Satellite Remote Sensing for Irrigation Management

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1. INTRODUCTION

Irrigation management deals with efficient use of water resources, canal system, command areas, plants, soils and knowledge of technical disciplines to bring water to the root zone at proper rate, time and place to produce food and fibre. Some of the key elements of irrigation management are performance monitoring, diagnostic appraisal, action research and people's participation.

In terms of rational monitoring and evaluation framework, irrigated agricultural projects can be categorised into four inter related levels: (1) Planning, design and construction of physical facilities (2) Operation and maintenance of irrigation and drainage facilities (3) Agricultural production and (4) Achievement of socio economic objectives. Amongst the above four levels, satellite remote sensing can play an effective role in monitoring and evaluation of agricultural production.

2. ROLE OF REMOTE SENSING

Irrigation planning and management involves knowledge of both the total demand and the distribution of demand for irrigation water over space and time. The major information required for irrigation studies is about crop types, acreage, condition and yield. From this information estimates of water demands can be made. Because of the vast areas involved, time constraints and dynamic changes, remote sensing is found to be an effective tool for irrigation studies compared to conventional methods which are point based, time consuming and cumbersome. Remote sensing based inventory of irrigated crops is useful for timely estimation of the crop areas: to find water demand over space and time, to monitor crop condition during the irrigation season, to forecast crop yields before the end of the season and for evaluating over all performance of irrigation projects.

2.1 Remote Sensing for command area management

Various applications of remote sensing for command area management are as follows.

1 Assessment of water availability in reservoirs for optimal management of water to meet the irrigation demand.
2 Identifying, inventorying and assessment of irrigated crops.
3 Determination of irrigation water demand over space and time.
4 Distinguishing lands irrigated by surface water bodies or by ground water withdrawals.
5 Estimation of crop yield.
6 Water logging and salinity problems in irrigated lands.
7 Irrigation scheduling based on water availability and water demand.
8 Evapotranspiration studies.
9 Irrigation system performance evaluation.

Many studies were undertaken in irrigation water management involving remote sensing techniques both in India and abroad.

3. IRRIGATED CROP AREA MONITORING

Crop Acreage and Production Estimation (CAPE) was initiated in India by Space Application Centre, Ahmedabad [1], and later taken up many remote sensing agencies. Accurate information about distributary command boundaries and permanent land features are essential to derive site specific crop information from satellite imagery. The field maps are normally approximated and may not have the details like permanent land features, which are required for image interpretation. So the base map of study area should be prepared from the corresponding Survey of India toposheets (in working scale) along with the information from field maps. This will highlight various landmarks like canal network, roads, towns, water bodies, drainage network, etc. to locate specific sites on ground. The path/row of the satellite scene covering the study area can be identified from the orbital calendar. Based on crop calendar and separability (which depends on crop cover, density, leaf area, leaf structure, crops growth stage etc.) of major crops cultivated in the command, satellite data is procured.

3.1 Visual interpretation

After rectification (geometrical correction of image to basemap) of the satellite data, standard False Colour Composite (FCC) is generated (sometimes, individual bands are digitally enhanced before generating FCC depending on classes to be separated). On the FCC, the distributary command boundaries are identified with the help of base map and revenue survey maps. For various crop classes to be identified, ground truth should be collected based on their accessibility, association with permanent land features like road intersections, canal-road intersection, aqueducts, from all over the command area. Spectral signatures of the major crops are Identified on the FCC (Table 1) and corresponding interpretation keys are developed based on collected ground truth like crop type, stage, etc.

Table 1. Spectral Signatures of Major crops

Crop Type	Growth Stage at the time of Satellite Data Acquisition	Possible signature on a Standard FCC
Paddy	2 to 3 weeks after transplantation	Greenish black to Reddish black
Paddy	Peak vegetative phase	Dark Red
Groundnut	Peak vegetative phase	Shades of bright red
Sugarcane	Peak vegetative phase	Light Pink to Pink
Cotton	Peak vegetative phase	Pink to Red

Using the interpretation keys the entire image is classified and the areas under different classes are measured from the interpreted map. The accuracy of classification is checked by tallying the classified crop areas with the ground information collected at selected sites (preferably 95% of selected sites of a given class should have been identified as the same class).

3.2 DIGITAL CLASSIFICATION PROCEDURE

Visual interpretation requires extensive training and is labour intensive. Further the spectral characteristics are not always fully evaluated because of the limited ability of the eye to discern various tones on image and difficulty of an interpreter to simultaneously analyze numerous spectral images. Hence digital interpretation techniques are adopted to accommodate multi date data sets and to reproduce the classification results with consistency while saving on turn-around time. The general procedure of digital classification of crop types/groups is explained below.

Well distributed and uniformly fixed training areas are identified for crops which were collected from ground and also for other non crop classes on FCC. If necessary more than one date may be used to identify crops with different sowing times or crop periods. Statistics of spectral signatures i.e. mean and standard deviation (M & SD) should be computed for the training areas. If the overlap of M & SD between any two classes is more than 25% (which means that those two crops are not separable since they have similar spectral radiance), the training areas of those two classes may be merged or redefined. Signatures should be generated again for the purified training areas and checked for separability between the classes. Maximum likelihood classification algorithm which takes into account the apriori probability of each pixel belonging to a particular crop/class as defined by M & SD of training areas of that crop/class is applied on the final signatures of different crop/classes. Other classification algorithms like minimum distance or parallelopiped or combination of either of these with maximum likelihood may also be used.

A portion of training areas, collected from ground, which were reserved for checking classification accuracy, are used to check whether the reserved training areas for a particular crop are classified as that particular crop or not. Classification accuracy is checked similarly for other crops/crop groups. The classification needs to be repeated if this classification accuracy for any crop is less than 90%.

4. IRRIGATED CROP CONDITION ASSESSMENT

Many researchers had established that vegetation indices which are ratios or differences or combination of both, of reflection near infrared and red bands are highly sensitive to crop vigour and crop moisture stress. Out of several vegetation indices, Normalized Difference Vegetation Index (NDVI) which is the ratio of difference to sum of reflectances in infrared and red bands, is widely used as it minimises most of the atmospheric effects and the effect due to differences in illumination geometry, making it amenable to multi-date comparisons. NDVI is a function of green leaf area and biomass and reflectiveness of the crop vigour.

4.1 NDVI Image and Statistics Generation

Normalized difference vegetation index (NDVI) images for each date should be generated using the following relation:

$$NDVI = \frac{\text{NRI Radiance} - \text{RED Radiance}}{\text{NRI Radiance} + \text{RED Radiance}}$$

NDVI values of all dates must be uniformly scaled between 0 and 255 by multiplying the output NDVI by a scaling factor before NDVI image generation.

Distributary-wise NDVI statistics (Mean and Standard deviation) are generated under each crop by overlaying distributary command area masks and classified crop theme on NDVI image, taking one crop at a time. This has to be repeated for other crop and other years as the case may be.

4.2 NDVI Analysis

Based on ground information on actual water deliveries and change in crop calendar over the years, if any, and also based on shift in seasonal profiles over the years, the distributary level NDVI statistics at peak stages of the crop over the years should be collected. From seasonal NDVI profiles, change in NDVI with respect to crop growth stage may be analysed. From seasonal change in peak NDVI over the years and from spatial comparison of seasonal peak NDVI of all the distributaries of a given crop, the affected distributaries can be identified.

4.3 Crop Yield Estimation

NDVI information can also be used for crop yield estimation. Crop yield data obtained form sources, like crop cutting experiments, can be used to develop a statistical model between crop yield and NDVI. For this, the areas where crop yield data is available are to be located on the NDVI image and a regression type model can be developed between crop yield and NDVI statistics for the respective location. Thus developed model can be extended to predict the yield for the entire command area [2].

5. CASE STUDY

5.1 Rajolibanda Diversion Scheme Command, A.P.

The Rajolibanda Diversion Scheme (RDS) is an inter state project between Karnataka and Andhra Pradesh in Krishna river basin upstream of Srisailam project. It comprises of an anicut constructed in Karnataka in 1955 across river Tungabhadra and a 143 km long left bank main canal. The initial 42.6 km of the canal lies in Karnataka consisting of 12 distributaries serving an authorized ayacut of 2,139 ha. The latter stretch of the main canal in Andhra Pradesh consists of distributaries 12A to 40, authorized to serve an ayacut of 35,410 ha of which 14,215 ha. during Kharif season, 19,332 ha during Rabi season and 1,863 ha. of perennial crops.

5.1.1 Problems in RDS command

A. As the source of release of water supply is located in other state, the timing and amounts of water release are uncertain and non-dependable.
B. As water releases are annually reducing in magnitude, the cropping pattern in the command is prone to changes. These changes lead to the following practices:
   i Concentration of paddy in head reaches due to assured water supply and misuse of initial releases for land preparation.
   ii Mid and tail end reaches receiving insufficient water supplies leading to violations of Command Area Development tenets i.e. development of unauthorized ayacut during Kharif, cultivating in areas earmarked

for Rabi I.D. (Irrigated Dry crops); cultivating Kharif wet crops in areas earmarked for Kharif I.D., etc., mainly by unauthorised withdrawal of water, thereby effecting canal water distribution.

iii Due to insufficient water availability in the tail end stretches, reduced crop acreages are reported, with portions of ID crops subjected to moisture stress.

5.1.2 Status of Irrigated Areas in RDS Command

The actual cropping intensities in RDS command have been visually identified from the geometrically corrected cloud free data of Indian Remote Sensing satellite (IRS), LISS II (Linear Imaging Self Scanner) sensor (path-26; row-57; sub scene-B1) of the study area. The distributary-wise crop group acreages for the Kharif 1992, Rabi 1991-92 and Rabi 1990-91 seasons have been measured by the grid enumeration technique (with concurrent ground verification) and compared with the field reported acreages. The cropped areas are also estimated with Digital interpretation and they compared well with the visual interpreted data.

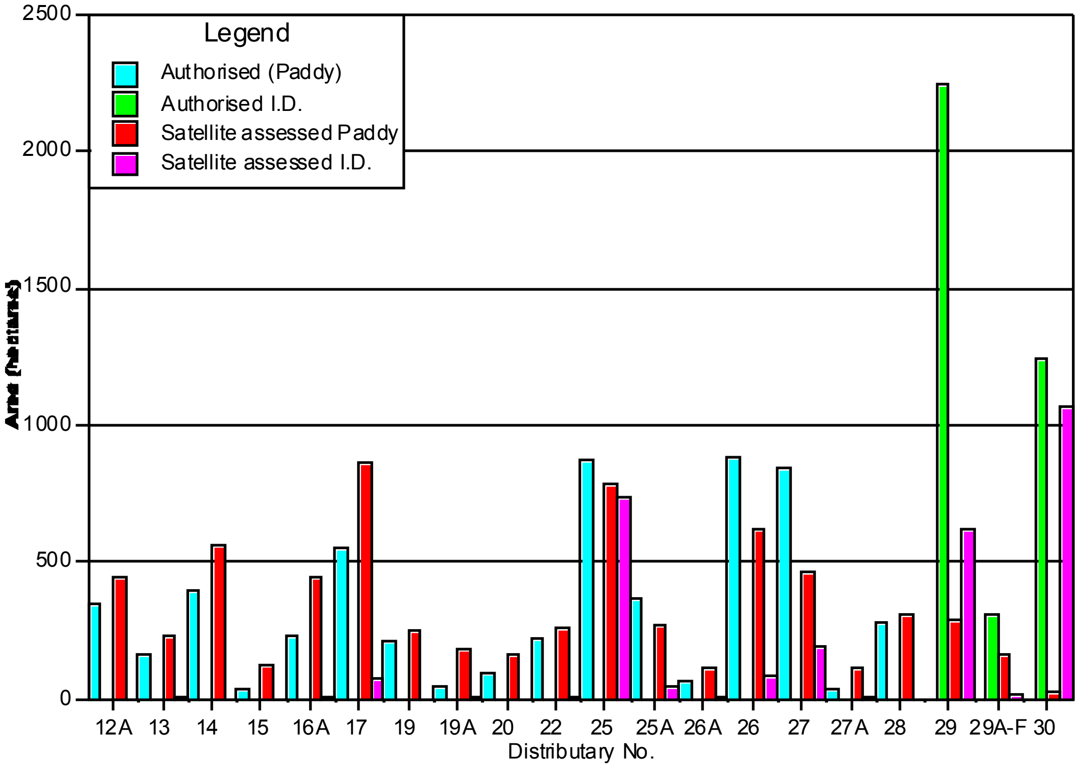
5.1.3 Irrigation Intensities

Table 2 shows the distributary-wise irrigated areas as assessed from satellite and the field agencies during Kharif 1992 season. It can be seen that the satellite assessed irrigated areas far exceed the authorised areas (and the field reported areas). The excess (predominantly wet) cultivation is concentrated in the head reaches and there is a shortfall in the tail end areas. Similar observations were made for other seasons [3,4]. In Table 2, Irrigated Dry crop is denoted by I.D.

5.1.4 Irrigation System Performance Evaluation

An analytical study is conducted for Kharif '92 season to evaluate the irrigation system performance. The daily main canal discharges (at various locations), daily rainfall data in the command area for the Kharif season and the crop acreages estimated from the satellite data have been used for this purpose. The fortnightly crop water requirements for each crop group (Paddy and dry) have been computed taking into account the corresponding crop coefficients, Potential evapotranspiration (PET), effective rainfall, field application and conveyance losses. Based on the locations of various gauges on the main canal, the distributaries have been grouped into five groups. The fortnightly irrigation requirements for different crop groups have been aggregated to determine the corresponding volumes necessary from each distributary group. Initially, fortnightly irrigation requirements for different crops were computed from the areas obtained from the field authorities and these were found to be far below the corresponding water releases. Figure1 shows the monthly irrigation requirements computed from the areas obtained using satellite data as well as field reported areas and fortnightly water releases for each distributary group during Kharif 1992. It can be observed from Figure 1 that the irrigation demands of the satellite assessed areas are more or less fulfilled by the corresponding water releases. This type of analysis is carried out for other seasons to identify the areas with water deficit and the field authorities were notified accordingly for better water regulation [5,6].

Fig. 1. Irrigation Intensities



5.1.5 Role of GIS

In RDS command a two seasonal crop, Cotton, is cultivated which extends from Kharif season to Rabi season. On the Rabi season imagery the two seasonal crop and the irrigated dry crops grown in that season had very close spectral signatures making it difficult to separate them. Geographic Information System (GIS) is used for delineation of Cotton from irrigated dry crops in the Rabi season. From the interpreted Kharif imagery, Cotton crop area is demarcated and developed as GIS layer which is overlaid on Rabi imagery (after registration) to delineate it from the other dry crops grown in that season.

GIS is also used for separation of crops irrigated from other sources such as Lift irrigation and Tank irrigation. For this purpose, base map of the command area, consisting of command areas at the distributary level, is digitised. For some distributaries the command area is not clearly available in the map. Only contour information at 10 m intervals was available. GIS is used to interpolate and prepare much closer interval contour maps and the information was used to identify command areas of such distributaries. Along with this, the recommended cropping pattern for Kharif and Rabi seasons for both wet and dry crops is digitised to identify any violation areas (such as wet crop cultivation in dry crop zones, cultivations in the zones to be left fallow etc.)

Table 2. Distributary-wise Crop-group Areas (in hectares) during Kharif 1992

Distributary Number	Authorised areas		Field reported areas		Satellite assessed areas	
	Paddy	I.D.	Paddy	I.D.	Paddy	I.D.
12A	352	---	340	---	448	2
13	165	---	150	---	227	4
14	393	---	340	---	561	2
15	38	---	38	---	126	---
16A	227	---	215	---	449	6
17	552	---	600	---	865	73
19	208	---	138	70	255	---
19A	50	---	35	15	178	4
20	93	---	96	---	163	---
22	218	---	212	8	257	8
25	873	---	485	395	791	734
25A	367	---	482	102	266	50
26A	62	---	68	6	111	8
26	885	---	451	292	619	84
27	842	---	326	332	460	193
27A	37	---	32	---	117	6
28	284	---	105	69	310	1
29	---	2,243	283	1,194	285	618
29A-F	---	310	106	65	160	21
30	---	1,244	20	628	30	1,071

6. FUTURE OF REMOTE SENSING UTILISATION

6.1 Future Missions

The present remote sensing missions are being continued into the near future with follow-up satellites in each of the NOAA (National Oceanographic & Atmospheric Administration, USA), Landsat (Land resources Satellite of USA), SPOT (France) and IRS (Indian Remote Sensing) series. They will provide continuity of data supply by replication of existing sensors and evolutional enhancements to current sensor designs with the addition of wave bands or increases in spatial resolution as shown in Table 3 [7].

Landsat-7 will carry the Enhanced Thematic Mapper (ETM+) which has a panchromatic channel at 15m spatial resolution. Spot-4 and Spot-5 will carry the High Resolution Visible and Infrared Radiometer (HRVIR) increasing the spectral coverage over the HRV sensor, with an additional waveband at 1.6 μm and a new sensor with identical spectral wavebands with a 1.1 km spatial resolution (VEGETATION). ERS-2 will carry a replicate of the C-band SAR (Synthetic Aperture Radar) on ERS-1 (Earth Resources Satellite) of European Space Agency (ESA), but also an enhanced version of the ATSR (ATSR-2) providing additional wavebands in the visible and near infrared. Completely new single mission satellites are also being planned such as the Canadian RADARSAT which will carry a C-band SAR with a standard 25 m spatial resolution and a variable look-angle capability.

Central to these developments is the Earth Observing System (EOS), a long-term, multidisciplinary international programme aimed at the collection of information on a wide range of terrestrial, oceanic and atmospheric processes. The EOS mission is a cooperative effort between NASA, ESA and Japan and will involve a series of polar platforms each carrying a complementary range of remote sensing instruments combined to address specific missions.

Table 3. Remote Sensing Missions up to year 2000 for Land Applications

Mission	Instrument	Number of wave bands	Waveband location[1] vis nir swir tir mw	Spatial Resolution	Off-nadir view	Launch year
IRS-1C	PAN LISS III WiFS	1 4 2		5.8 m 23.5 m 188 m	Yes No No	1996
IRS-P2	LISS-II	4		36.25 m	No	1996
NOAA-J	AVHRR/2	5		1.1km nadir	No	1995
ERS-2	AMI SAR ATSR-2	1 8		30m C-band 1km at nadir	NA Yes	1995
Radarsat	SAR	1		9-100 m	v'ble	1995
ADEOS	POLDER AVNIR	8 5		6x7km nadir 8-16 m	Yes No	1996
NOAA-K	AVHRR/3	6		1.1km nadir	No	1996
IRS-1D	PAN LISS III WiFS	1 4 2		< 10 m 23.5-70.5 m 188 m	Yes No	1997
NOAA-L	AVHRR/3	6		1.1km nadir	No	1997
SPOT-4	HRVIR vegetation	4 or 1 4		20 m & 10m 1km at nadir	Yes No	1998
Envisat-1	MERIS ASAR AATSR	15 1 8	(2.5-30nm)	300 or 1200m 30-1000 m 1 km	No NA Yes	1998
Landsat 7	ETM +	7 or 1		30; 60;15m	Yes	1998
EOS-AM1	MODIS MISR ASTER	36 4 14		250, 1000m 240m nadir 15-90 m	No 9angl p'tabl	1998
NOAA-M	AVHRR/3	6		1.1km nadir	No	1999

[1] Waveband location: vis - Visible; nir - Near Infrared; swir - Shortwave Infrared; tir - Thermal Infrared; mw - Microwave.

6.2 IRS-1C WiFS data

To create a data base on cropping system of an area, one needs to monitor the area repetitively within a year to account for all crops, their growth stages and the fallow periods. It will become possible to derive accurate information on cropping pattern, crop rotation, crop duration, progress of harvest, crop growth and crop condition profiles using multi date data which is possible with sensors having high temporal resolution. IRS-1C Wide Field Sensor (WiFS) data with spatial resolution of 188 m and high temporal resolution of 5 days provides an ideal opportunity to monitor irrigation system performance more effectively. WiFS has two spectral bands in red and NIR regions. In addition IRS-1C has Panchromatic sensor with a spatial resolution of 5.8 m which is the highest spatial resolution civilian earth observing system in the world [8].

6.3 Microwave Remote Sensing

There will be loss of information if there is any cloud cover on the imagery as the optical sensors can't penetrate through the clouds. Also the information under cloud shadows will be incorrect. It may so happen that, it may not be possible to get even one cloud free imagery in the entire crop season during monsoon period. Due to this reason, monitoring of the irrigated area during monsoon periods will not be possible for some seasons. Microwave remote sensing provides answer to this problem as microwave sensors have the cloud penetration capabilities. Earth Resources Satellite, ERS-1 SAR, is the first satellite launched by European Space Agency for microwave remote sensing. Interpretation of microwave image is different from interpretation of optical data and there is scope for further research in this area [9].

6.4 Global Positioning Systems (GPS):

GPS is a consortium of 24 satellites orbiting around the globe in such a way that at any time, any point on the Globe is under the foot-print of three or four satellites. As can be seen from the knowledge of Geodesy, with the help of three celestial bodies (here satellites), one should be able to identify his location properly. The fourth satellite helps in identifying the elevation of any specific point on the Globe with respect to Mean Sea Level (MSL) or any other datum. So with the help of GPS, it is possible to know the Latitude, Longitude and Elevation of any point on the Globe. This will go a long way in collecting the Ground Truth and locating them properly on the Satellite image (With very high spatial resolution).

7. Conclusions

Satellite remote sensing plays a vital role in Irrigation management. Various applications of Satellite remote sensing techniques for Irrigation management like, Crop acreage, crop condition, crop yield and irrigation canal system performance evaluation were discussed and demonstrated through a case study. Role of Geographic Information System (GIS) for irrigation management was demonstrated. Further scope for remote sensing applications with the future remote sensing missions were also discussed. It is concluded that the remote sensing should be utilised more effectively for national agriculture monitoring.

Acknowledgements

The work on the case study was carried out by the author, while working as a Scientist in the Water Resources Group (WRG) of National Remote Sensing Agency (NRSA), Hyderabad, along with Mr J Harikishan, under the able leadership of Dr S.T. Chari, Group Director, WRG, NRSA. The project was partly financed by Department of Space. Author wishes to place on record his sincere thanks to water resources group, NRSA, for the cooperation during his stay there.

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