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CROP WATER DEMAND ESTIMATION USING MULTI-TEMPORAL LISS III SATELLITE DATA

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ABSTRACT

The present method of crop water demand estimation by conventional technique is very time consuming, costly and error prone. Thus, the crop water demand estimation using a new methodology viz. Remote sensing based approach has been investigated. The study was undertaken in Butana distributory for wheat crop with a canal command area of about 231 km^2. The results obtained in the chosen area from remote sensing based method have been compared with field method i.e. Epan. The crop water demand for initial, middle and late stage of wheat has been found using remote sensing as 0.9 mm/day, 3.2 mm/day and 2.0 mm/day respectively, whereas as per Field method it is estimated as 0.7 mm/day, 3.10 mm/day and 1.5 mm/day. Thus the results were found to be comparable for estimation of crop water demand for the wheat crop in Haryana state. The advantage of remote sensing based method is that the actual area of the crop cultivation is known from the satellite imagery which leads to real -time crop water requirement, thus supplying of canal water becomes more realistic than supplying based on previous practice/ feed - back from the farmers. This leads to most efficient use of water.

Key words: *Crop water demand, CROPWAT, Remote sensing and evapotranspiration.*

INTRODUCTION

Water is an essential resource for all life on the planet. The rapid population growth has increased urbanization. More mouths mean more water for foodgrains production, more water for drinking, and more water for household/ sanitation; while industrialization has also raised the water demand for manufacturing, commercial and service sectors. Environmental flows to replenish depleted river flow are being released in a number of developed countries. The resulting total of these demands put more pressure on water resources and efficient water uses.

Much effort in water resource management is directed at optimizing the use of water and in minimizing the environmental impact of water use on the natural environment. Dwindling water resources for increasing food grain requirements require greater water use efficiency in irrigated agriculture. Efficient water management is the key to success in augmenting crop production. Increasing water-use efficiency in irrigation necessitates improved irrigation scheduling techniques based on integrated effect of climate, soil and crop characteristics. Reliable estimate of evapotranspiration as a function of crop stage is important for determining crop water demand and efficient irrigation management.

One of the most important concepts regarding water balance in semi-arid areas is crop Evapotranspiration (ETc) (Doorenbos and Pruitt, 1977) which is a key factor for determining crop water demand, proper irrigation scheduling and for improving water use efficiency in irrigated agriculture. Accurate estimation of evapotranspiration constitutes an important part of irrigation system planning and designing, accurate spatial determination is also crucial to achieve sustainable agriculture. Environmental physics based on electromagnetic radiation and micro-hydrology has evolved in the development of quantitative algorithms to convert remotely sensed spectral radiances into useful information such as evapotranspiration, root-zone soil moisture, and biomass growth (Bandara, 2006). Actual evapotranspiration can be estimated from satellite remote sensing (Engman and Gurnay, 1991, Kustas and Norman, 1996, Bastiaanssen et al., 1998 and 2002, Kustas et al., 2003, Gontia and Tiwari 2004, Ambast et al., 2005). Satellite remote sensing is very useful tool to monitor the spatial and temporal variability of vegetation phenology (Baret and Guyot, 1991, Hall et al., 1995, Carlson and Ripley, 1997, Myneni et al., 1997, Duchemin et al., 1999, Gutman, 1999, Bastiaanssen et al., 2000, Kumari et al., 2013)

Several studies in the recent past have been done on estimation of crop water demand using Remote sensing (Choudhary et al., 1994, Hadjimitsis et al., 2008, Kumari et al., 2013, Magd and Tandon, 2008, Mishra et al., 2005, Patel et al., 2006, Ray and Dadhwal, 2001, Romaguera et al., 2010, Shirbeny et al., 2014, Singh et al., 2013, Xiao et al., 2006). In the present study, an attempt has been made to determine the evapotranspiration of an agricultural area in the Butana distributory Canal Command, which has an important aspect in assessing the actual crop water requirements for determining water allocations and for the design of irrigation canals and diversion structures using remote sensing technique.

STUDY AREA

The Butana distributary is situated in the north- west part of Sonipat district and north of Rohtak district in Haryana. The Butana distributary is a part of western Yamuna canal. The Butana watershed lies between 28°45’ to 29°43’N latitude and 76°53’ to 77°44’E longitude with geographical area 231 km^2. The Location map of the study area is shown in Fig.1.

Butana command area falls under arid and semi-arid region. The mean monthly minimum air temperature during the winter is around 6.2^{0}C, while the maximum mean air temperature during peak summer is around 38.8^{0}C. The relative humidity is low in April to June and high in July to

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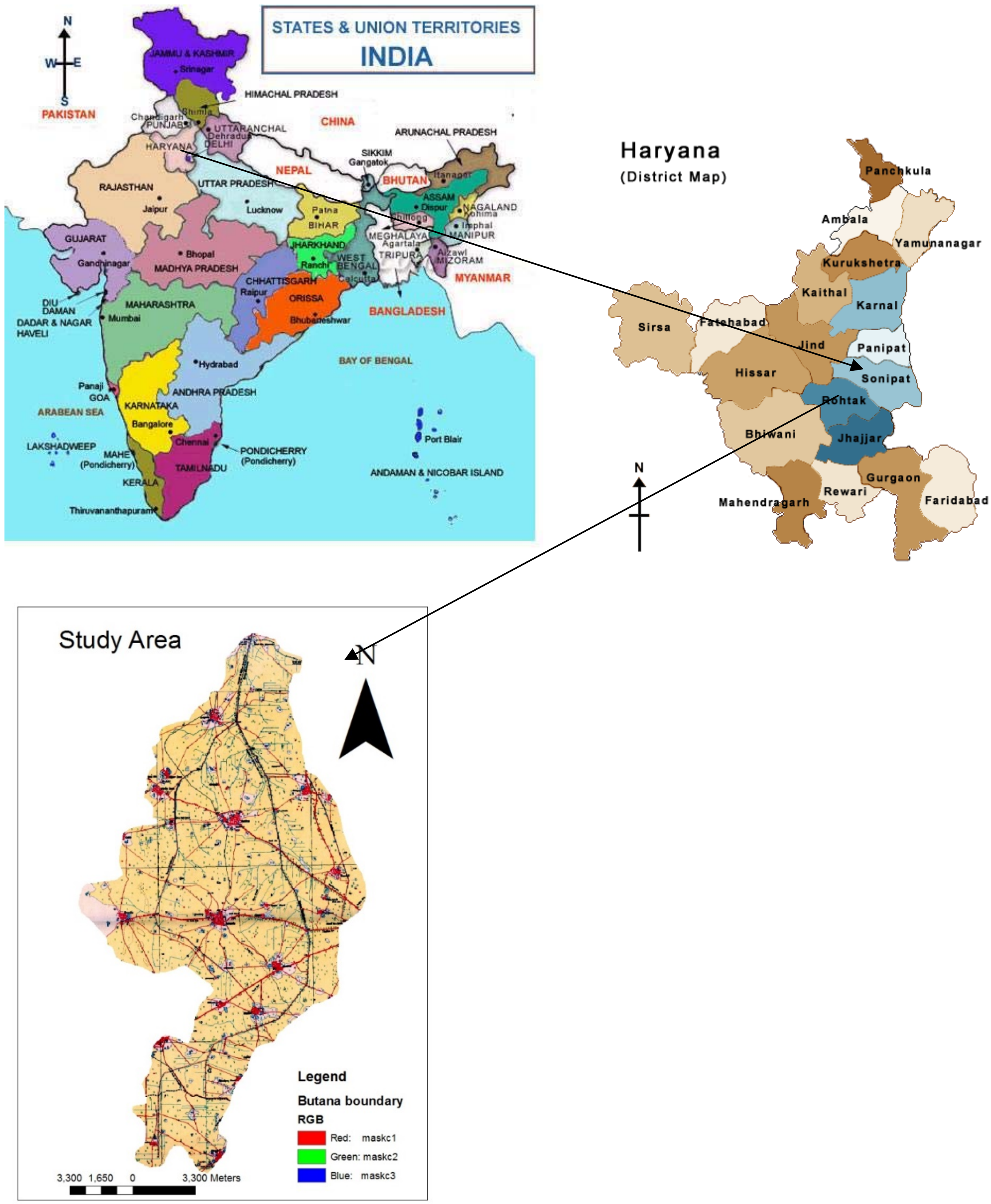

Fig. 1: Location map of Study Area

September. The pan evaporation is maximum (8.38 mm/d) during the month of May. The solar radiation flux varied from 285.6 to 315.7 W/m^2 during April to June. The average annual rainfall of command area is 748.6 mm. The important source of water is rainfall. Rainfall from south west monsoon starts from first week of July and ends in third week of September. About 79% of the annual rainfall is received during the active monsoon season extending from late June to September. Rainfall also received due to western disturbances during January to March occasionally.

Data Used

- The data and software used in the present study of Butana distributary, Haryana (India) are The daily meteorological data of 1 year period (2010-2011) was obtained from the Meteorological department, CSSRI, Karnal, Haryana.

- Open series map (OSM) of topo-sheets of 1:50,000 scale obtained from Survey of India. The maps were acquired, scanned and mosaiced for the purpose of geo-referencing. The study area covered under the series of following topo-sheets i.e. 53C/12, 53C/15, 53D/5 and 53D/9. The coordinate system used in all maps and images in this study is as follows:-

  Projection – UTM, Spheroid - WGS 1984, Datum - WGS 1984, UTM Zone – 43 North
- Cropwat 8.0 for estimation of crop water demand, Irrigation water demand, effective rainfall and scheduling etc.
- Arc GIS 9.3
- Earth Resources Data Analysis (ERDAS) Imagine 9.1
- Satellite images of LISS III for the period 19 December 2010, 5th February and 22 March 2011. Details of Imagery data of the study area is shown in Table 1.

Table 1: Details of Imagery data

Satellite sensor	Resolution (m)	Bands	Date of pass
IRS-P6 LISS-III	23.5	4 B1 0.52-0.59 (Green) B2 0.62-0.69 (Red) B3 0.77-0.89 (NIR) B4 1.55-1.75 (SWIR)	19 December 2010 5 February 2011 22 March 2011

MATERIALS AND METHODS

Various theoretical methods are used to estimate crop water demand for crops, but they differ in some respects from each other. Details of these methods are available ((Xu and Singh, 2002, Pereira and Pruit, 2004, Popova et al., 2006, Chen et al., 2005). Remote sensing based method is a recent method which uses input data like as imagery of land use/ land cover map, NDVI map, classified map, agricultural map and crop map.

ETo estimated from Penman- Montieth equation

The ETo was computed by FAO Penman–Monteith method (Eq. 1) using meteorological data such as radiation, air temperature, air humidity and wind speed data (Allen et al., 1998). Weather data was collected from the Meteorological observatory of CSSRI, Karnal.

From the original Penman-Monteith equation and the equations of the aerodynamic and surface resistance, the FAO Penman-Monteith method, ETo can be derived in mm/day

$$ET_0 = \frac{0.408(R_n - G) + \gamma \frac{900}{T+273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)} \quad (1)$$

Where, ET_o = reference evapotranspiration [mm day^{-1}], R_n = net radiation at the crop surface [MJ m^{-2} day^{-1}], G = soil heat flux density [MJ m^{-2} day^{-1}], T = mean daily air temperature at 2 m height [°C], U_2 = wind speed at 2 m height [m s^{-1}], e_s = saturation vapour pressure [kPa], e_a = actual vapour pressure [kPa], e_s-e_a = saturation vapour pressure deficit [kPa], Δ = slope vapour pressure curve [kPa °C^{-1}] and γ = psychrometric constant [kPa °C^{-1}].

Crop Coefficient (Kc)

The trend in Kc during the growing period is represented in the crop coefficient curve. Only three values for Kc are required to describe and construct the crop coefficient curve those during the initial stage ($K_{c\ ini}$), the mid-season stage (Kc_{mid}) and at the end of the late season stage (Kc_{end}). The crop coefficient for initial growth stage Kc_{ini} was interpolated from FAO56 (Allen et al., 1998) and typical value of crop coefficient for mid season growth stage, Kc_{mid} and late season K_{cend} are taken from FAO 56 (Allen et al., 1998). Monthly crop coefficient (Kc) was estimated using guideline given in Irrigation and Drainage paper FAO-56 (Allen et al., 1998) for wheat crop. Monthly crop coefficient (Kc) was estimated using the guidelines given in irrigation and drainage paper FAO-56 (Allen et al., 1998) for rice and wheat crop depending upon the stage of growth. For specific adjustment in climates where minimum relative humidity (RHmin) differs from 45% or where wind velocity measured at 2 m height (u_2) is larger or smaller than 2.0 m s^{-1}, the Kc values at mid and end of season are adjusted as below:

FAO-Kc co-relation as per the local weather condition,

$$Kc_{mid} = Kc_{mid}\ (tab)+[0.04(u_2\text{-}2)\text{-}0.04\ (RH_{min}\text{-}45)]\ (h/3)\ 0.3 \quad (2)$$

$$Kc_{end} = Kc_{end}\ (tab) + [0.04\ (u_2\text{-}2)\text{-}0.04\ (RH_{min} - 45)]\ (h/3)\ 0.3 \quad (3)$$

where, Kcmid*(tab) and* Kcend*(tab)* is the tabulated crop coefficient value for Kc from FAO 56 at mid and end stage, RHmin is the mean value for daily minimum relative humidity during the midseason growth stage (%), for 20% ≤ RHmin ≤ 80%, and h is mean plant height during the mid-season stage (m) for 0.1 m < *h < 10 m.*

Satellite data processing

In order to estimates evapotranspiration in Rohtak district the data used for the study includes multi date (3) images IRS P6-LISS III of year 2010-1011. The image contains four bands. In the context IRS-P6 data can play a major role in phonological study of crop. Table 2 shows the growth stages and satellite data date of wheat crop.

Table 2: Satellite data of different crop growth stages

Crop	Growth stage	Satellite data (2010-11)
Wheat	Crown root initiation	19 December
	Flowering	5 February
	Maturity	25 March

Computation of vegetation indices

NDVI was used to describe the dynamics of vegetation and seasonal growth of vegetative cover. NDVI function available with the software ERDAS Imagine was used. The details of methods are available (Carlson and Ripley, 1997;, Chandrashekhar et al., 2010;, Gutman, 1999, Huete, 1988;

Jachson and Huete, 1992). The formula used to calculate NDVI is given below.

$$NDVI = \frac{(NIR - RED)}{(NIR + RED)} \quad (4)$$

Where,

NIR is the reflectance in near infrared band and RED is the reflectance in red band

Many factors affect NDVI values like plant photosynthetic activity, total plant cover, soil moisture, and plant stress. Because of this, NDVI is correlated with many ecosystem attributes that are of interest to researchers and managers (e.g., net primary productivity, canopy cover, bare ground cover). Values of NDVI *can* range from -1.0 to +1.0, but values less than zero typically do not have any ecological meaning, so the range of the index is truncated to 0.0 to +1.0. Higher values signify a larger difference between the red and near infrared radiation recorded by the sensor - a condition associated with highly photosynthetically active vegetation. Low NDVI values mean there is little difference between the Red and NIR signals. This happens when there is little photosynthetic activity, or when there is just very little NIR light reflectance (i.e., water reflects very little NIR light).

The normalized difference vegetation Index (NDVI) as suggested by Turcker (1979) is generated for each image.

(5)

Where, NDVIi is the NDVI value of particular pixel, NDVImax and NDVImin are maximum and minimum growing season, respectively

Similarly LSWI was derived from multi-temporal data in order to account for surface water pounding. LSWI for each date of image acquisition was estimated as:

(6)

Where, NIR and SWIR are atmospherically corrected reflectance in NIR and SWIR region

Cropping pattern generation

The cropping pattern is defined as a spatial arrangement of crops in a given area. The wheat crop map for the year 2010-2011 was generated by post classification. Layer stacking of three NDVI images was classified by rule-based Classification.

Relationship of Kc and Vegetation indices

The relation between derived vegetation indices and interpolated Kcadj (estimated by equation 2 and 3) of wheat for corresponding month were developed crop coefficient is generated in model maker of ERDAS imagine

Calculation of Crop water Requirement of Wheat Crop

For estimation of crop water demand (CWD) Kc value of wheat were estimated and multiplied with the reference evapotranspiration (ET_0)

$$CWR = Kc * ET_0 \quad (7)$$

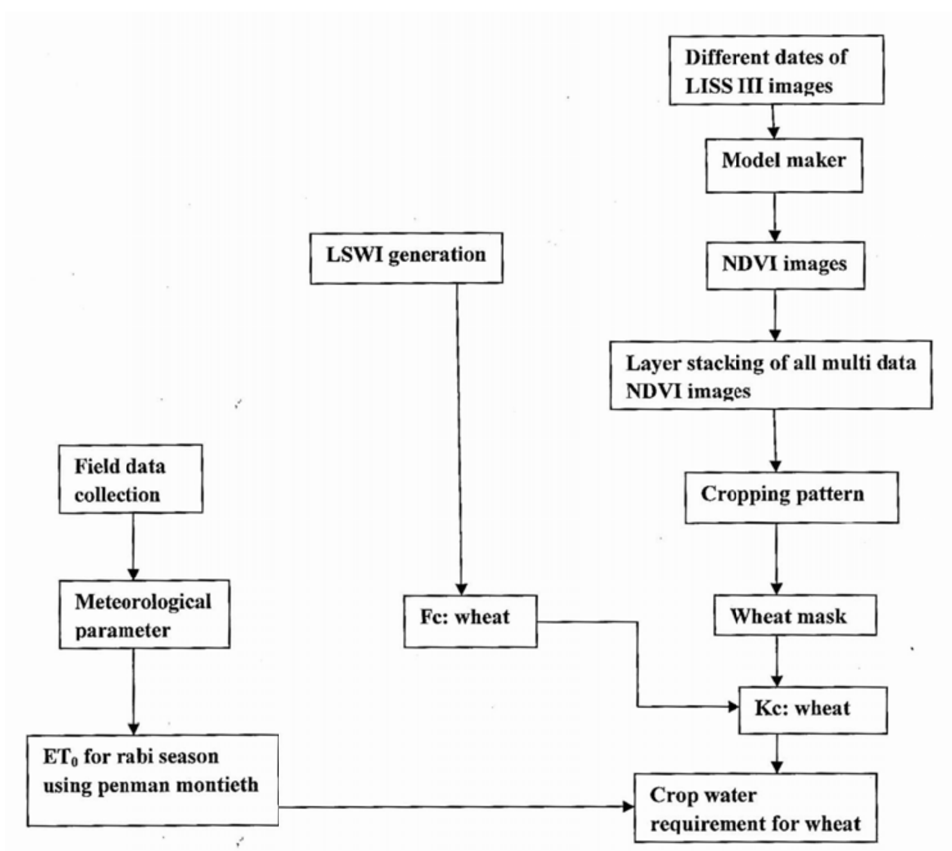

Fig. 2: Flowchart of methodology

RESULTS AND DISCUSSION

NDVI of different stages of wheat crop

The NDVI was estimated that ranged between -0.225 and 0.562. The highest value is found in non-wheat (Berseem) cropped area lands by the magenta color (0.45-0.6). The lighter green shade (0.3-0.45 shows the wheat cropped area. Fig 3 shows the NDVI curve.

Cropping map using rule based classified technique

NDVI shows wheat covers 12510.13ha (59%) out of total distributory area and non-wheat cropped area is 3618.90 ha which is 16.8% area. Computation of crop water demand of wheat crop in distributory by remote sensing based method is 3.2 mm/day. Fig. 4 shows the wheat map of study area. The Rabi season meteorological data were applied to CROPWAT model to calculate the crop-water demand of wheat crop during Rabi season in 2010-2011. Fig 7 shows the stage of crop, crop coefficient factor, cropwater demand, Effective rainfall and Irrigation requirement. Fig 4 shows the wheat crop map of study area.

Development of relationship of Kc and fc for wheat crop

The Kcin, Kcmid and Kcend value for wheat crop obtained from FAO-56 and adjusted for local condition were 0.35, 1.14 and 0.34 respectively. The pixel values of fc of wheat were extracted for each satellite pass to produce crop specific Kc FAO curve for the growing season. The regression equation were developed by correlating fc withal the weather adjusted Kc FAO value for wheat. Fig 5 shows the relationship of crop coefficient Kc with Kcadj.

Estimation of crop coefficient and crop water requirement of wheat crop season

Monthly crop coefficient was mapped at pixel resolution by applying regression equations developed for *f*c with Kc FAO (corrected for local conditions and interpolated) in Spatial Modeler module of of ERDAS IMAGINE. The output of the model represents the spatially distributed crop coefficient maps with pixel-wise Kc values. The Kc (based on *f*c) values of wheat crop varied from <0.3 to 0.45, 0.7 to 1.2 and <0.3 to 0.6 for different months of winter season December (initial stage), February (Mid stage) and March (late stage) respectively. Fig. 6 shows the NDVI map of different crop growth date.

Comparison of Results with field data

In this research, the ETc values estimated by remote sensing based method reult was compared with Pan Evaporation method result. It was expected that the pan evaporation method would give acceptable estimates because it used the measured values from the E-pan.

The average ETc value from the Remote sensing based method for wheat crop over the study area is 0.9 mm/day, 3.2 mm/day and 2.0mm/day. The evaluation results with Epan methods showed that the remote sensing based method has the closest performance with widely accepted Epan(field method). Therefore, remote sensing based method model can

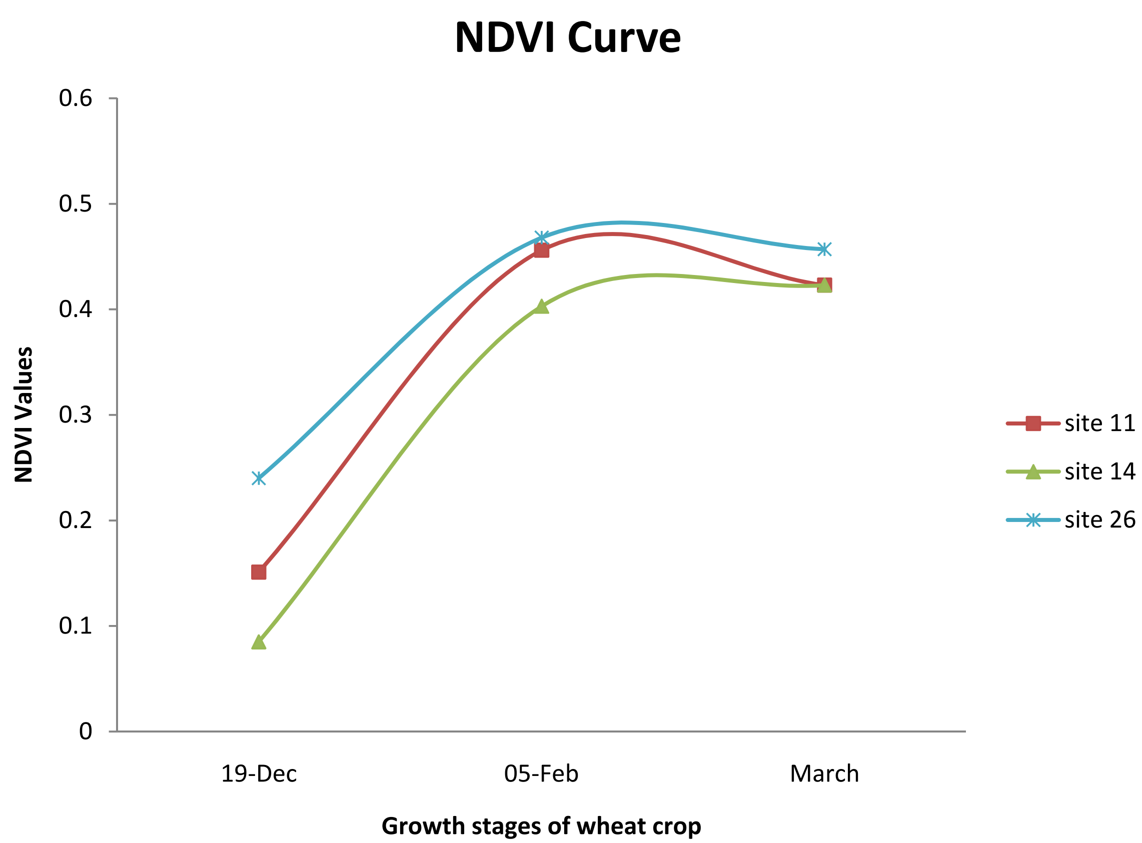

Fig. 3: Temporal profile of NDVI of crop growth stages.

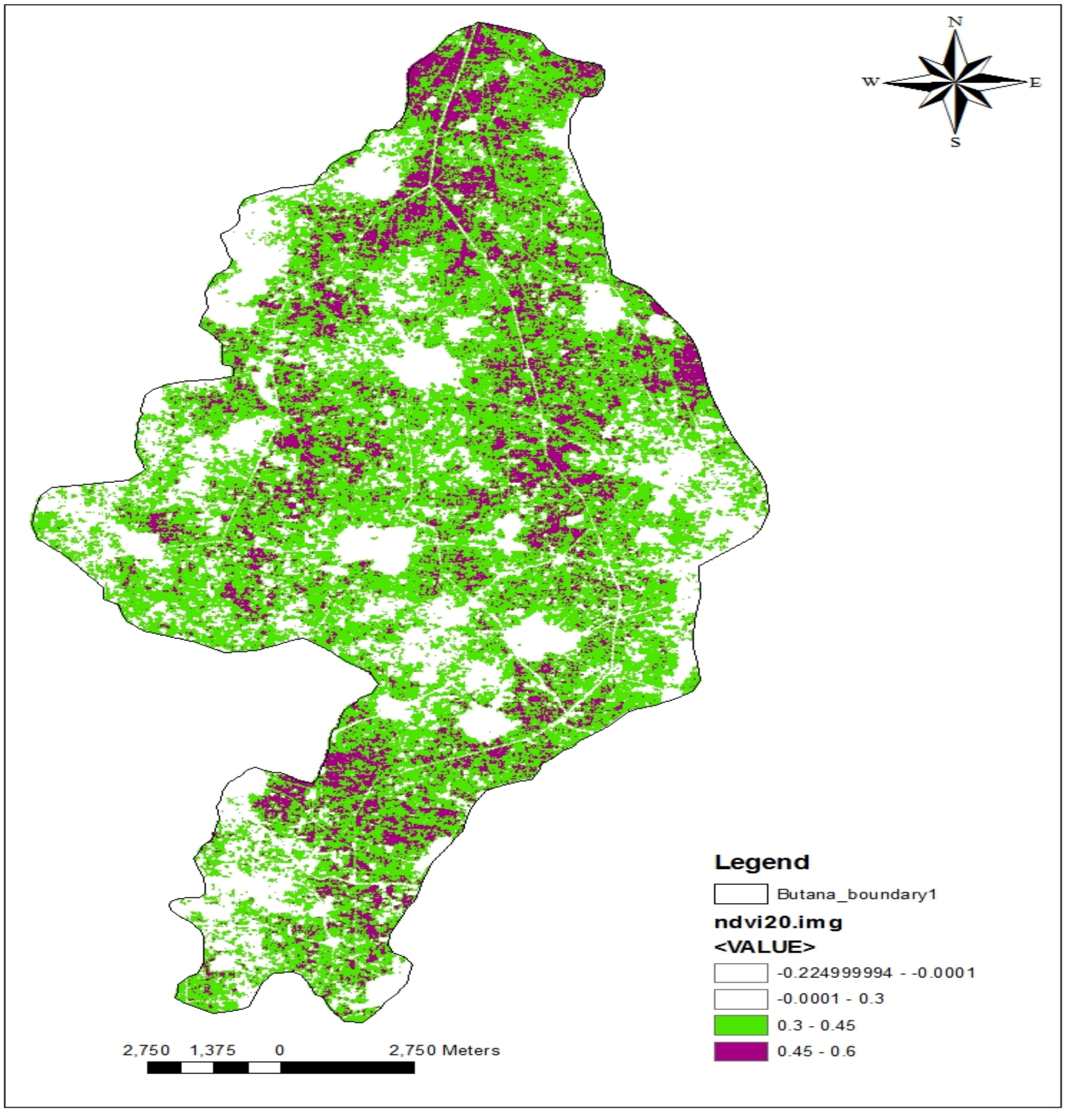

Fig. 4: Wheat map of study area

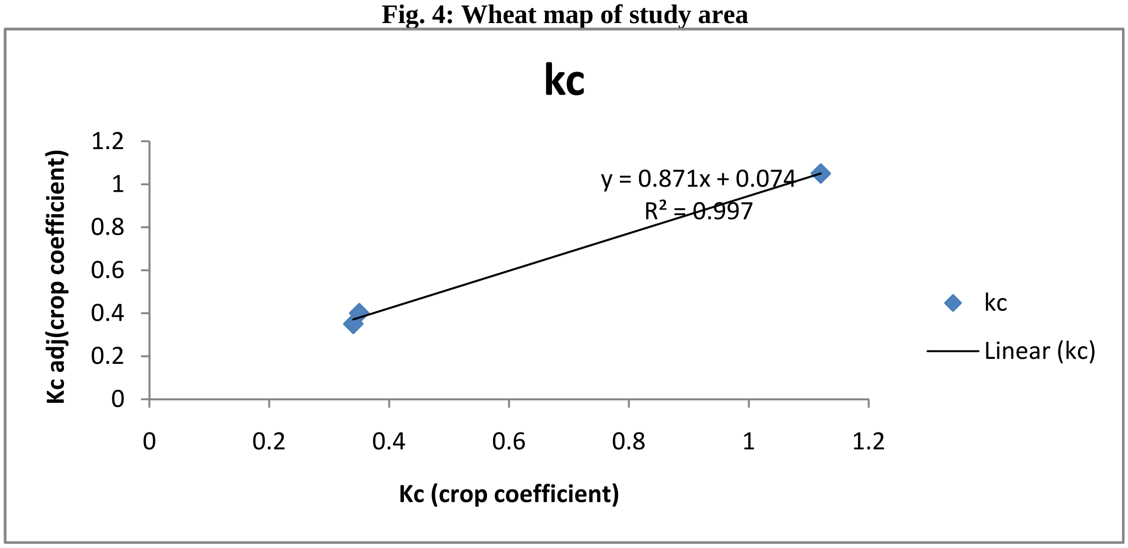

Fig. 5: Relationship of Kc with Kcadj

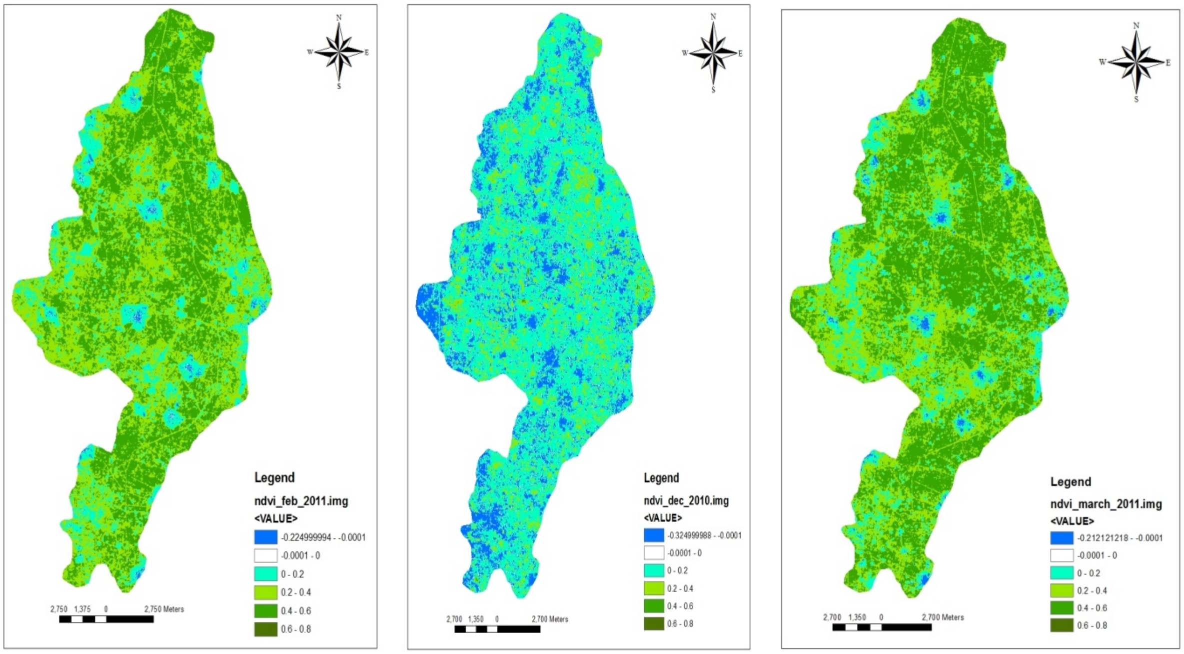

Fig. 6: NDVI map of different crop growth stages

be recommended for estimation of the ETc for crop water demand management. Table 3 shows the Comparison of results. Table 3 shows the comparison of both method results.

Table 3: Comparison of crop water demand by CROPWAT and remote sensing based NDVI methods

Date	Remote sensing based approach	Epan (Field method)
19 Dec	0.9 mm/day	0.7 mm/day
5 Feb	3.2 mm/day	3.10mm/day
22 March	2.0mm/day	1.5 mm/day

CONCLUSION

The primary aim of this work was to utilize and evaluate Remote sensing based method for crop water demand of the wheat crop in the Butana distributory Canal Command. Remote sensing based approach are appropriate methods for estimation of crop water requirement/ need. The Cropwater requirement from Epan is 3.10 mm/day and from remote sensing based approach is 3.2 mm/day. Satellite based method is used in that place where satellite imagery data available and only two to three field visit are sufficient for calculation of crop water demand and satellite imagery method calculate ETc for a particular study area. Satellite imagery method has following advantages:-

- Actual land being for a particular crop is known.
- Realistic water demand is known.
- Real time estimation is done.

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