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Remote Sensing and GIS Techniques in Agricultural Development - A Case Study of Punjab

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ABSTRACT

The agriculture in the Punjab state has made spectacular progress during the last three decades. The notable achievement is reflected in about eleven-fold increase in the index of production of cereals during the period 1960-61 to 1999-2000. However this growth of agriculture is associated with a major shift in cropping pattern, high input use in terms of fertilizer, pesticide, water etc. Advance estimates of crop area and production are required for taking decisions on procurement, storage and pricing. The crop production forecast is a challenging task because of the diverse nature of Indian agriculture. Remotely sensed data has a unique potential in monitoring crop acreage and production at state and national level due to synoptic and repetitive coverage. Using Remote Sensing data at the peak vegetative stage of the crop, it is possible to give timely pre-harvest estimates of crop acreage at district level. Yield forecast can be given using spectral indices such as band ratio, normalized difference vegetation index (NDVI) etc. In the present article emphasis has been laid to explore the role of Remote Sensing and GIS in Agriculture with special emphasis on Crop Acreage and Production Forecasting and Cropping System Studies.

Indian Remote Sensing programme has been primarily application oriented. Among the various applications, agriculture has been accorded highest priority because this sector accounts for 27 per cent of Gross Domestic Product (GDP) and provides livelihood to about 64 per cent of the population. among the various applications of remote sensing in agriculture, crop studies remain in the fore front. Some of the applications of Remote Sensing in crop studies are crop acreage and production forecasting, crop condition assessment, cropping system studies, precision agriculture etc. GIS techniques are playing an increasing role in facilitating integration of multilayer spatial information with statistical attributes data to arrive at alternate development scenarios

Punjab occupies a special place in Indian agricultural scenario, known as granary of India, Punjab has made enormous contribution to the national pool of foodgrains, i.e. around 70 per cent of wheat and 50 per cent of rice. The agriculture in the Punjab state has made spectacular progress during the last three decades. The notable achievement is reflected in about eleven-fold increase in the index of production of cereals during the period 1960-61 to 1999-2000. However this growth of agriculture is associated with a major shift in cropping pattern, high input use in terms of fertilizer, pesticide, water etc. (Grewal and Sidhu, 1990).

The farmers' are concerned with the net immediate returns, unmindful about the long term consequence. A significant chunk of area, which was under maize, millets, groundnut and cotton cultivation has come under rice during *kharif* and that from gram, rapeseed/mustard and barley has come under wheat during *rabi*. At present, about 95 per cent of the total food grain area in Punjab is under Rice and Wheat (Aulakh, 2002). Apart from these, there is no scope for horizontal expansion as the total cropped area has increased tremendously (89 thousand ha per year). In this context cropping systems research holds a key for a sustainable growth in the food production in Punjab

Advance estimates of crop area and production are required for taking decisions on procurement, storage and pricing. The crop production forecast is a challenging task because of the diverse nature of Indian agriculture. Some of the characteristics of Indian agricultural scene are small field size, large diversity of crops grown in an area, large field to field variability in sowing and harvesting dates, large area under rainfed/dryland agriculture with poor crop canopies, practice of inter cropping and mixed cropping and extensive cloud cover during *kharif* season. However Remote-sensing technology provides many advantages over the traditional methods in agricultural resources survey. The advantages include,

i) capability to achieve a synoptic view,
ii) potential for fast survey,
iii) capability of repetitive coverage to detect the changes
iv) low cost involvement
v) higher accuracy
vi) use of multi-spectral data for increased information, and so on.

Remotely sensed data has a unique potential in monitoring crop acreage and production at state and national level due to synoptic and repetitive coverage. Using Remote Sensing data at the peak vegetative stage of the crop, it is possible to give timely pre-harvest estimates of crop acreage at district level. Yield forecast can be given using spectral indices such as band ratio, normalized difference vegetation index (NDVI) etc. In the present article emphasis has been laid to explore the role of Remote Sensing and GIS in Agriculture with special emphasis on Crop Acreage and Production Forecasting and Cropping System Studies.

Crop Acreage and Production Forecasting

Advance forecasting about crop condition and crop production has a strong bearing on national economy as well as day-to-day life of the public (Navalgund *et al.*, 1991). The sugar and onion crisis of late 90's showed that a faulty crop forecasting system could create havoc for the government and the public. In India, the first systematic attempt towards crop inventory through remote sensing technique was carried out under a joint Indian Space Research Organization (ISRO) and Indian Council of Agricultural Research (ICAR) - Agricultural Resource Inventory and Survey Expenditure (ARISE), in which aerial colour infrared (CIR) photographs were used to estimate crop acreage in Anantpur district of Andhra Pradesh (Sahai, 1976) and in Patiala district of Punjab (Dhanju and Shankranarayana, 1978). Under IRS utilization programme (IRSUP) of Deptt. Of Space in 1984, three projects, namely i) Crop Production Forecasting, ii) Crop Yield Modelling, and iii) Crop Stress Detection were initiated to study different aspects of crop inventory using RS data (Navalgund and Sahai, 1985). Later on, Crop Acreage and Production Estimation (CAPE) project was formulated under the Remote Sensing Applications Mission in 1986.

CAPE project, at present, provides district level crop production forecasting for major crops wheat, rice and cotton in all the districts in Punjab. Crop acreage is estimated using the remote sensing data following stratified sample segment method. The stratification is done on the basis of various criteria, e.g. agro climatic regions, historical crop proportions, crop conditions as seen from satellite imageries. The most commonly used segment sizes are 10 x 10 km, 7.5 x 7.5 km and 5 x 5 km, with a sampling fraction of 10 or 15 per cent. Digital classification of RS data is carried out using a Maximum Likelihood Classifier with the help of field information collected synchronous to the satellite pass. The district level RS based yield models have been developed using the empirical relationships between yield and single or multi-date (spectral profile) RS parameters (Dadhwal and Ray, 2000). In some of the yield models RS parameters have been used along with other agro meteorological variables and/or a time trend variable.

FASAL (Forecasting Agricultural output using Space, Agro meteorology and Land based observations) is a new system, whose objective is to integrate various approaches and organizations for creating a hierarchical information system, which will help in providing information, related to crop condition and crop production any time of the season from sowing to harvest (Dadhwal, 1999). A pilot study of FASAL multiple forecasting system has been implemented in Orissa. As a part of the techniques development for FASAL project, national level rice (Chakraborty and Panigrahy,

2000) and wheat (Oza *et al.*, 1999) forecasts are provided using multidate microwave and optical data, respectively, following a hierarchical classification approach.

Cropping System Analysis

A cropping system can be defined as the cropping and their management used to derive maximum benefits from a given resource base under specific environmental conditions. The success of any cropping system depends on its planning. The analysis of the present cropping system to evaluate its long term performance with respect to sustainable productivity and environmental impacts, forms the scope of the cropping systems study. RS data from space borne sensors, due to its perspective view; multi-spectral multi-resolution and frequent monitoring capability can provide various spatial information amendable to cropping system analysis. Those are crop area, cropping pattern, crop rotation, crop calendar, crop vigour, soil type, soil moisture etc. (Panigrahy *et al.*, 1996). This information, when integrated with other physical, environmental and economic resources, through a GIS based simulation model, the long term performance of the cropping system can be evaluated. Deptt. of Space has taken up such studies for the states of Punjab, West Bengal and Assam.

Precision Agriculture

The area available for agriculture is getting reduced day-to-day because of rapid industrialization and Urbanization. The problem in front of the modern day farmer is to produce more from less area. Hence, the grower has to treat different grids of its large field differently for input application. In recent years the expanded use of Global Positioning System (GPS) and GIS has given rise to agricultural advances in spatial data management that have revolutionized the way many growers manage their fields (Anderson *et al.*, 1999). In near future, a farmer will go to the field with a spreader or combine equipped with a GPS that records positional information related to variable rate of fertilizer application or yield at harvest for his farm. This ability to monitor the variability in the field and then to pinpoint areas for input application using variable rate method is known as precision farming. Many growers in developed countries, use this information for time and site specific field analysis with the assistance of farm management systems. Farm management systems are essentially GIS with functions tailored to the activities of farming.

Case Studies from Punjab

Crop acreage and production estimation

Cotton

During the year 2002-03 cotton acreage in five districts of Punjab, viz. Bathinda, Faridkot, Firozpur, Mansa and Muktsar was estimated through digital analysis of IRS-1C & 1D LISS-III data of first week of October, 2002 following the sample segment approach The analysis of the data was supplemented by ground verification carried out in September 2002. District wise cotton acreage for the year 2002-03 is given in Table 1.

There was a marginal increase of 1.65 per cent in the area under cotton estimated through Remote Sensing Techniques as compared to BES estimates (2002-2003), while the Remote Sensing estimates showed an increase in production of cotton in the Punjab State by 10.34 per cent as compared to BES estimates.

Rice

The rice acreage and production estimation in Punjab is being undertaken since 1999 For the year 2002, RADARSAT Scan SAR Narrow (SCAN-B) data of three dates viz. July 13, July 19 and August 20, 2002 covering all the districts of the State. The district-wise acreage, yield and production estimates of rice are given in the Table 2:A perusal of the figures in Table 2 shows that rice crop in the State covered an area of 2514.7 thousand hectares (Remote Sensing estimates) during the year 2002. Sangrur district has the highest area (69.5%) under rice followed by Amritsar (64.2%), Ludhiana (63.0%) districts.

The area under rice crop in Fatehgarh Sahib, Kapurthala and Patiala districts is also more than 60 per cent of the total geographical area (TGA) of the district. The area under rice in three districts namely Gurdaspur, Moga and Faridkot is between 50 and 60 per cent of TGA. The area under rice in

Table 1. Districtwise Acreage and Production of Cotton for the year 2002-03 based on Remote Sensing Data Analysis

District	Geographical Area ('000 ha)	RS Estimates (2002)		
		Cotton Area ('000 ha)	Yield (Kg/ha)	Production ('000 bale)
Bathinda	337.7	129.65	433.8	330.84
Faridkot	147.2	13.12	402.2	31.04
Firozpur	527.8	111.03	457.9	229.06
Mansa	217.4	77.64	455.5	208.03
Muktsar	263.0	71.81	443.5	187.34
Total for 5 districts	1493.1	403.25		986.31
PUNJAB STATE		457.44	451.3	1214.39
BES Estimates 2002-2003		450.0	409.0	1086.0
Per cent increase/ Decrease w.r.t. BES estimates		1.65		10.34

rest of the districts of the state varies from 30 to 50 per cent of the TGA of the respective districts. The Hoshiarpur and Rupnagar districts having sizeable hilly and choe affected area has less area under rice i.e. 20.0 per cent and 24.2 per cent of TGA of the district respectively. The Nawanshahar district has nearly 40 percent area under rice.

The cotton belt comprising Bathinda, Muktsar and Mansa districts has relatively less area under rice which is 33.1, 31.0 and 33.9 per cent of TGA of these districts, respectively. Firozpur district had 45.7 per cent area under rice. As compared to 2001-2002 estimates in Ludhiana and Patiala districts the area under rice has increased, however decrease in rice area in district Firozpur, Faridkot, Kapurthala and Mansa has been observed.

The average yield of rice based on 10 years Trend Yield Model was estimated, which vary between 3.808 t/ha (Fatehgarh Sahib) and 3.766 t/ha (Firozpur) with 3.434 t/ha as the average yield for the state. Corresponding yields for these districts as reported by Directorate of Agriculture are 3.998 t/ha and 3.755 t/ha respectively, which is slightly higher in Fatehgarh Sahib than the predicted yields using Trend Yield Model. Expected production based on Trend Yield Model during this year was 86.35 lac tonnes and as per BES estimates it is 88.16 lac tonnes.

Wheat

The district wise wheat acreage and production estimates for the year 2002-2003 through Remote Sensing are given in Table 3. The total wheat area in the state as estimated using remote sensing data was 3.38 million ha i.e. 67.21 per cent of the total geographical area of the state. IRS-1D LISS-III digital data of second week of February and March, 2003 was analysed using Sun Sparc Station 10 and Silicon Graphics Workstations using EASI-PACE software following sample segment approach

The district wise wheat yield and production estimates were based on Spectral-Trend-Yield Models. Estimated wheat production in the State is 15.51 million tones. The State level wheat area and production shows marginal reduction of 1.3 and 0.08 per cent respectively, as compared to the previous years (2001-02) BES estimates.

District level wheat acreage in Nawanshahar, Fatehgarh Sahib and Firozpur districts showed a reduction in wheat acreage by 3.4, 3.8 and 3.5 per

Table 2. Rice acreage and production in different district of Punjab for the year 2002-2003

District	Geog. Area ('000 ha)	RS Estimates (2002-2003)				BES Estimates (2001-2002)		
		Area (000 ha)		Yield (t/ha)	Prod. ('000t)	Area (000 ha)	Yield (t/ha)	Prod. (000 t)
Amritsar	508.8	326.4	(64.2)	3.082	1005.96	319.0	3.003	958.00
Bathinda	337.7	111.9	(33.1)	3.703	414.37	82.0	3.742	307.00
Faridkot	147.2	79.3	(53.9)	3.506	278.03	70.0	3.823	267.00
Fatehgarh Sahib	116.2	72.6	(62.5)	3.808	276.46	81.0	3.998	324.00
Firozpur	527.8	241.4	(45.7)	3.766	909.11	230.0	3.755	864.00
Gurdaspur	356.2	183.8	(51.6)	2.884	530.08	194.0	2.944	571.00
Hoshiarpur	337.5	67.4	(20.0)	3.042	205.03	60.0	2.847	171.00
Jalandhar	263.5	129.8	(49.3)	3.462	449.37	132.0	3.369	445.00
Kapurthala	163.0	102.6	(62.9)	3.448	353.76	103.0	3.471	357.00
Ludhiana	370.0	233.0	(63.0)	3.699	861.87	235.0	3.897	916.00
Mansa	217.4	73.7	(33.9)	3.342	246.31	68.0	3.562	242.00
Moga	223.0	132.1	(59.2)	3.641	480.98	152.0	3.807	579.00
Mukatsar	263.0	81.5	(31.0)	3.460	281.99	65.0	3.673	239.00
Nawanshahar	125.8	50.3	(40.0)	3.260	163.98	45.0	3.17	143.00
Patiala	368.0	229.2	(62.3)	3.336	764.61	251.0	3.619	908.00
Rupnagar	209.1	50.6	(24.2)	3.196	161.72	51.0	3.197	163.00
Sangrur	502.0	349.1	(69.5)	3.738	1304.94	349.0	3.902	1362.00
State	5036.2	2514.7	(49.9)	3.434	8634.74	2487.0	3.545	8816.00

Figures in parentheses are Percentage of rice area to the Total Geographical Area (TGA) of the district/state.

cent, respectively. In other districts variation was less than 3 per cent as compared to previous years BES estimates. District level production Bathinda district showed an increase of 11.9 percent, whereas, production in Fatehgarh Sahib and Muktsar districts showed reduction by 10 and 7.2 per cent respectively. In other districts variations were less than 5 per cent as compared to previous years BES estimates (2001-2002).

Cropping System Studies

For analysis of cropping system in Punjab state both spatial and non spatial data were used. The data from Indian Remote Sensing Satellites (IRS-1A, IRS-1C and IRS-1D) were used to create spatial database of cropping system. IRS LISS III data (red, green, NIR bands and 23 m resolution) were used for general land use/cover database and other spatial information like communication, drainage and canal network. For studying the cropping pattern of current season IRS WiFS and RADRSAT ScanSAR data were used. WiFS (Wide Field Sensor) is a medium resolution (188 m) sensor with a revisit period of 5 days, which provide data in red, near infrared and middle infrared ranges. ScanSAR operates in C band, HH polarisation with spatial resolution of 50 m. Remote sensing data derived from IRS (1A/1B) LISS I for 1988-89 were used for studying long term changes in cropping pattern. IRS LISS I sensor provides data in four multispectral bands (blue, green, red and near infrared), with spatial resolution of 72.5 m and a repetivity of 26 days.

Cropping Pattern Maps

Cropping pattern maps for three seasons of

Table 3. Estimates of area, yield and production of wheat for the year 2001-02

District	G. Area (000 ha)	RS Estimates (2002-03)			BES Estimates (2001-02)			% Increase/Decrease w.r.t. BES Estimates	
		Area (000 ha)	Yield Kg/ha	Production (000 tonnes)	Area (000 ha)	Yield Kg/ha	Production (000 tonnes)	Area (000 ha)	Production (000 tonnes)
Amritsar	508.8	355.1	4687	1664.44	363	4683	1700	-2.18	-2.09
Bathinda	337.7	244.7	4339	1061.73	243	3905	949	0.70	11.88
Faridkot	147.2	107.9	4626	499.16	111	4468	496	-2.79	0.64
F.G. Sahib	116.2	81.8	4603	376.51	85	4925	418	-3.76	-9.93
Ferozpur	527.8	369.7	4651	1719.46	383	4336	1661	-3.47	3.52
Gurdaspur	356.2	216.2	4615	997.82	217	4660	1011	-0.37	-1.30
Hoshiarpur	337.5	139.6	3709	517.72	139	3616	502	0.43	3.13
Jalandhar	263.5	166.7	4744	790.8	167	4703	785	-0.18	0.74
Kapurthala	163	110.9	4674	518.36	114	4722	535	-2.72	-3.11
Ludhiana	370	254.1	5047	1282.37	257	5073	1304	-1.13	-1.66
Mansa	217.4	161.2	4045	652.12	165	4045	667	-2.30	-2.23
Moga	223	172.8	3865	667.84	167	4664	779	3.47	-14.27
Muktsar	263	189.6	4006	759.45	193	4238	818	-1.76	-7.16
N. Shahar	125.8	68.6	4453	305.49	71	4566	324	-3.38	-5.71
Patiala	368	262.9	4858	1277.06	265	4944	1310	-0.79	-2.51
Rupnagar	209.1	87.1	4157	362.08	88	3942	347	-1.02	4.35
Sangrur	502	395.9	4955	1961.71	392	4822	1890	0.99	3.79
State	5036.2	3384.8	4583	15514.14	3420	4532	15499	-1.03	0.10

1998-99 were generated using unsupervised classification approach applied on NDVI data of three to four dates for each season.

The *kharif* cropping pattern map was generated using the NDVI values based on the analysis of satellite data of May, June, September and October. During *kharif* season the major crops were rice and cotton. Other crops included maize/sugarcane/ fodder in kandi belt and vegetables in Amritsar, Kaputhala, Jalandhar and Nawan shehar. The major cotton growing districts were Firozpur, Muktsar, Bathinda and Mansa.

The data of December, January and February were used for generating *rabi* cropping pattern map. During *rabi* season wheat was the major crop covering upto 93 per cent of the total cropped area, where as the other minor crops, including potato, *rabi* maize, sugarcane, *rabi* pulses and oilseeds. The districts like Hoshiarpur, Jalandhar and Muktsar have large acreage of non-wheat crops.

The summer cropping pattern map were generated using the NDVI data of four dates of, April, May, May and June. K-means classification approach was followed, after masking the non-agriculture area. The summer crops included vegetables, maize, sugarcane, fodder etc. The summer cropping is mostly restricted to Jalandhar, Hoshiarpur and Nawanshehar.

Crop Rotation Mapping

The False Colour Composite (FCC) of images of all the twelve dates were used to arrive at the crop rotation map. Two distinct crop-growing patterns are apparent. In the first pattern the crop is sown during the period from May to June and harvested in September and November. This includes rice (towards northern side) and cotton (towards southern side). This crop growing period is called *kharif* (rainy) season. In the second pattern the crop is grown during November to December, peaks during January to February and is harvested in April. This is mostly wheat crop and the growing period is called *rabi* (winter) season.

The temporal NDVI profiles also showed the similar pattern for different crop rotations. The NDVI of rice-wheat system drops very fast, after September, while the cotton-wheat system drops gradually, since cotton is harvested much later than rice. In the vegetable based system, the NDVI profile has a non-zero value for a longer period, since in this system, there are three crops of vegetable grown one after another in succession. Potato is plotted separately, as there is distinct area and pattern of potato grown in Punjab.

Using this NDVI profile the knowledge based (If <>, then <>, else<>) hierarchical classification system was formed. In the beginning the non-agriculture classes such as wasteland, degraded forest, built-up, water, sand etc., were masked. These were followed by delineation of vegetable, cotton, potato and maize. Rice was delineated using logical classification on ScanSAR backscattering coefficients.

The crop rotation map showed that the farmers of Punjab, mostly follow two major crop rotations, i.e. rice-wheat and cotton-wheat. Cotton-wheat rotation is mostly practised towards the southwestern side of the state. The other prevalent crop rotations are maize based, vegetable based (which includes potato) and also sugarcane based. The maize-based systems are generally followed northeastern part of Punjab, in the foothills of *Siwalik.*

Conclusion

Applications of remote sensing and GIS in agriculture are very wide. The above discussion only cites a few examples of these. The use of remote sensing technology in the Punjab state is in operation since 1986-87 and the results have demonstrated the application of this technique for early stage assessment of acreage and production of major crops (wheat, rice, cotton etc.) at the state and district level. A comparison of remote sensing based production forecasts showed a good agreement with the conventional estimates made by Bureau of Economics and Statistics at the state level. Although district level deviations were larger in some districts due to variation in satellite data acquisition dates and non availability of required Agro-meteorological data at the district level used as input in the yield prediction models. However, like any other tool, remote sensing is not a stand alone system. It has to be properly integrated with other information for better resource monitoring. When combined with other data inputs, remote sensing technology provides a fast, reliable, accurate and effective method for studying crops and to make pre-harvest forecasts for area and production.

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