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Vegetation Index Based Coefficients to Estimate Crop Evapotranspiration of Wheat in Punjab, Pakistan

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Abstract: Vegetation index based crop coefficients are widely used to determine crop evapotranspiration (ETc) for estimating water need at its different stages of growth for sustainable agricultural development. The recent study was carried out in Punjab where, Wheat is the main food crop. Our main objective is to estimate ETc of Wheat by using satellite based vegetation coefficients. Reference evapotranspiration (ET^0) was calculated by Penman-Monteith method. Climate data of 24 years (1991-2015) were used to calculate ETo. About 112 Landsat 8 satellite images for Rabi season (year-2016) were utilized in the study. Normalized difference vegetation index (NDVI) was derived by using satellite data in ArcGIS 10.2 software. Further NDVI was used to determine vegetation coefficients (Fov) for Wheat. ETc was calculated by multiplying ETo with Fov. Seasonal ETo for Wheat was 568 mm or 3.43 acre ft/year and Seasonal ETa was 558 mm or 328 acre ft/year. Seasonal ETc map showed spatial distribution of wheat in Punjab highlighting areas with low to high water requirement. The study provides information about use of water for irrigation and can be helpful for farmers, field managers and policy makers. Further studies should be investigated for other food and cash crops of Pakistan.

Keywords: Crop evapotranspiration (ETc), Landsat 8 images, Reference evapotranspiration (ETo), NDVI based crop coefficient

1. INTRODUCTION

Punjab lies in arid and semi-arid climatic zone. Wheat is widely grown food crop of Pakistan. It is sown from October-November and harvested in April-May (Naheed and Mahmood, 2009). It is grown in sub-tropical areas with 4 to 5 times irrigation and adequate sunshine throughout its vegetative growth. It requires average air temperature 15°C to 17°C and maximum 30°C to 35°C temperature and 20 to 30 inches rainfall throughout its vegetative growth. Upper part of Punjab receives average annual rainfall of about 20-30 inches while southern part receives less than 10 inches rainfall contributing to arid type of climate. About two-third part of Punjab receives rainfall in summer due to monsoon winds and winter rainfall from western disturbances (Ahmad *et al.*, 2015).

Vegetation indices based crop coefficients were used to estimate crop evapotranspiration (Singh *et al.*, 2013). To map land cover changes ETo, NDVI and temperature fraction approach was adopted by using AVHRR and Landsat TM satellite data (Dempewolf *et al.*, 2014). Reflectance based crop-coefficients were derived from satellite data to estimate crop evapotranspiration (Glenn *et al.*, 2011). SSEBop approach was attempted to predicted water use for crops in United States (Senay *et al.*, 2013).

1.1 Objectives

Our first objective is to calculate Reference evapotranspiration (ETo) by using Penman monteith method. The second objective is to derive vegetation coefficients from satellite based NDVI. The third objective is to estimate crop evapotranspiration of wheat in Punjab.

2. MATERIALS AND METHODS

2.1 Study Area and Data used

Punjab lies geographically between 31.17° N latitude and 72.70° E longitude. It geographical area is about 205,344 km². It lies in arid and semi-arid type of climate. The slope of the land is from north-east to south-west.

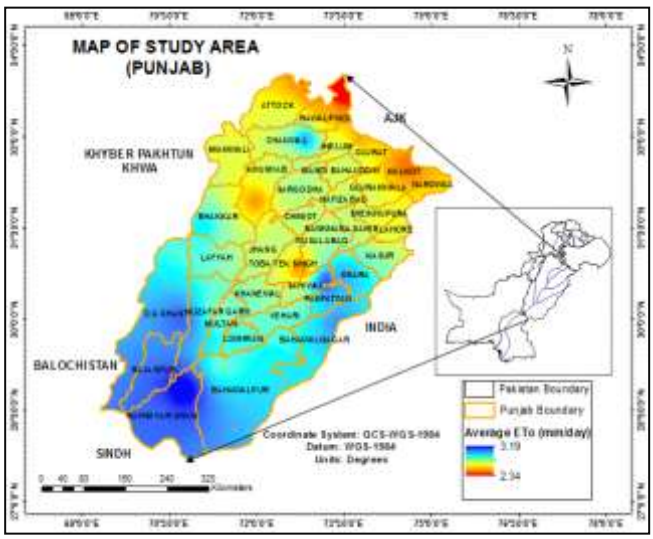

Figure 1. Map showing location of study area

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Maximum annual temperature fluctuates between 28°C to 32°C and minimum annual temperature varies between 14°C to 19°C in Punjab. Rainy season in Punjab starts from July and runs till September. Total area under wheat in Punjab is 6901,000 hectares in 2013-14 (Punjab Bureau of Statistics, Lahore). Average annual rainfall varies from 38 inches in sub-mountain region to 19 inches in the plains. Humidity fluctuates from 52% to 64%. Length of day varies from 7 to 9 hours.

Climate data (average of 24 years 1991-2015) of 20 weather stations of Punjab was collected from Pakistan Meteorological Department (PMD) was utilized for calculating ETo. The climatic normals are maximum and minimum temperature (°C), relative humidity (%), wind speed (mph), sunshine (hours) and rainfall (mm).

About 130 Landsat 8 satellite images with less than 10% cloud cover, were browsed and downloaded for the year 2016 (Rabi season), from USGS Earth Explorer website. Whole Punjab covers almost 16 images to make one scene/ image assuming to be one date image for one month. Spectral bands (Green band 3, Red band 4, NIR band 5) were used in the study. About 7 RGB stacked mosaic images for whole year 2016 were utilized in the study.

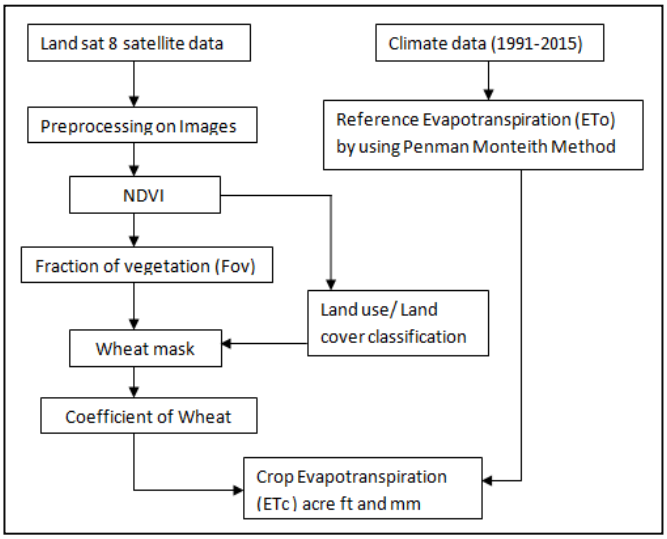

Figure 2. Flow chart showing methodology

2.2 Reference Evapotranspiration (ETo)

FAO Penman monteith method is a standardized method for calculating reference evapotranspiration used by many researchers. Climate data of maximum and minimum temperature (°C), relative humidity (%), wind speed (mph), sunshine (hours) and rainfall (mm) were used for estimation of ETo in CropWAT 8.0 software. Equation used by (Smith *et al.*, 1998) for ETo is given below:

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

Where,
ET_o = reference evapotranspiration (mm/day);
Rn = net radiation at the crop surface (MJ/m^2/day);
G = soil heat flux density (MJ/m^2/day);
T = mean daily air temperature at 2 m height (°C);
u2 = wind speed at 2 m height (m/s);
es = saturation vapour pressure (kPa) ;
ea = actual vapour pressure (kPa);
es - ea = saturation vapour pressure deficit (kPa);
Δ = slope vapour pressure curve (kPa/°C); and
γ = psychrometric constant (kPa/°C).

2.3 Reference

After pre-processing, stacking and mosaicing of images, widely used Normalized difference vegetation index (NDVI) is calculated in ArcGIS 10.2 software. Two reflectance bands (Red=band 4 and NIR= band5) of Landsat 8 were utilized for calculation of NDVI (Mu *et al.*, 2007) by following equation:

NDVI = band5 – band 4 / band 5 + band 4 (2)

Fraction of vegetation (Fov) was derived from NDVI output maps for all months by using equation (Brunsell and Gillies, 2003) given below:

Fov = NDVI – NDVIo / NDVImax+ NDVIo (3)

where,

Fov = Fractiona of vegetation
NDVI = NDVI value of image
NDVImax = NDVI value of vegetation
NDVIo = lowest value of bare soil

Finally Crop ET was calculated by using following equation:

ETc = ETo * Fov (4)

Where,

ETc = crop evapotranspiration
ETo = reference evapotranspiration
Fov= fraction of vegetation

3. Results and Discussion

3.1 NDVI and Fraction of vegetation

NDVI for all months was determined by using Eq. 2. from composited, mosaiced satellite images in Arc GIS 10.2 software package. It is an indicator of vegetation cover. NDVI based wheat coefficients were calculated by using Eq.3. These coefficients are indicator of percent of vegetation cover.

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3.2 Iso-cluster Unsupervised Classification

Unsupervised classification of NDVI image for the month of February was performed in GIS environment and Wheat crop class was derived from classified image after validation of crop growing areas with a crop pattern map for Rabi crops in Pakistan, Pakistan Agriculture Research Council (2007).

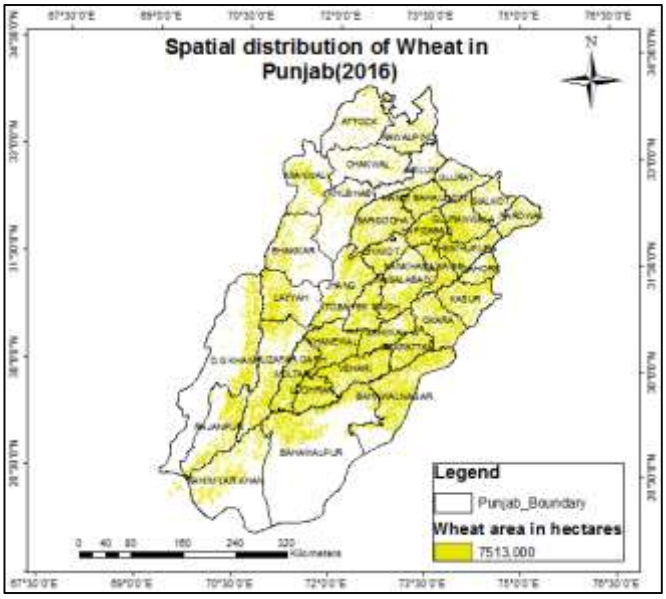

Figure 3. Map showing Wheat distribution in Punjab

Further Wheat class pixels were validated with fractional NDVI pixels in Arc GIS 10.2 software. Area of Wheat crop was calculated in GIS environment and validated with the area taken from Punjab Bureau of statistics, Lahore. This shows minor deviation from area given in 2013-14. Results showed Lahore, Gujranwala, Hafizabad, Multan, Faisalabad and Sargodha are main wheat producing regions. Mostly winter wheat is grown in the study area and it is grown almost all districts of Punjab.

3.3 Vegetation coefficients vs Crop coefficient

Vegetation coefficients for wheat crop derived from NDVI fraction images were shown by graph given below, compared by crop coefficient (Kc) values derived by literature (FAO). High NDVI values indicate full vegetation cover at Wheat's development stage. Fraction of vegetation differs at its different stages of growth.

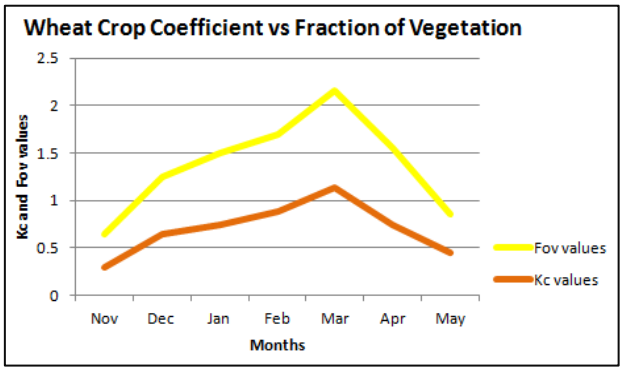

Figure 3. Kc vs Fov

High NDVI values indicate full vegetation cover at Wheat's development stage. Fraction of vegetation differs at its different stages of growth. Fraction of vegetation is validated with crop facto showing strong relationship with the coefficient value of R^2= 0.95.

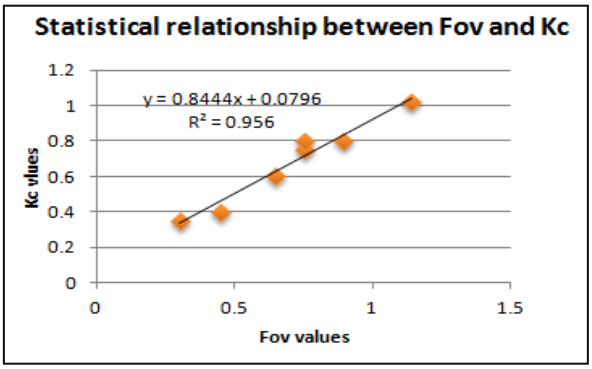

Figure 4. Statistical relationship of Fov vs Kc

3.4 Daily ETo and ETc

Daily ETo for all images for the dates of 16 Nov, 27 Dec, 1st Jan, 27 Feb, 30 Mar, 24 Apr and 24 May at satellite overpass time 10:00 am was determined in CropWAT 8.0 software. Daily ETc in mm and acre ft was estimated by using Eq. 4. ETo is interpolated by using Spline interpolation method by using 90 % point data of ETo in Arc GIS 10.2 software. It is a method develops a smooth surface passing through all input points and gives best spatial results. And 10 % non-interpolated data was used for validation of interpolated data. Coefficient value of R^2= 0.99 shows 99 % accuracy of results.

Finally ETc maps were developed by multiplying ETo maps with Vegetation fraction maps. Results showed more ETo in the month of March, April and May due to increase in temperature. Wheat crop need more water in the months of March and April because May is the harvesting month and when crop becomes mature, not much water needed for its growth.

Table 1. Daily ETo and ETc of Wheat crop

Date of images	ETo (mm/day)	ETo (acre ft)	ETc (mm/day)	ETc (acre ft)
16th Nov	2.03	0.01	2.9	0.017
27th Dec	1.68	0.009	1.68	0.01
1st Jan	1.45	0.008	1.8	0.01
27th Feb	1.81	0.01	1.81	0.01
30th Mar	3.04	0.01	2.7	0.016
24th Apr	3.97	0.02	2.9	0.017
24th May	5.0	0.03	4.81	0.029

3.5 Monthly ETo and ETc

Monthly ETo and ETc was calculated by multiplying ETo with 30 (assuming every month of 30 days). ETc maps were prepared in Arc GIS 10.2 software. Results showed more water is required in the months of March and April. Crop evapotranspiration differs at different stages of growth. At the start of crop growth, it needs less water but its development stage, needs optimum level of water for full-fledged nourishment and at the time of harvesting water need becomes too less as crop acquires its maturity stage. Sesonal ETo for wheat 568 mm/ year or 3.43 acre ft and annual crop ET is 558 mm/year or 3.28 acre ft.

Seasonal ETo and ETc showing same trend of spatial distribution of Wheat in punjab. ETo and ETc is high in western and southern Punjab in the districts of Mianwali, Sahiwal, Pakpattan, Vehari, Multan, Bahawalpur, Rahim Yar Khan, Rajanpur, D.G. Khan and Muzzafargarh. ETo is high in the months of March, April and May due to hot temperature and long hours of sunshine. Irrigations are required in southern parts of Punjab in these months. In May, the crop becomes mature, and no more water is needed at the time for harvesting.

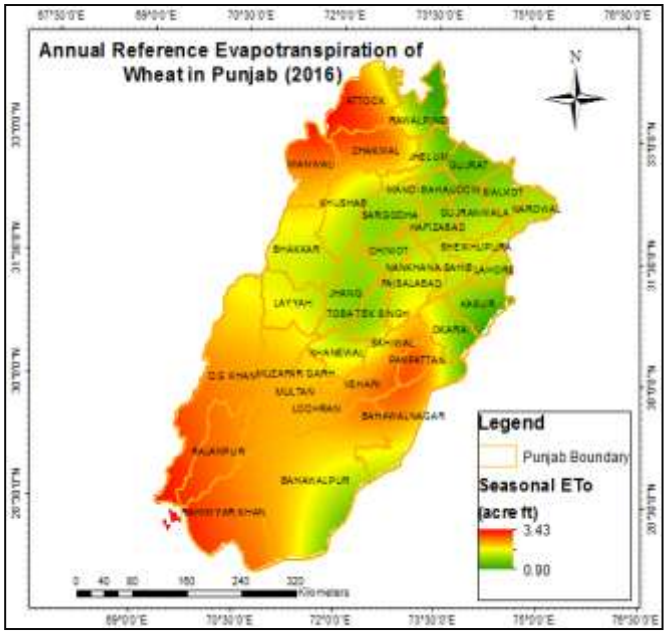

Figure 4. Spatial distribution of seasonal ETo of Wheat in Punjab

Table 1. Monthly ETo and ETc of Wheat crop

Months	ETo (mm/month)	ETo (acre ft)	ETc (mm/month)	ETc (acre ft/month)
Nov	60.9	0.37	87	0.52
Dec	50.4	0.30	50.4	0.30
Jan	42	0.25	54	0.32
Feb	54.3	0.33	54.3	0.33
Mar	91.2	0.55	81	0.49
Apr	119.1	0.72	87	0.52
May	150	0.91	144	0.87
Total	567.9 mm/year	3.43 acre ft/year	557.7 mm/year	3.28 acreft/year

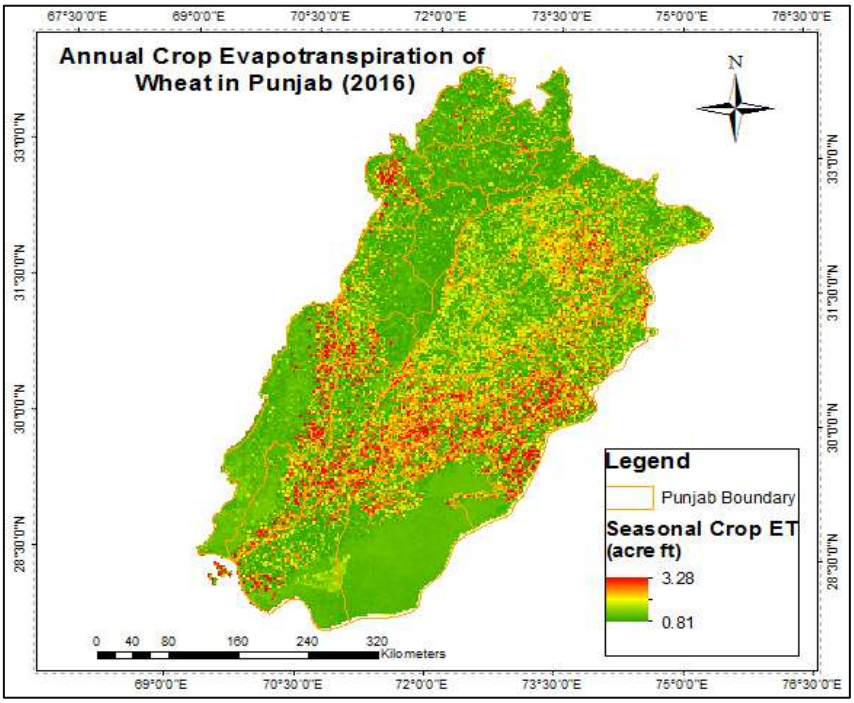

Figure 5. Spatial distribution of seasonal ETc of Wheat in Punjab

The recent study showed minor spatial deviation from the results presented by Naheed and Mahmood (2009) and this study is based upon satellite based ETc. Results showed more irrigations required in southern areas of Punjab in the months of February and March and it can be grown under rainfed conditions in upper part of Punjab.

4. Conclusion

Penman monteith method of reference evapotranspiration shows better results with minor deviation from Crop evapotranspiration. NDVI based crop coefficients play significant role in estimating real time crop water need in different parts of Punjab. Remote sensing based ETc provides better estimate of spatial distribution of water requirement in a large area especially when dealing with multidate satellite data. The recent study will helpfull in providing in time information of water requirement for wheat at its different stages of growth. It also gives useful information for irrigation and field activity planners. Further studies should be occured in other provinces of Pakistan for sustainable agricultural development.

5. Acknowledgements

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