Remote sensing and GIS applications in crop mapping

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Introduction

For irrigation water resources management and planning, cropping pattern is an important input. During project planning, project cropping pattern is proposed and based on this irrigation water demand are estimated. This demand, along with other demand for water supply, hydropower, industry, recreation etc. is used to compute total water demand for the project. Utilization of irrigation potential increases post dam construction as progress in irrigation infrastructure development occurs. Thus, area under irrigation increases over time. Apart from this increasing trend, fluctuations in irrigated area occur due to variability in water availability in the project. Conventionally, crop and irrigated area statistics are collected at village level. Remote sensing provides an alternate method for crop and irrigated area monitoring. In India, there is high spatial and temporal variability in agriculture land cover, mainly due to fragmented and small land holding. This leads to variability in crop type, rotation and their sowing dates etc. in turn posing challenges in their delineation using remote sensing. Various methods used in monitoring of crops and irrigated area in discussed here.

Vegetation indices

Vegetation indices are mathematical expressions involving two or more band data, which has capability of discriminating vegetation and its characteristics from other objects on earth. These indices are useful in mapping and monitoring of vegetation, its growth stages, stress condition caused due to pest and diseases in vegetation etc. Expressions for various indices are given in Table 1.

NDVI: NDVI is most widely used vegetation index. It is a variation of RVI. Values of RVI range from zero to infinity. Through mathematical transformation, this index is restricted in rage of -1 and 1. Index in this form is called NDVI. For all green vegetation classes including scrub, forests and crops, NDVI is high. For barren area, snow, sand, NDVI value is low (<0.1). NDVI value increases with increase in vigor in vegetation. NDVI value also varies with crop growth stages. Within unit area, fraction of canopy ground cover increases with crop growth up to middle of vegetative growth stage. Further, during crop maturing to ripening due to fall off of leaves, canopy ground cover decreases. With changes in canopy ground cover, NDVI also varies. With least canopy ground cover, area may look similar to fallow area. Several other indices have been devised and they are sensitive to different characteristics of vegetation and soil (Deekshatulu and Gupta 1994).

SAVI: Vegetation indices for vegetation with partial canopy ground coverage are highly affected by wetness condition of soil. NDVI values increase with increase in soil wetness for same canopy coverage. PVI value reduces with increase in soil wetness. To offset this affect for partial canopy coverage, SAVI is used. In SAVI, the origin of the axis in Red- NIR spectral plot is shifted. In NDVI formula, denominator is increased by a constant L and the index is further multiplied by a factor (1+L) to keep the index value in range -1 to 1. In general, value of L is taken as 0.5 (Deekshatulu and Gupta 1994).

TSAVI: The index is modification over SAVI. It was developed by Baret et al. in 1989 and Baret and Guyot in 1991. Value of the index varies between -1 and 1. The index involves soil line slope and intercept and an adjustment factor (Ray 1994).

MSAVI: Modified SAVI is an improvement over SAVI. The index was developed by Qi et al in 1994. Adjustment factor used in SAVI is devised for moderate canopy cover. In MSAVI, variable adjustment factors are used. The factor is computed from NDVI, WDVI indices and soil line slope. The index varies between -1 and 1 (Ray 1994).

MSAVI2: The index eliminates prior computation of NDVI and WDVI and soil line slope for finding MSAVI. MSAVI is computed recursively. The index was developed by Qi et al in 1994. Adjustment factor L in MSAVI is replaced with 1-MSAVI2 of previous iteration. The index varies between -1 and 1 (Ray 1994).

PVI: PVI was first described by Richardson and Wiegand in 1977. It is perpendicular distance of vegetation point in Red- NIR scatter plot from soil line. Soil line is a line through which spectral response of bare soil varies in Red- NIR spectral plot, due mainly to soil moisture conditions. This response is in general linear for bare soil. With increase in wetness of soil, spectral response of soil reduces and but moves along this line. It is assumed with increase in vegetation vigor and canopy ground coverage, the plot of reflectance for vegetation will move perpendicular to soil line. A line parallel to soil line is called vegetation isoline. The index is sensitive to atmospheric effect. Soil line is assumed to pass through origin. The value of index varies from -1 to 1 (Ray 1994).

LSWI: The index is useful for delineation of vegetation. It may be used with NDVI for mapping of vegetation. It uses NIR and SWIR bands. Both bands have high reflectance from vegetation compared to visible bands. NIR band is not sensitive to water content in vegetation. SWIR band is weakly sensitive to water content in vegetation. Reflectance from NIR band is affected by internal structure of leaf cells and dry matter content. Reflectance from SWIR band is affected by leaf water content and spongy mesophyll structure of plant cells. Interaction of EMR in SWIR band is enhanced due to scattering in vegetation canopy. Reflectance of EMR from SWIR band reduces due to water content in the plant canopy. The index is useful in quantification of plant water content. It is positively correlated with leaf water content. Leaf internal structure and dry matter content have less effect on the index.

Table 1 Remote sensing based vegetation indices

Vegetation index	Abbreviation	Formula
Normalized Difference Vegetation Index	NDVI	$\frac{\rho_{NIR} - \rho_R}{\rho_{NIR} + \rho_R}$
Ratio Vegetation Index	RVI	$\frac{\rho_{NIR}}{\rho_R}$
Enhanced Vegetation Index	EVI	$2.5\frac{\rho_{NIR} - \rho_R}{\rho_{NIR} + 6\rho_R - 7.5\rho_B + 1}$
Soil Adjusted Vegetation Index	SAVI	$\frac{\rho_{NIR} - \rho_R}{\rho_{NIR} + \rho_R + L}(1 + L)$
Land Surface Water Index	LSWI	$\frac{\rho_{NIR} - \rho_{SWIR1}}{\rho_{NIR} + \rho_{SWIR1}}$
Normalized Difference Built-up Index	NDBI	$\frac{\rho_{SWIR1} - \rho_{NIR}}{\rho_{SWIR1} + \rho_{NIR}}$
Triangular Vegetation Index	TVI	$\sqrt{\frac{\rho_{NIR} - \rho_R}{\rho_{NIR} + \rho_R} + 0.5}$
Difference Vegetation Index	DVI	$\rho_{NIR} - \rho_R$
Infrared Percentage Vegetation Index	IPVI	$\frac{\rho_{NIR}}{\rho_{NIR} + \rho_R}$
Perpendicular Vegetation Index	PVI	$\frac{\rho_{NIR} - a\rho_R - b}{\sqrt{1 + a^2}}$
Rice Growth Vegetation Index	RGVI	$1 - \frac{\rho_B - \rho_R}{\rho_{NIR} + \rho_{SWIR1} + \rho_{SWIR2}}$
Weighted Difference Vegetation Index	WDVI	$WDVI = \rho_{NIR} - s\rho_R$
Transformed Soil Adjusted Vegetation Index	TSAVI	$\frac{s(\rho_{NIR} - s\rho_R - a)}{a\rho_{NIR} + \rho_R - as + X(1 + s^2)}$
Modified Soil Adjusted Vegetation Index	MSAVI	$\frac{\rho_{NIR} - \rho_R}{\rho_{NIR} + \rho_R + L}(1 + L)$ $L = 1 - 2s \times NDVI \times WDVI$

ρ=Reflectance, R=Red, NIR=Near infrared, SWIR1 and SWIR2= Shortwave infrared centered at 1.64 and 2.22 μm wavelengths, a and b= Gain and offset derived from Red- NIR scatter plots (used in PVI expression), LSWI= was termed as Normalized Difference Water Index (NDWI) by Gao et al. (used SWIR1 centered at 1.54 μm), NDWI term is also used for a different index used in delineating water bodies (Mosleh et al. 2015), s=slope of soil line, a=intercept of soil line, X=adjustment factor equals 0.08, used in minimizing soil noise (s, a and X used in WDVI, TSAVI, MSAVI).

Principal Component Transformation

Satellite remote sensing data are obtained for multiple bands. Each band contain information specific to different objects on earth. Principal component transformation (PCT) is a methodology for transforming these bands to new set of bands, equal in number, in such a way that maximum information regarding objects on earth is contained in first few bands. Thus, fewer bands may be utilized to extract information on themes or objects from PCT. The transformation rotates the multidimensional axis in to new orthogonal axis sets.

Tasseled Cap Transformation

Tasseled Cap Transformation (TCT) is a PCT developed specific to crops and vegetation by Kauth and Thomas in 1976. With four Landsat MSS bands, the resulted bands are called Greenness Vegetation Index (GVI), Brightness Soil Index (BSI), Yellowness Stuff Index (YSI) and Non-Such Index (NSI). Last index portrays atmospheric effect. Mathematically, the indices are linear combination of values in four bands of satellite data. In TCT space, soil line lies along the brightness axis. Greenness is orthogonal to this line. Higher GVI indicates higher canopy coverage and crop vigor.

$$GVI = -0.28317MSS4 - 0.66006MSS5 + 0.57735MSS6 + 0.38833MSS7$$

$$BSI = 0.33231MSS4 + 0.60316MSS5 + 0.67581MSS6 + 0.26278MSS7$$

$$YSI = -0.89952MSS4 + 0.42830MSS5 + 0.07592MSS6 - 0.04080MSS7$$

$$NSI = -0.01594MSS4 + 0.13068MSS5 - 0.45187MSS6 + 0.88232MSS7$$

Crist and Cicone in 1984 developed TCT using six bands of Landsat Thematic Mapper data. The coefficients for the bands for four TCT indices are given in Table 2. Third component indicated wetness. In wetness plane, turbid water has highest value followed by clear water, wet soil, dry soil and concrete surfaces.

Table 2 TCT coefficients for Landsat TM bands

Index	Band 1	Band 2	Band 3	Band 4	Band 5	Band 7
Greenness	-0.24717	-0.16263	-0.40639	0.85468	0.05493	-0.11749
Brightness	0.33183	0.33121	0.55177	0.42514	0.48087	0.25252
Third	0.13929	0.22490	0.40359	0.25178	-0.70133	-0.45732
Fourth	0.84610	-0.70310	-0.46400	-0.00320	-0.04920	-0.01190

Crop growth stages

Crops are either seeded or transplanted. Field preparation starts one month prior to seeding. Various inputs of water, fertilizer, weedicide or insecticides are needed before and during crop development. After seeding, germination, vegetative growth, reproduction, ripening, harvesting and residue management takes place. Various growth stages for paddy are described here.

Transplantation: From nursery, seedlings are transplanted to the field. After transplantation, seedling recovery takes place.

Tillering: It is process in which more stems or shoots originate from plant root, after growth of the parent stem. It causes vegetative growth in the plant. Typically up to 40 days, maximum number of tillers appears.

Stem elongation: In late tillering stage, stem begins to lengthen. Stem continues to grow up to panicle initiation at the end of vegetative phase. Total length of vegetative phase is nearly 70 days.

Panicle initiation: This indicates start of reproductive stage of the crop. Panicle initiates from stem. In this bulging at top of the stem occurs. The process is also called booting.

Heading: Heading is a process in which panicles grows.

Flowering: At the end of heading, flowering and pollination takes place. The process takes nearly 7 days.

Ripening: Ripening starts after fertilization. It is divided in to sub stages namely, milky, dough, yellow, ripe and mature. The division is made based on softness, texture and color of grain. Length of ripening stage is nearly 15- 40 days. Length is more in cooler climate.

Crop spectral growth profile

Crop spectral growth profile is plot of vegetation spectral index, typically greenness index and time. The growth profile starts at spectral emergence date, attains a maximum and the indices values decreases thereafter till crop matures. Spectral emergence day is a day when indices value increases than that of bare soil or fallow land. Typical value for NDVI is 0.1 for bare soil or fallow land. Spectral growth profile is modeled by beta distribution.

$$G_t = G_0 \left(\frac{t}{T_o}\right)^{\alpha} e^{-\beta\left(t^2 - T_0^2\right)}$$

$$T_{max} = \sqrt{\frac{\alpha}{2\beta}}$$

T_0=spectral emergence day, t=day, G_t= Crop vegetation index at time t, G_0=Soil vegetation index at T_o, α, β=distribution parameters, T_{max}=day for peak of spectral growth profile. Typical parameter values for wheat in Haryana (Sehgal et al. 2002) and paddy for All India are given in Table 3.

Table 3 Parameters for spectral growth profile of wheat (Haryana) and Paddy (All India)

Parameter	Wheat (Haryana)	Paddy (All India): wet	Paddy (TN): wet (Samba)	Paddy (All India): Dry
To	320- 360	119- 192	291	338- 374

Tmax	42- 54	203- 286	354	40- 72
Go (NDVI)	0.1	0.1- 0.258	0.289	0.282- 0.374
α	30- 80	5- 17	30	19- 38
β	$9.1e^{-5}$- $2.3e^{-4}$	$9.8e^{-5}$- $1.0e^{-4}$	$9.8e^{-5}$	$9.1e^{-5}$- $1.0e^{-4}$

Applications

Rice crop mapping in Kashmir valley

Kashmir valley has area of nearly 15856 sq. km. Rice zone is defined as irrigated temperate zone in the valley. MODIS data of May, June, July, August and October for year 2010 were utilized for mapping of paddy. Classes e.g. forest and water pose problem in delineation of crop areas. It is best to exclude these areas by masking them out. For the purpose, existing GIS data for these themes may be utilized. In this case, for forest area, reserve forest area boundary available from Department of Forest, Government of Jammu and Kashmir were utilized. For water mask, water body map of National Wetland inventory of India prepared by Space Application Centre, Department of Space, Government of India was utilized. Information for crop calendar was obtained from Department of Extension Education Sher-e-Kashmir University of agricultural science and technology (SKUAST-K), Shalimar. Both NDVI and LSWI were used for delineating crops. LSWI was used for mapping flooding and rice transplantation. NDVI was used for mapping crop area and harvested areas. Classification accuracy was assessed using 50 stratified random samples for each class. Water depth generally varies from 2 to 15 cm. About 50 to 60 days after transplanting, rice plant canopies cover most of the surface area. Transplantation starts in May, peaks in June and continues up to July. LSWI and NDVI thresholds were 0.69- 0.82 and 0.21- 0.39 and varied between images. LSWI was used with May, June and July images and NDVI was used with October image. August image was not useful in delineating paddy area, as other vegetation classes are mixed with this class. Paddy harvest starts in September and completes in October. NDVI of October scene was used to identify harvested area. Three NDWI based maps (May, June and July) and one NDVI based map (October) were combined to obtain paddy areas. Total paddy area was 1392 sq. km. Kappa statistic was 0.90 and 0.86 for NDWI and NDVI based maps (Muslim et al. 2015).

$$LSWI = \frac{MODIS_{band\ 2} - MODIS_{band\ 5}}{MODIS_{band\ 2} + MODIS_{band\ 5}}$$

$$NDVI = \frac{MODIS_{band\ 2} - MODIS_{band\ 1}}{MODIS_{band\ 2} + MODIS_{band\ 1}}$$

Crop mapping in Malaprabha, Karnataka

Evaluation of irrigation efficiency require statistics of irrigated area, water supply etc. Irrigated areas are conventionally collected by Revenue Department at village level. Remote sensing data have potential for mapping of irrigated area. Such an application was done in Malaprabha, Belgaum district, Karnataka utilizing IRS LISS-III multi date data. The extent of area is 2202 sq.

km. Double cropping has increased in area up to 33% by year 2000. Average land holding has decreased to less than 2 ha. Subsistence dryland crops (e.g. millet and sorghum) have declined while cash crops (e.g. soybeans, maize, and sugarcane) has increased. Cropping seasons are Kharif (June- November), Rabi (November- February) and summer (February- May). In sugarcane, harvesting and replanting is done in January in general. In crop mapping LISS-III data of November, January and March were used. Atmospheric correction was applied to data prior to use. Cloud, cloud shadow, water bodies, builtup and forest area were masked out. Water bodies were masked out using supervised classification. Available map of land use cover was used for built up area mask. For forest area, supervised classification was done. A composite map with forest area in either of classified map or available map was used as mask. Forest area includes degraded areas and tree groves. After masking, multidate images were stacked and classified. Ground truth was collected. Homogeneous areas on all images and area with identified field boundaries were retained. Ground truth information was used selectively based on spectral signature. Stacked hierarchical classification technique was used in which classification details were increased at each successive classification. At level 1, three classes were single rainfed paddy, perennial irrigated (mostly sugarcane) and other. At level 2, other area was divided in to irrigated and non irrigated. At level 3, irrigated and non irrigated area was further divided in to seven classes. Crop rotations for both irrigated and non-irrigated, namely paddy-other and other-other and other classes, namely rainfed- other, rainfed- orchard and grassland were mapped. Kappa varies between 0.52 and 0.81 (decreases with level of classification). Classification results (2007) were compared to Census of India statistics (2001), and another study (year 2000 done for larger area). Differences in statistics were found, which may be due to class definition, variability in ground truth information, misclassification, under reporting of irrigated areas, data, scale, method, spatial- temporal variability especially in short duration crops, irrigated area (sowing date varies due to assured availability of water) etc. Other study utilized single date remote sensing data and was done for large area with limited ground truth. This led to misclassification of irrigated area to riparian vegetation, inclusion of scrub/hilly vegetation and barren land to grass land category etc. Irrigated areas in two remote sensing applications were 35 and 16% respectively. Census of India, irrigated area vary between 15-17%. Large changes in land cover over small time interval of 10 year as seen in the statistics of different studies are not possible and thus are attributed to other causes (Heller et al. 2012).

Crop mapping in Haryana

Kumar et al. (2015) has mapped crop area in Fetahabad district of Haryana. Paddy and cotton are two main crops in the district. Paddy is mainly grown in Ghagghar flood plain. Landsat 8 data of August and September 2014 were used. Data were stacked and ISODATA clustering technique was applied. Mixed pixels were masked out and area within mask was again reclassified. To identify features in the ISODATA clusters, information from ground truth were used. Area under paddy and cotton were 39 and 29% respectively. Other crops cultivated are Guar, Bajra and vegetables. Similar studies were done for Hisar and Kurukshetra districts in Haryana for crop mapping (Saroj et al. 2014, Sarma et al 2011). In Hisar, the mapping was done for year 2007-08 using LISS-III data. Cotton, wheat and Bajra are major crops. Other crops are maize, Mustard, Jowar and Moong (summer). Relative deviation is 0.13- 2.86% for major crops to DES statistics. Mapping in Kurukshetra district Haryana was done using LISS- III data. Paddy, sugarcane and wheat are major crops. Bajra, Maize, Jowar are other crops. In Pahowa and Thanesar paddy-wheat- fallow are dominant rotations and paddy- wheat- other is second important rotation. In Shahbad, both rotations are major rotations. Significant sugarcane perennial crop exists in Thanesar, Shahbad, Badain and Ladwa blocks. Paddy- wheat- other rotation also exists in latter two blocks. Sharma et al. (2014) mapping crop areas in Bhiwani district using LISS-III data. Major Kharif crops are Bajra (Comparatively large area to that of cotton) and Cotton. Major Rabi crops are wheat and Mustard. In Siwani and Tosham blocks, gram is dominant Rabi crop.

Sethi et al. (2014) used ETM+ data of growing season September- October to delineate paddy in Haryana. Data were classified using ISODATA clustering technique. Delineated area was compared with statistics of Department of Agriculture, Haryana. Coefficient of determination between two statistics is 0.67. Paddy is dominant crop in north east Haryana and extends up to parts of central Haryana. In districts, namely Panchkula, Ambala,Yamunanagar, Kurukshetra, Kaithal, Karnal, Jind, Panipat and Sonipat *kharif* (July Beginning to Mid October) paddy is dominant crop. In districts, namely Hisar, Jhajjar, Sirsa and Rohtak moderate area is sown under paddy. The paddy sown area is 24% of total geographical area.

Paddy mapping using active microwave data

Rice mapping was done using RADARSAT data for March- December 1996 and April- July 1997 in Zaoqing, Guangdon, China (Shao et al. 2001). Simultaneous, ground observations (plant water content, stem height and leaf length) are taken on same day and 1- 2 days before and after the satellite overpass. Data have calibration accuracy of 1 dB. Digital numbers were converted in to radar backscatter using calibration constants. Forested mountainous area was masked out using a DEM threshold. Enhanced Lee filter with 5 X 5 pixel window was used to remove speckle and small patches of objects. Due to speckle noise in radar data, backscatter value varies over wide range for objects. For paddy backscatter varies from 10 to -40. The effect is minimized by selecting large number of samples for the classes and taking a representative value from them. Multi date representative values are used to obtain backscatter profile for objects. Backscatter for various growth stages of paddy is given in Table 4. Empirical cubic polynomial is fitted to the profile. Classes delineated were paddy, banana, and sugarcane. For paddy, different paddy classes were delineated. Neural net supervised classification technique was used in classification. Ground truth information at 368 sites was used with six fields per class in training and 12 field per class for accuracy assessment. Post classification sieve filter of 7 X 7 pixels was used to remove additional small patches. Yield was calculated using crop duration based empirical relationship. During transplantation and seedling recovering period, backscatter from paddy field is similar to water. Up to ear differentiation, backscatter increases. During paddy maturity, again backscatter drops. The backscatter signature may be utilized in mapping paddy crop and discriminating paddy of different duration. Paddy of medium, late, late-medium and early maturity type are grown. Late- medium are transplanted and harvested at later date than medium and late varieties. Suitable dates for paddy monitoring are during transplantation, seedling development and maturity (before harvest). Transplanting and seedling development period images may be used with change detection technique. Kappa classification accuracy of 0.9 was obtained.

Table 4 Radar backscatter at different growth stages of paddy

Growth stage	Backscatter in dB
Transplantation	-25
20 days from transplantation (seedling recovery)	-15
Seedling development 20- 45 days	-12
Ear differentiation 45- 75 days	-9
Middle of ear differentiation 65 days	-6
Maturity >75 days	-8

$$\sigma_{jk}^{0} = 10log_{10}\{(DN_{jk}^{2} + A_0) + A_j\} + 10log_{10}\sin I_j$$

j=pixel, k=scan line, A_0, A_j=calibration constants, I_j=incidence angle, DN_{jk}=digital number, $\sigma_{jk}{}^{0}$=radar backscatter

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