86	3.64	3.65
50	2.49	2.42	2.27
51	3.46	3.31	3.42
52	3.59	3.44	3.37
1	3.21	3.25	2.57
2	3.64	3.49	3.21
3	4.08	4.30	3.90
4	4.21	4.33	4.54
5	4.91	5.12	4.76
6	4.95	5.00	5.42
7	4.82	4.77	4.72
8	5.34	5.24	5.44
9	6.45	6.22	6.28
10	5.72	5.49	6.32
11	5.87	5.82	6.46
12	5.82	5.92	6.23

Fig.1 (a, b, c, d and e) Relationship of crop coefficients with vegetation indices of wheat

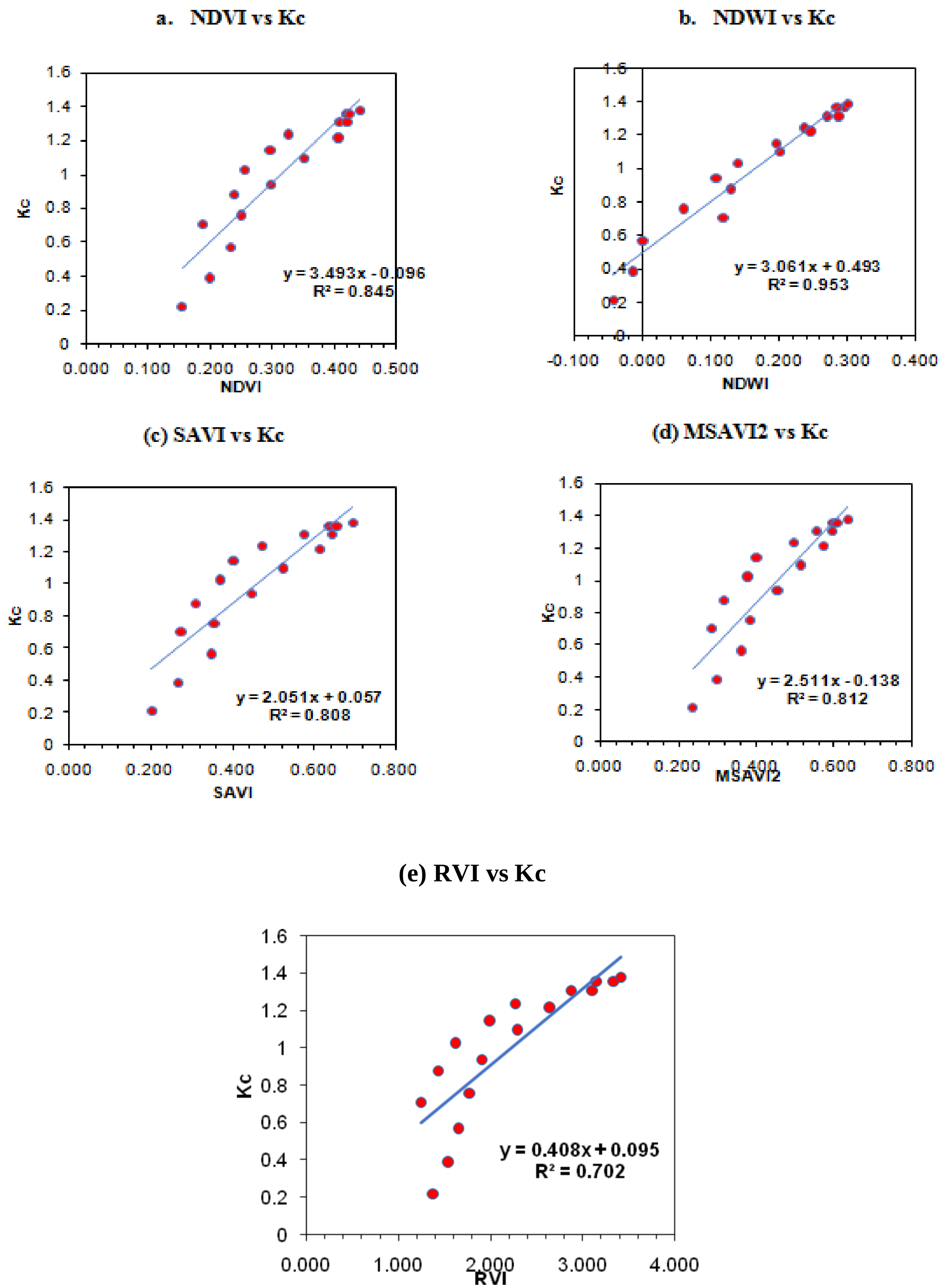

Table.3 Crop evapotranspiration for wheat

Weeks Past Sowing	Crop evapotranspiration (ETc) (mm)		
	Dhule	**Jalgaon**	**Nashik**
1	21.20	19.61	20.89
2	21.50	20.11	19.59
3	21.17	20.23	19.64
4	26.58	25.23	24.55
5	32.79	30.89	31.02
6	22.97	22.28	20.91
7	33.69	32.23	33.31
8	35.44	33.89	33.26
9	30.53	30.96	24.44
10	34.87	33.35	30.75
11	35.46	37.31	33.89
12	32.47	33.43	35.05
13	28.14	29.36	27.27
14	23.31	23.58	25.52
15	16.53	16.36	16.19
16	16.64	16.32	16.95
17	16.36	15.77	15.93
Total	**449.65**	**440.92**	**429.16**

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