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Vegetation Index-Deduced Crop Coefficient of Wheat (*Triticum aestivum*) Using Remote Sensing: Case Study on Four Basins of Golestan Province, Iran

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Abstract**—**Crop coefficient (Kc) is an important factor contributing to estimation of evapotranspiration, and is also used to determine the irrigation schedule. This study investigated and determined the monthly Kc of winter wheat (*Triticum aestivum* L.) using five vegetation indices (VIs): Normalized Difference Vegetation Index (NDVI), Difference Vegetation Index (DVI), Soil Adjusted Vegetation Index (SAVI), Infrared Percentage Vegetation Index (IPVI), and Ratio Vegetation Index (RVI) of four basins in Golestan province, Iran. 14 Landsat-8 images according to crop growth stage were used to estimate monthly Kc of wheat. VIs were calculated based on infrared and near infrared bands of Landsat 8 images using Geographical Information System (GIS) software. The best VIs were chosen after establishing a regression relationship among these VIs with FAO Kc and Kc that was modified for the study area by the previous research based on R^2 and Root Mean Square Error (RMSE). The result showed that local modified SAVI with R^2= 0.767 and RMSE= 0.174 was the best index to produce monthly wheat Kc maps.

Keywords**—**Crop coefficient, remote sensing, vegetation indices, wheat.

I. Introduction

ONE of the most important factors in irrigation scheduling is Kc. Wheat is a major strategic crop cultivated in the world. In addition to environmental conditions, agricultural practices determine its developmental stage and growth period. Kc depends on various factors such as crops characteristics, sowing or harvest time, crops developing rate, growth length, and climatological situations. Monthly Kc for wheat was estimated using the guidelines given in FAO Irrigation and Drainage Paper, number 56 [2].

Kc values are represented in literature or estimated using potential evapotranspiration and crop requirement, which may provide a practical guideline for crop water requirement as the proper Kc. However, because of the empirical nature of this element, considerable error may occur during the process, so it should be localized in every region according to its features [5].

In many researches performed in Iran, there was no precise method to estimate Kc, whereas Kc has been estimated accurately via new methods such as remote sensing and VIs in recent years. For example, Duchemin et al. [3] and Akdim et al. [1] determined this parameter based on NDVI in central and west regions of Morocco. Rahimian et al. [7] modified the Kc value using nine VIs in Azadegan plate in Iran.

Because of the inadequate data in domestic researches for localized wheat Kc, especially in Golestan province, this research was conducted to accurately estimate wheat Kc in four basins of the province using new methods such as remote sensing approaches and Landsat-8 images.

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II. Materials and Methods

A. Study Area

Golestan province is one of the most important regions in agriculture, and irrigated and dryland wheat is cultivated across the province. Despite the small extent, there are variable climates in this region. This research was performed in four basins of the Golestan (Qaresoo, Mohammadabd, Zaringol and Gharnabad) covers an area of 4000 km^2 (Fig. 1). It has latitudinal extent of 36° 30′ to 38° 8′ and longitudinal extent of 53° 57′ to 56° 22′. A large part of the basins is covered by forests and there are residential and fields in the south. The main part of this study is based on the results obtained from Zolfagharnejad's [8] MSc thesis.

B. Satellite Images

Landsat satellite was launched in 2013 and is consisted of two sensors: OLI and TIRS with the spatial resolution of 30 meter. In this study, we used 14 OLI images in different data during wheat growth stage, and radiometric correction was done.

C. Estimation of VIs

VIs are defined according to different bands of sensors, and especially red and infrared bands and are used to evaluate and survey crops through satellite images. Five VIs: NDVI, DVI, IPVI, SAVI and RVI were used in this research and are shown in Table I.

After calculation of these VIs via satellite images, linear regression was used along with FAO-based Kc and local-based Kc proposed by Farshi et al. [4] which has modified wheat Kc for Gorgan city and OLI derived VIs. The best model was chosen according to high accuracy based on the coefficient of determination (R^2), RMSE, and Mean Absolute Error (MAE) as statistical indicators.

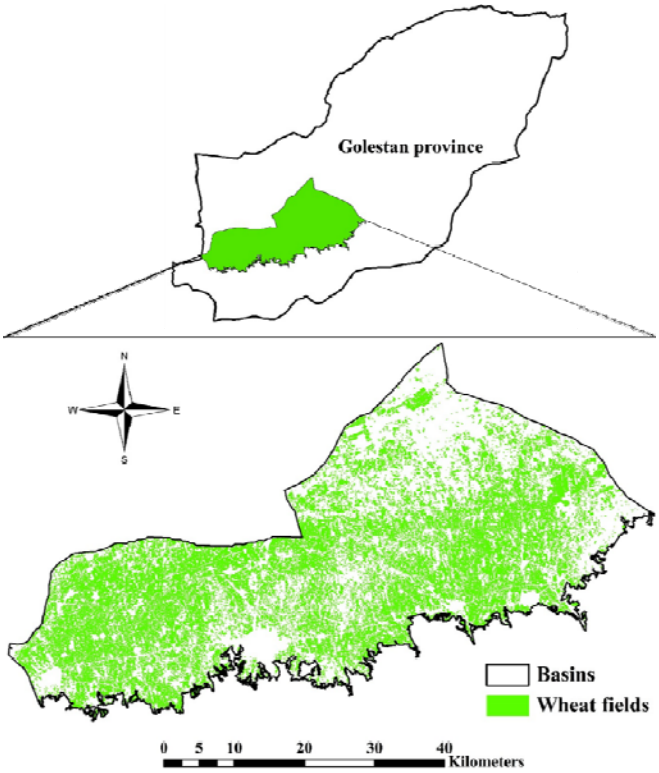

Fig. 1 Location of the Study area and wheat field

TABLE I
VIs USED IN THIS STUDY FOR ESTIMATION OF WHEAT KC

VIs	Equation
DVI	IR–R
NDVI	(IR–R)/(IR+R)
SAVI	[(IR–R)/(IR+R+L*)]*(1+L)
IPVI	IR/(IR+R)
RVI	IR/R

R and IR: Red and Infrared bands, L is the soil line.

1. Soil Line (L) Determination in SAVI

In arid and semi-arid regions, because of thin crop canopy, soil reflectance disturbs the crop reflectance during computing of NDVI, so SAVI is introduced as the solution to reduce the effects of the background soil. In order to determine SAVI, soil line (L) should be calculated first. 13 points were chosen from bare-soils through study area and their values in red and infrared bands were extracted. Finally, according to linear regression between these extracted values, L was calculated, and then SAVI was determined.

D. Mapping Kc

Based on the best regression between VIs and two mentioned Kcs, the monthly Kc map was provided during wheat growth stage.

III. Result and Discussion

A. Determination of VIs

Linear regression between two FAO based Kc, and Local based Kc with five VIs is represented in Table II.

TABLE II
RESULT OF THE REGRESSION BETWEEN FAO BASED KC AND LOCAL BASED KC WITH FIVE VIS

Kc	VIs	r	RMSE
FAO	DVI	0.060	0.453
	NDVI	0.731	0.242
	SAVI	0.662	0.271
	RVI	0.033	0.459
	IPVI	0.727	0.244
Local	DVI	0.032	0.341
	NDVI	0.740	0.177
	SAVI	0.747	0.174
	RVI	0.005	0.345
	IPVI	0.737	0.188

SAVI is known as the best vegetation index in determination of wheat Kc according to local-based Kc estimation. The result shows that SAVI index has the capability to modify wheat Kc in the study area that this result is similar with Rahimian et al [7]. The other result is the second place for NDVI in estimation of Kc. Since the influence of soil on canopy reflection decreases as a result of its computation, SAVI index will give a better viewpoint of the region's condition compared with NDVI, especially in arid and semi-arid regions.

The linear regression between local-based Kc and SAVI is presented in Fig. 2.

B. Generation of Kc of Wheat Crop

According to the equation represented in Fig. 2 and SAVI raster maps driven from Landsat images, monthly Kc maps were drawn (Fig. 3)

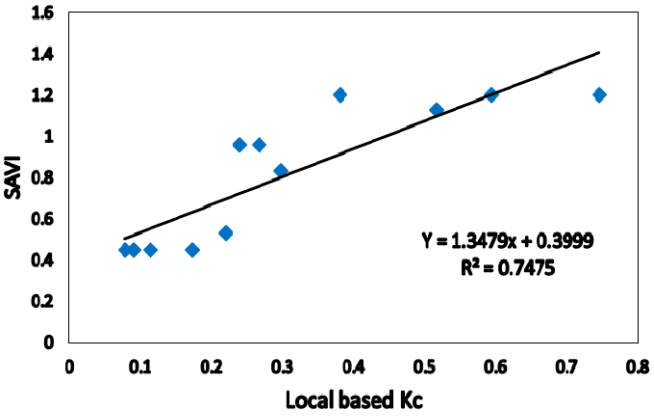

Fig. 2 Linear regression between SAVI and Local based Kc

Kc trend was not constant during wheat growth stages (Fig. 4). Actually, a Kc curve shows distribution of Kc values with smooth continuous function during growth stages of crop.

After canopy closure, the Kc trend will decline, which depends on the particular crop growth characteristics and the irrigation management during the last season [1]. The main factors affecting crop physiology, turbulence, and surface wetness like light absorption by the canopy, dynamics of canopies, and canopy roughness are the strongest elements influencing Kcs [6]. During development of the crop canopy,

because of high evapotranspiration resulting from transpiration, the ratio of transpiration to evapotranspiration will increase. This occurs because interception of radiant energy by the foliage increases, trapping most of the light before it reaches the soil.

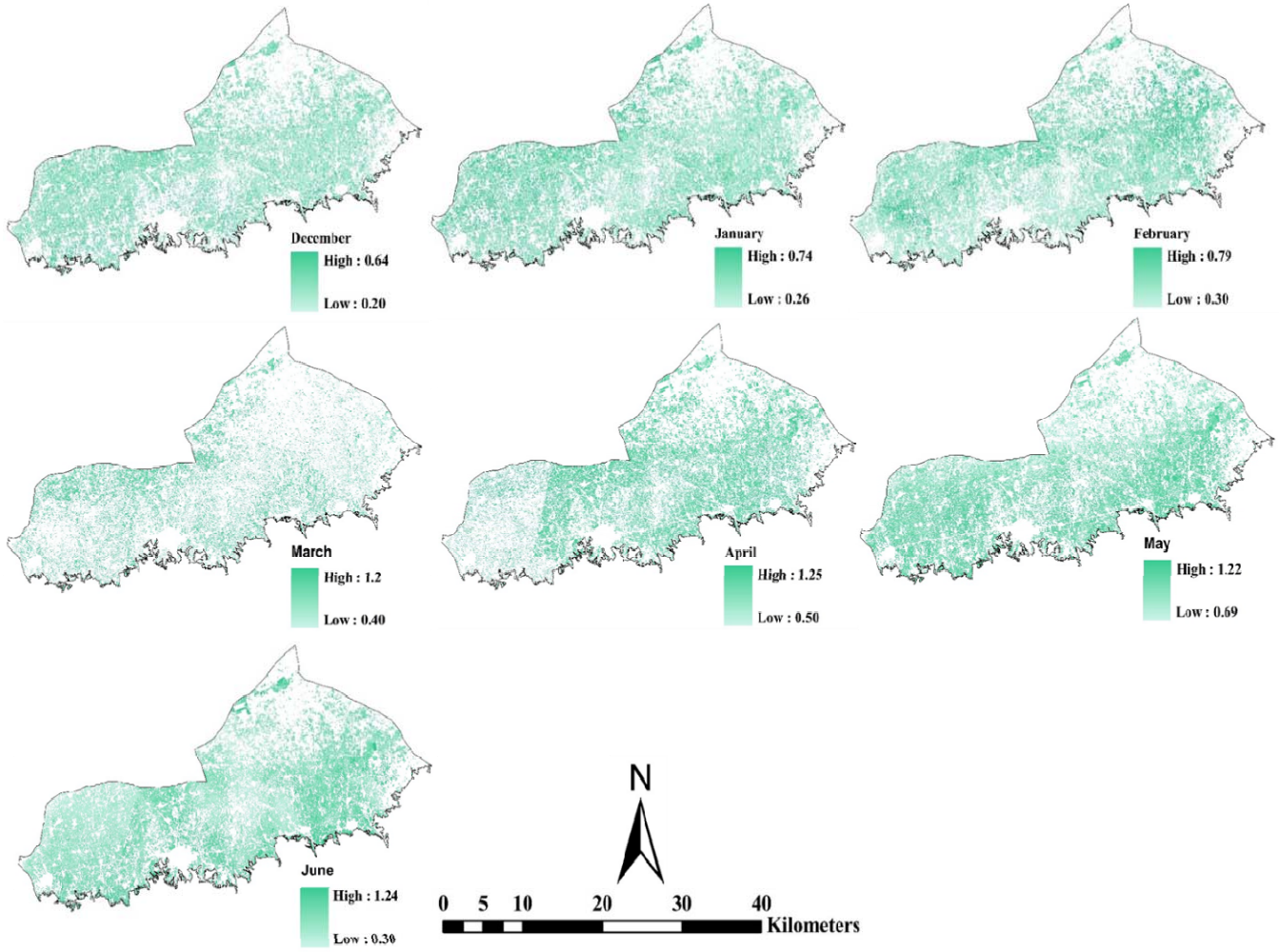

Fig. 3 Monthly wheat Kc maps were derived SAVI

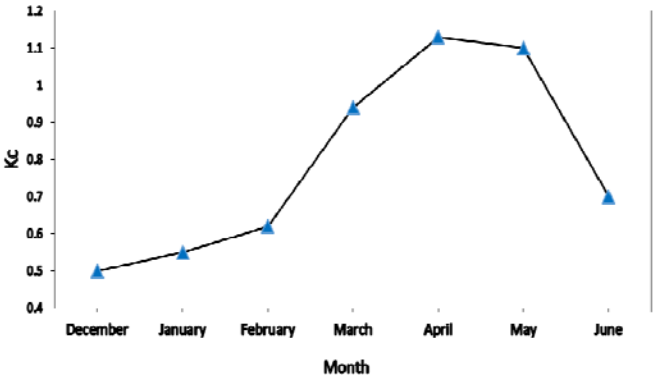

Fig. 4 Kc trend during wheat growth stages

IV. Conclusion

Cop coefficient is the main factor in accurate estimation of water requirement, although in most researches scientists use the suggested FAO Kc. This may seem as a proper solution, but it should be noticed that Kc is not a constant parameter, especially in a region with different climatological conditions. In this study, we tested the regression relation among the five VIs with two Kcs; one suggested by FAO and another was a local Kc estimated by Farshi et al. [4]. The results showed that SAVI was the best index among the five VIs, according to localized L factor for the studied area. It shows the importance of using proper VIs that describe the region more accurately. Besides, local-based Kc had a stronger relation with SAVI compared to FAO based Kc, and this indicates that one should modify crop Kc over years to achieve better results.

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