Normalized Difference Vegetation Index as a Tool for Wheat Crop Coefficient and Evapotranspiration Estimation: A case study of Nankana Sahib District Pakistan

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Abstract

Pakistan is an agricultural country and major part of its economy is also based on agriculture and among all crop wheat is most preferable in Pakistan to grow according to its climate condition and natural resources, but due to abrupt changes in climate, the agriculture sector is adversely affecting and water scarcity is the biggest part of this issue which is also being increased day by day, rapidly increasing in population rate is also affecting water resources. In Pakistan, almost all farmers use flood irrigation to fulfil their crop water requirement. A large portion of water is applied to the field used by evapotranspiration and only a very small quantity of water is used by plants for their growth, metabolism and other activities, etc. Therefore, this has been needed to calculate the crop water requirement at the field level and for this purpose, remote sensing is one of the best technique which calculates the crop coefficient KC and evapotranspiration Etc at field level and also helps to efficient use of water for crops. Normalized difference vegetation index (NDVI) is used as a tool for the calculation of crop coefficient and Evapotranspiration by using the following formula $N = (Ndvi_{Landsat} - bare\ soil\ Ndvi) / (Maximum\ Ndvi - bare\ soil\ Ndvi)$ Where $KC = N^2$ and the calculated crop coefficient was 0.28 to 1 and Evapotranspiration 0.9mm/day to 3.33 mm/day from January to April respectively.

Keywords: NDVI (Normalized Difference Vegetation Index); ETo (Reference Evapotranspiration); Etc (Crop Evapotranspiration); Kc (Crop Coefficient); FAO (Food and Agriculture Organization)

Introduction

Rainfall is one of the major factors which affects the wheat yield. In northern areas, rainfall also caused the annual flow of water in rivers. Climate change effect maturity level and harvesting time of wheat in northern areas of Pakistan. Sometimes wheat is not obtained proper maturity due to low temperature and used as fodder, but due to unexpected variations in climate, the temperature is raised and high level of maturity is achieved by wheat and it also causes worst climate condition in other semi-arid regions of the country [2]. Meteorological parameters affect the wheat crop at its main stages, including germination, development, and maturity. Rainfall affects the direct yield, but rainfall excess or deficiency at the critical stages also affects yield. Rainfall at maturity stage reduces yield because at this stage wheat crop requires a

high temperature for drying [1]. On-time irrigation, uses of pesticides and irrigation scheduling, enhance wheat productivity and save water [3]. The Crop water requirement is changed according to climate condition and region [4]. Water table depth also affects the crop water requirement, for example, if water table depth is 1m then the water requirement will be more than 0.5m because groundwater also contributes to the water requirement of a crop [5]. Crop water requirement depends on reference evapotranspiration and crop coefficient and these two parameter changes on different growth stages according to climatic conditions of each year [6,7].

The evapotranspiration is the combination of two processes one evaporation and second transpiration. Evaporation is a physical change of water from the soil and other surfaces into the

atmosphere. Transpiration is the removal of water by plants into the atmosphere. A very huge quantity of water which is taken up by plant roots become the part of transpiration, only small remaining quantity is used by plants for their growth and metabolism activities. CROPWAT 8.0 for Windows software is developed by FAO with the help of National Water Research Center Egypt and Institute of Irrigation Development Studies of Southampton of UK. Crop Wat windows calculate crop evapotranspiration using the FAO-56 Penman-Monteith equation [9]. CROPWAT 8.0 for Windows software helps to develop irrigation schedules on the basis of daily soil moisture condition and crop water requirement using previous literature crop coefficients. It is essential for water resources, planning, development and management and also help to plan strategies to improve crop yield under water scarcity conditions. Crop evapotranspiration is calculated by FAO-56 Penman-Monteith equation [10]. Sonu Kumari calculated crop water requirement and irrigation scheduling for major crops and found that by improving irrigation strategies water can be saved and also increased command area under cultivation [11]. Nowadays water resources, decreasing by and by due to increase in population calculation of crop water requirement and its coefficient must be concluded at the field level for future forecasting and to manage water requirement and therefore remote sensing is the best technique to calculate all these parameters [12]. Evapotranspiration is calculated by crop coefficient and reference evapotranspiration and to calculate crop coefficient simple model ($K_{csat} = 2NDVI - 0.2$) is used according to Egypt climatic conditions [8,13]. Two methods were used for crop evapotranspiration one Penman-Monteith method using FAO CROPWAT 8.0 for Windows software other ET calculated directly from satellite-based data using the sensible heat flux approach (SEBAL) also Possible differences were discussed and preferred SEBAL approach for better management at the field level [14]. The SEBAL model is used in Faisalabad and the surrounding areas to calculate actual evapotranspiration accuracy was approximately 95%, 90%, and 83% [19]. A simple model ($K_{csat} = 1.457NDVI - 0.1725$) developed to create a relationship between NDVI and crop coefficient using (MODIS) satellite data and compared the results with measured Kc and found a strong relationship [15]. Crop coefficient can be calculated using relationship= $(N_{dvi} \text{ Landsat-bare soil } N_{dvi}) / (\text{Maximum } N_{dvi} - \text{bare soil } N_{dvi})$ and $K_c = N^2$. This method is based on the fraction of the vegetation cover and fraction between emissivity and canopy of the crop. The evapotranspiration of wheat is calculated in West Bengal India by this method and found that maximum crop evapotranspiration for wheat is 5.57mm/day and the minimum is 1.59mm/day [16,17]. The research was conducted in near Florence, SC, the USA under pivot irrigation system under

different variation rate of water and used NDVI for development of crop coefficient and development of spatial irrigation method and found that NDVI based spatial irrigation method warranted [18]. The crop report of wheat in central Punjab is published by Pakistan Meteorological Department (2016-2017) and crop coefficient is used for the whole wheat season from November to April . The Kc value is changed from 0.3 to 1 . the results of our research also within this range [19].

Material and Method

Study area

Nankana Sahib is an agricultural district of Punjab province, Pakistan is located at 31.449561°N 73.70648°E between Rachna Doab (Ravi River + Chenab River=Rachna). The District Nankana Sahib is bounded on East by Sheikhpura, west of Faisalabad north of Hafizabad and South side of the Kasur district. The total area of the district is 2,720 square kilometers, but the population is 1,356,374 and population density is 460/Km² [22]. The surface irrigation technique is used to fulfil the requirement of crops and the fixed amount of water allocates to farmers, according to the land is held by the farmer and in a local language, it is called a Warabandi system in which water is given to farmers after the interval of seven days.

Figure 1

Reference crop evapotranspiration (ET_o)

Reference evapotranspiration of wheat was calculated using the CROPWAT 8.0 for Windows software and FAO Penman-Monteith equation used for calculation of evapotranspiration by considering hypothetical grass as a reference crop for calculation of evapotranspiration of another crop during the whole year and other regions can be calculated.

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

ET_o= Reference evapotranspiration (mm day⁻¹)

T= Mean daily temperature at 2m height(°C)

u₂= Wind speed at 2 m height (m s⁻¹)

G= Soil heat flux density (MJ m⁻² day⁻¹),

e_a= Actual vapour pressure (kPa),

e_s-e_a= Saturation vapour pressure deficit (kPa),

R_n net radiation at the crop surface (MJ m⁻² day⁻¹),

e_s= Saturation vapour pressure at T_c (kPa),

Δ= Slope of the saturation vapour pressure and temperature relationship (kPa °C⁻¹),

γ= Psychrometric constant (kPa °C⁻¹).

During our study, we used the weather station of Faisalabad District which is an attached district to Nankana sahib at 55 Km Distance. Pakistan is an under developing country weather station availability in each district is very difficult, so we used the following data.

Month	Min Temp	Max Temp	Humidity	Wind	Sun	Rad	ET _o
	°C	°C	%	km/day	hours	MJ/m ² /day	Mm/day
January	13.1	19.2	81	115	5.4	10.5	1.55
February	9.1	20.3	79	106	6.7	14.0	2.01
March	13.8	26.0	68	115	8.9	19.5	3.33
April	20.6	35.0	42	120	9.0	22.0	5.30
May	23.9	39.0	47	121	10.1	24.9	6.39
June	27.9	39.8	56	101	9.3	24.0	6.23
July	28.0	38.0	70	125	7.9	21.7	5.68
August	29.5	39.0	67	100	as	21.6	5.65
September	26.5	37.2	65	103	8.7	19.9	5.11
October	18.7	32.2	65	69	8.8	17.1	3.58
November	12.4	27.0	75	82	6.9	12.5	2.30
December	6.5	21.7	81	70	6.9	11.3	1.49
Average	19.2	31.2	66	102	8.1	18.2	4.05

Table 1

Data

The Landsat images are used on the following dates, 29 January, 28 February, 16 March, and 1st of April. These are the cloud-free images available during these months. On 29th of January tillering, February heading, the march flowering and during the April month, maturity stages were recorded. During February month images were a little bit cloudy on a small portion We couldn't use December images due to clouds throughout the month because of the winter season of 2018-19 of the wheat season under rainy conditions during the whole season as compared to 2017-18 and

2016-17 winter seasons. Below graph show months on X-axis and rainfall in mm on Y-axis 2018-19, 2017-18 and 2016-17 respectively.

Classification

Land use and the land cover maps were used to develop an NDVI using unsupervised classification which is a cluster analysis technique that assigns a value to the cluster of the similar pixel value. Base map and ground truth values were also used to verify classification [21].

Graph 1

Figure 2

Graph 2

Graph 3

Algorithm

Figure 3

Radiometric correction

The Landsat8 images were collected from 2019 January to April used in this study. For radiometric correction, we have been using the following model.

$$P = M_p * Q_{cal} + A_p$$

P= TOP, Planetary reflectance, without correction for solar angle

have not a correction for the solar angle.

$$P= Mp*Qcal+Ap/Cos(\theta SZRadians)$$

$$Mp= Reflectance\ multiband=2.0000E-05$$

$$Qcal= Band\ radiometric\ correction\ required=Band4,\ Band5$$

$$Ap= Reflectance\ add\ band=-0.100000$$

$$\theta SE= Sun\ elevation=31.41727603$$

$$Local\ zenith\ angle= \theta SZ90- \theta SE=90-31.41727603=58.58272397$$

$$\theta SZ\ Radian= \pi/180*Degree$$

$$Cos\ (\theta SZ\ Radian)$$

Results and Discussion

Normalized difference vegetation index

$$NDVI= (Band\ 5-Band4)/(Band\ 5+Band4)$$

Landsat 8, band 5 is the near-infrared and band 4 is the red band. After radiometric correction and extraction required area from the selected images, we put the data into the above equation and we calculate the Ndvi value of the wheat crop, which changes from 0.47 to, 0.80, 0.54 and 0.82,0.64 then 0.86, 0.34 to 0.61 in January, February, March, April respectively. Maximum Ndvi during the grain filling time and lowest at maturity level [23]. The same sequence was found in our selected wheat fields whose coordinates we took during the season. "Rainfall duration in winter was long during the 2018-19 season in Pakistan due to Climatic condition, temperature, rainfall pattern effect maturity

time of wheat and Ndvi value were also changed along the growth stage [2].

NDVI and Kc

The Crop coefficient and evapotranspiration of wheat were calculated by using Arc Gis 10.1 and CROPWAT 8.0 for Windows software. NDVI was used to calculate the of Kc and Etc of wheat by using relationship= (Ndvi Landsat-bare soil Ndvi)/(Maximum Ndvi- bare soil Ndvi) and $Kc=N^2$ [16,17]. Normalized vegetation index NDVI(NIR-RED/NIR+RED) NIR denote the reflation of near-infrared Landsat 8. NDVI shows the vegetation distribution in the area of seasonal variation and growth status of different crops within the area. During the winter season, wheat was the major crop in our study area and the Kc value was also Changing from, 0.58to0.90, 0.62 to 0.92, 0.67 to 1.00, and 0.28 to 0.61 in the month of January, February, March, April respectively. These results are within the range of previous studies in Pakistan [19,20].

Evapotranspiration Etc

$$ETc=ETo*Kc$$

Reference evapotranspiration ETo was calculated by using the CROPWAT 8.0 for Windows software and Kc maps were generated in Arc GIS, both values were multiplied. Etc maps were also generated and found that the value of Etc for wheat was increased from January to March due to the long winter season and high rainfall in Pakistan 2019-18 as compared to previous years. ETc values were found 0.9 to 1.4 mm/day, 1.24 to 1.83mm/day,2.24 to3.33 and 1.52 to 3.04mm/day in January February, March, April respectively.

Figure 4

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