Crop And Irrigation Water Requirement Estimation By Remote Sensing And GIS: A Case Study Of Karnal District, Haryana, India

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Abstract- **The paper focuses on analyzing the irrigation water requirement of wheat crop for rabi season from 1999 to 2003 in Karnal district of Haryana state, India. Area under wheat cultivation has been determined using Landsat ETM+ image by applying Artificial Neural Network (ANN) classification technique. Potential evapotranspiration has been estimated using Hargreaves model. Potential Evapotraspiraiton and crop coefficient for wheat was used for estimating crop water requirement. Effective rainfall was determined using India Meteorological Department gridded rainfall data. Effective rainfall and crop water requirement was used for determining irrigation water requirement. By assuming 35% losses, net irrigation water requirement was estimated. Multiplying the wheat cropped area and net irrigation water requirement the volume of water required for wheat during the rabi season was estimated.**

I. INTRODUCTION

Experts' estimates that demand for food crops will double during the next 50 years with limited land and water resources, farmers need to increase their output from existing cultivated areas to satisfy the food demand of increasing population. Irrigation systems will be essential to enhance crop productivity in order to meet future food needs and ensure food security. However, the irrigation sector must be revitalized to unlock its potential, by introducing innovative management practices and changing the way it is governed.

Developments in irrigation are often instrumental in achieving high rates of agricultural goals but proper water management must be given due weightage in order to effectively manage water resources. Better management of existing irrigated areas is required for growing the extra food to fulfill the demand of increasing population. [1]

Irrigation contributed in number of ways. It enables farmers to increase yields and cropping intensities, stabilize production by providing a buffer against the vagaries of weather, and create employments in rural areas. Rural poverty in intensively irrigated areas, such as states of Punjab and Haryana in India, became much lower than in predominantly rain fed states such as Orissa and Madhya Pradesh.

II. STUDY AREA:

Karnal district lies on western bank of river Yamuna. Karnal is located at 29.43^o N latitude and 76.58^o E longitudes and is about 250 meters above mean sea level. [2]

The topography of Karnal district is almost plain and well irrigated through canals and tube-wells. Irrigated area is about 205627 ha. While the gross irrigated area is 388917 ha.The important crops grown in this district include wheat, rice, sugarcane, sorghum, maize and berseem.

The climate of the district is dry and hot in summer and cold in winter. Its maximum and minimum temperatures vary from 43^{o}C to 21.5^{o}C in June and from 22^{o}C to 4^{o}C in January.

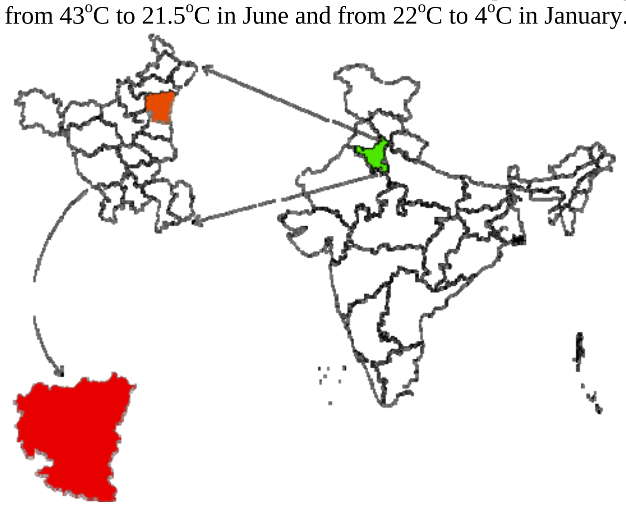

Fig. 1. Study area

The land of Karnal district is plain and productive. The soil texture varies from sandy loam to clay loam. The soils are alluvial and are ideal for crops like wheat, rice, sugarcane, vegetables etc. [2]

III. Materials and Methods

In order to accomplish the task, the data used for the study includes Landsat ETM+ imagery. The image contains 8 bands including a panchromatic band covering a swath of 185 km.

The meteorological data was obtained from IMD (India meteorological Department, Pune). The data consists of 0.5° x 0.5° gridded daily data of rainfall, maximum and minimum temperature. The data was subsequently processed in a GIS environment and converted into TIFF format to facilitate GIS analysis.

Landsat ETM+ image was processed in order to prepare crop mask for the area. The processing includes conversion of DN values into radiance; the following formula was used for conversion. [3]

$$L_\lambda = \left(\frac{LMAX - LMIN}{QCALMAX - QCALMIN}\right) X \left(DN - QCALMIN\right) + LMIN$$

where LMAX, LMIN, QCALMAX and QCALMIN were taken from header file of the image for each band. The equations prepared for calculating radiance values for each band are as follows,

$R_1 = [1.18 * (DN-1)] – 6.2$

$R_2 = [1.204 * (DN-1)] - 6.4$

$R_3 = [0.945* (DN-1)] - 5$

$R_4 = [0.639* (DN-1)] – 5.1$

$R_5 = [0.126* (DN-1)] + 1$

$R_{61} = [0.067* (DN-1)]$

$R_{62} = [0.037* (DN-1)] + 3.2$

$R_7 = [0.044* (DN-1)] – 0.350$

$R_8 = [0.975* (DN-1)] – 4.7$

where, R_{band} is the radiance image of a particular band and DN is the digital number of the input pixel. The Karnal district boundary map was overlaid on the radiance image to extract the study area.

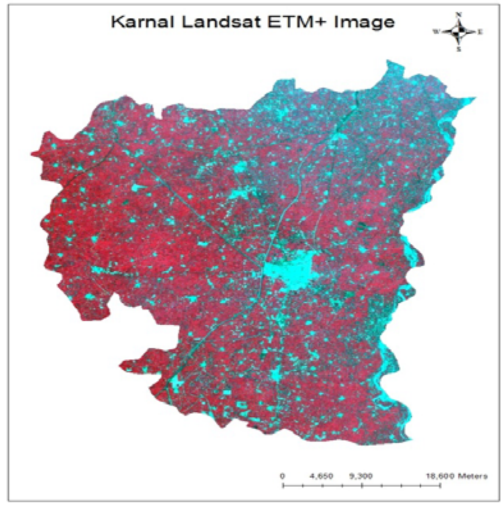

Fig. 2. Radiance Image (Landsat ETM+)

The radiance image was subjected to supervised classification using Artificial Neural Network (ANN). The multi layer perception (MLP) network with the back-propagation (BP) algorithm is used in ENVI software. [4]

Training parameters used during the classification are as follows: Number of Training Iterations: 1000, Training RMS Exit Criteria: 0.1, Initial learning rate: 0.01, Training Threshold Contribution: 0.9, Training Momentum: 0.9 and Minimum Output Activation Threshold: 1.00e-8.

Ground truth data has been collected during rabi season and that was provided as training sites for various land use types. Information about crops and cropping pattern were obtained from the farmers of the area. Based on the field visits, and classified image obtained from ANN, an area of interest (AOI) for wheat crop has been identified. Crop mask of the area has been prepared based on extracted wheat area and as indicated below in Fig. 3.

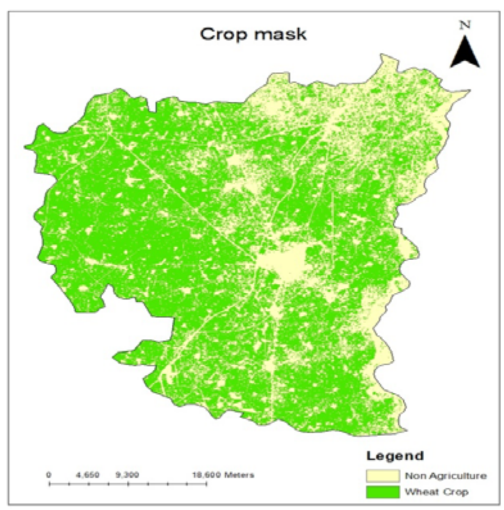

Fig. 3. Wheat crop mask

With the help of meteorological data, daily potential evapotranspiration was estimated using the Hargreaves equation as shown below.

$$PET_{HG} = 0.0023 * R_a * (T_{mean} + 17.8) * \sqrt{(T_{max} - T_{min})}$$

where, $PET_{HG:}$ potential evapotranspiration rate, Ra: extraterrestrial radiation (calculated from latitude and time of year), T_{mean}: mean temperature, T_{max}: maximum temperature, T_{min}: minimum temperature. [5]

The Hargreaves equation was adopted due to non availability of other meteorological variables in the study area. In order to compute the crop water requirement (CWR), crop coefficient (K_c) values for the wheat crop were obtained and multiplied with the potential evapotranspiration

$$CWR = K_c * PET_{HG}$$

The crop coefficient values of wheat crop for Karnal station are as follows, [6]

TABLE I
CROP COEFFICIENT VALUES OF WHEAT CROP

Growth stage	Crop coefficient
Initial	0.50
Crop development	1.36
Mid-season	1.24
Late-season	0.42

Effective rainfall is estimated based on FAO approach (Food and Agricultural Organization). The empirical equation given by FAO is as follows, [7]

$$y = 0.0011x^2 + 0.4422x$$

where, y is effective rainfall (ER) in mm and x is total rainfall in mm. The effective rainfall (ER) and the crop water requirement decide the amount of irrigation water that has to be applied. The effective rainfall is subtracted from the crop water requirement to calculate the irrigation water requirements (IWR).

$$IWR = CWR - ER$$

Net irrigation water requirements (NIWR) is the total water to be supplied to the crops during their life cycle, considering the losses due to infiltration into the subsoil and conveyance losses. Based on soil types, field losses and conveyance losses are assumed as 35% of the irrigation water requirements.

$$NIWR = IWR + LOSSES$$

In the present study, the net irrigation water requirements have been computed on monthly basis. IWR values are converted into discharge units (million cubic meters / month) by multiplying with crop acreage values.

IV. RESULTS AND DISCUSSION

The accuracy of classification is based on ground truth samples. From ground truth samples the confusion matrix is created. Confusion Matrix shows the accuracy of a classification result by comparing a classification result with ground truth information. The accuracy of classification was found to be 96.80% and the kappa value was 0.9418 for the cropping season. From the classified image area under the wheat crop was found out to be 127340 ha.

Daily potential evapotranspiration was calculated using Hargreaves method. The daily values were aggregated to monthly values for the five years (1999-2003).

TABLE III
VALUES OF MONTHLY POTENTIAL EVAPOTRANSPIRATION

Year	1999	2000	2001	2002	2003
Nov	167.03	163.25	165.29	163.25	164.12
Dec	140.55	143.46	141.72	141.14	141.43
Jan	120.18	127.46	125.13	128.33	126.29
Feb	147.54	145.50	150.45	146.96	148.99
Mar	188.86	181.58	187.99	183.62	183.04

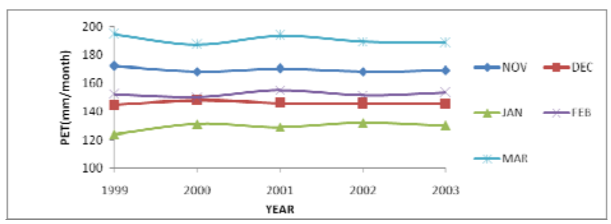

Fig. 4. Variation of PET across different years during rabi season

From the above graph it is observed that the potential crop evapotranspiration is at peak at the beginning stage i.e in the month of November, slightly reduced at growing stage, than at mid stage and at late-season stage it shows increasing trend as the temperature was on higher side.

Crop water requirement was estimated on a monthly basis by multiplying the PET with crop coefficient values.

TABLE IIIII
CROP WATER REQUIREMENT FOR WHEAT

Year	1999	2000	2001	2002	2003
Nov	85.15	83.22	84.26	83.22	83.67
Dec	194.89	198.93	196.50	195.70	196.11
Jan	166.65	176.73	173.51	177.95	175.12
Feb	186.53	183.95	190.20	185.79	188.36
Mar	80.87	77.76	80.49	78.63	78.38

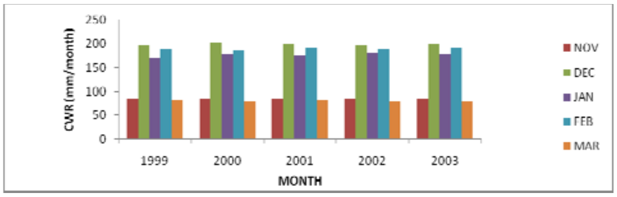

Fig. 5. Variation of CWR for wheat across different years during rabi season

The crop water requirement graph shows that wheat water requirement is increasing with the passage of time and require maximum amount of water at the crop development and mid season stage. The crop water requirement varied from 78.63 mm/month to 201.14 mm/month. The maximum CWR was observed in the month of December while the minimum was observed in the month of March. CWR decreases in the month of March as wheat was in maturity stage. It was also found that crop water requirement was less in the maturity stage as compared to the initial stage.

From the CWR and effective rainfall the irrigation water requirement (IWR) is calculated. The simulated values of irrigation water requirement (IWR) for the wheat crop in Karnal district are given below.

TABLE IVV
IRRIGATION WATER REQUIREMENT FOR WHEAT

Year	**1999**	**2000**	**2001**	**2002**	**2003**
Nov	58.12	80.65	81.98	83.39	82.43
Dec	175.46	166.04	184.91	192.86	184.30
Jan	158.35	169.10	166.56	178.31	175.01
Feb	174.48	170.37	181.30	186.17	181.98
Mar	56.82	59.79	71.67	78.79	71.04

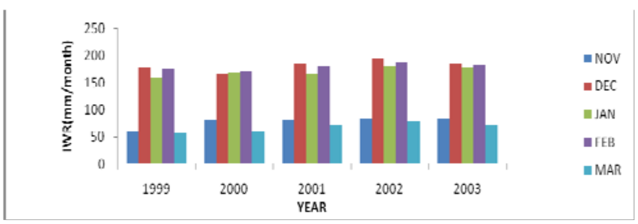

Fig. 6. Variation of IWR for wheat across different years during rabi season

As wheat is grown in rabi season the amount of rainfall is very less. The irrigation water requirement is directly dependent on crop water requirement.

A scatter plot was generated by plotting the monthly mean values of crop water requirement with irrigation water requirement. A strong relationship was observed between the two variables with a coefficient of determination (R^2) of 0.994.

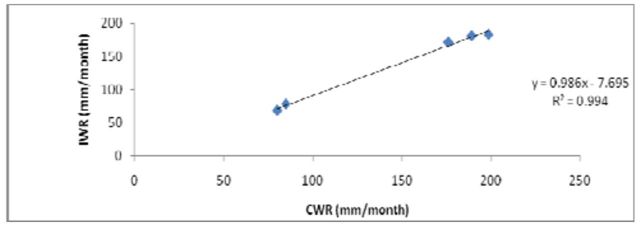

Fig. 7. Scatterplot between CWR and IWR

Assuming 35% of conveyance and field losses, the net irrigation water requirement (NWIR) for wheat crop was calculated.

TABLE V
NWIR FOR WHEAT

Year	**1999**	**2000**	**2001**	**2002**	**2003**
Nov	78.07	108.32	110.11	112.01	110.72
Dec	235.67	223.02	248.37	259.04	247.55
Jan	212.70	227.13	223.71	239.51	235.07
Feb	234.35	228.84	243.52	250.06	244.43
Mar	76.33	80.31	96.26	105.84	95.43

The net irrigation water requirement was multiplied with cropped area of wheat to estimate the volume of water required for the entire growing season.

TABLE VI
VOLUME OF WATER REQUIRED FOR WHEAT

Year	**1999**	**2000**	**2001**	**2002**	**2003**
Nov	100.82	139.90	142.20	144.66	142.99
Dec	304.36	288.03	320.77	334.55	319.70
Jan	274.69	293.35	288.93	309.32	303.59
Feb	302.66	295.55	314.51	322.95	315.68
Mar	98.57	103.71	124.71	136.68	123.24

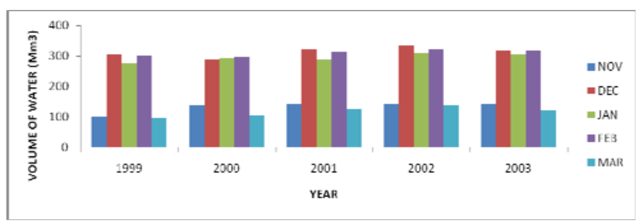

Fig. 8. Volume of water required for wheat crop across different years during rabi season

V. CONCLUSION

The present study shows that Remote Sensing and GIS integrated approach can be used for estimation of crop water requirement and irrigation water requirement. In the study area the wheat water requirement was higher in the vegetative and mid-season stage and shows decreasing trend towards the maturity stage. In the study area it was found that irrigation water requirement highly correlated with crop water requirement due to absence of monsoon in rabi season (November to March).

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