

REMOTE SENSING IN AGRICULTURE

Proceedings of the Symposium on Remote Sensing in Agriculture

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Edited by

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PREFACE

The Ahmedabad Chapter of the Indian Society of Remote Sensing (formerly known as Indian Society of Remote sensing and Photo Interpretation) is the first and the largest chapter (more than 20 per cent of the total membership) of the Society. The Symposium on "Remote Sensing in Agriculture" was organised by the Chapter at the Space Applications Centre (SAC), Ahmedabad in February 1985. Director SAC had kindly provided all the facilities for holding the Symposium. It had attracted participants from many other states as well.

The theme of the Symposium " Remote Sensing in Agriculture" was chosen because agriculture forms the backbone of the Indian economy and provides livelihood to majority of the population. The remote sensing technology faces the toughest challenge in providing information for the agriculture sector all over the world. In fact, practically every orbiting remote sensing satellite launched till date, starting from the Landsat 1 launched by US in July 1972 to IRS-1A launched by India on March 17, 1988, has been designed primarily to cater to the needs of information in agricultrue.

The symposium had five sessions encompassing remote sensing technology as well as applications. These were on:

- i. Sensors
- ii. Data Products and Information Systems
- iii. Crop Production, Yield Modelling and Crop Stress
- iv. Land Use and Land Degradation
- v. Soil Mapping and Soil Moisture

A panel discussion on "Development and Management of Agricultural Resources in Gujarat" was also organised to focus attention on the problem areas faced by agricultrue in the state of Gujarat to see if remote sensing could aid in finding solutions.

Out of the papers presented six review talks and twenty four contributed papers were selected for inclusion in this volume.

I must thank the Steering Committee for the trust reposed in me by asking me to edit the proceedings and also for the indulgence shown for the delay which was caused by unforeseen technical problems.

The volume was made possible by the unstinting assistance by Shri N. Ravi in editing and Shri N.H. Solanki in typing. It is their enthusiasm, in spite of the technical problems, which finally accomplished the task.

It is hoped that this volume would be found to be

useful in apprising the readers about the developments vis-a-vis applications of remote sensing in agriculture in the country. It should , however, be mentioned that as far as crop census is concerned, rapid advances have been made under the Indian Remote Sensing Satellite Utilisation Programme since the Symposium.

June 15, 1988

Baldev Sahai

ACKNOWLEDGEMENTS

The Ahmedabad Chapter of the Indian Society of Remote Sensing places on record its deep sense of gratitude to the Director, Space Applications Centre for not only providing facilities for holding the Symposium but also for extending the Library printing facility to bring out the proceedings of the Symposium.

We are indeed grateful to all the co-sponsoring organisations i.e. National Dairy Development Board, Narmada Development Department (Dept. of Irrigation) , Govt. of Gujarat, Indian Space Research Organisation and Gujarat Water Resources Development Corporation.

Steering Committee under the Chairmanship of the then Chapter Chairman, Shri O.P.N. Calla deserves special thanks for chalking out a balanced programme and providing whole-hearted support in making the Symposium a success.

We express our gratitude to Dr. Baldev Sahai, currently the President of the Indian Society of Remote Sensing, who kindly agreed to edit the proceedings, for his tireless efforts in bringing out this volume which, we hope, will find enthusiastic appreciation by the remote sensing community.

V. TAMILARASAN
Organising Secretary

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OPTICAL SENSORS FOR AGRICULTURAL RESOURCES SURVEY - AN OVERVIEW

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ABSTRACT

Recording of observations of the earth's surface from an orbiting spacecraft began in early 1960 with the launch of first U.S meteorological satellite TIROS. However, remote sensing as we conceive today started with the launching of the first Earth Resources Technology Satellite (now known as LANDSAT-1). The present maturity of remote sensing for earth resources survey is primarily due to the advancement in sensor technology and digital image processing. In this paper we shall review the evolution of optical IR (OIR) sensors, their present status and future prospects, with special reference to the requirements for agricultural resources survey.

An important question in the design of a remote sensor is "What is the optimum set of specifications for a multispectral camera?". Unfortunately, there is no unique answer, since the optimum parameters depend on the application. Even if we identify an ideal set of parameters, the realisation of the combination of these parametric values (i.e. IFOV, FOV, number of spectral bands, spectral bandwidth, signal to noise ratio etc.) in a multispectral sensor system is a complex problem due to the strong interrelationship these parameters have with one another. Implications of some of the major sensor parameters for proper utilisation of data are discussed.

Though data from LANDSAT MSS have been extensively used for agricultural resources survey, the sensor parameters were not optimal. Based on the experience of LANDSAT MSS and series of experiments conducted to enhance remote sensing capability, the thematic mapper specifications were evolved. The SPOT system planned to be launched by the end of 1985 has some specific advantages which are not available in the earlier systems. Some of the future OIR sensor systems which are already planned for launch and are under study are discussed with special reference to their application for agricultural resources surveys.

INTRODUCTION

Recording of observations of the earth's surface from an

orbiting spacecraft began in 1960 with the launch of first U.S meteorological satellite TIROS. However, remote sensing as we conceive today started with the launching of the first Earth Resources Technology Satellite-1 (now known as LANDSAT-1). The present maturity of remote sensing for earth resources survey is primarily due to the advancement in sensor technology and digital image processing. In this paper, we shall review the evolution of optical IR (OIR) sensors, their present status and future prospects, with special reference to the requirements for agricultural resources survey. We shall first consider the various system parameters for an optimal remote sensor.

SENSOR SYSTEM PARAMETERS

An important question in the design of a remote sensor is "What is the optimum set of specifications for a multispectral camera?" Unfortunately, there is no unique answer, since the optimum parameters depend on the application. Even if we identify an ideal set of parameters, the realisation of the combination of these parametric values (i.e. IFOV, FOV, number of spectral bands, spectral bandwidth, signal-to-noise ratio etc.) in a multispectral sensor system is a complex problem due to the strong interrelationship these parameters have with one another. We shall consider some of these parameters which are usually debated.

Spatial Resolution

'Spatial resolution' is a term talked about maximum, less understood and most confusing. Generally, the spatial resolution is understood as the projection of a detector element (which defines the instantaneous field of view, IFOV) on to the ground. Based on this definition the spatial resolution of LANDSAT MSS is 80 m, thematic mapper 30 m, SPOT (multispectral channel) 20 m, and IRS LISS-II 36 m. The question is: are we justified in comparing these values in relation to classification without considering other sensor parameters? Since this debate cannot be resolved in the present lecture, we shall for the present discussion consider the spatial resolution as defined earlier.

The spatial resolution at which data are acquired has two effects on the ability to identify and assess vegetation. The first one relates to the ability to accurately make mensuration and the second relates to the classification accuracy. It is obvious that the accuracy of measurement of an area will depend upon the accuracy of locating the boundary. Since it is not possible to locate better than a fraction of a pixel, larger the pixel, more will be the error in the area estimation. The percentage error will obviously be higher for plots of smaller area. As an example, let us consider a field $1000 \times 1000 \text{ m}^2$. If one has 80 m pixel, then there is an uncertainty as to the actual location of each end of a line. With modern techniques even if we assume that we locate pixels to $1/4$ of a pixel

accuracy, the area can be measured as $(1000 \pm 20)^2 \text{ m}^2$, which yields an error of more than 4%.

As for classification accuracy, one important aspect is the contribution of boundary pixels. It is obvious that as resolution improves, pure centre pixels increase in comparison to pixels containing boundary. Thus, the boundary error gets reduced with improved resolution. However, the final accuracy for classification cannot be improved by going on reducing the pixel size. As the pixel size is reduced below a certain level, the scene noise starts affecting accuracy of classification. The scene noise in the present context refers to the variability within a given land cover category. This variability tends to lower the classification accuracy. The study carried out by Markham and Townshend (1981), shows that land cover classification accuracy degrades as the pixel size is decreased below a certain value. This threshold value is dependent on the type of land cover. However, classification of boundary pixels is difficult since they are not similar to either of the class which they represent. Hence, improvement in classification is expected with improved resolution since as the pixel size is decreased, the proportion of pure centre pixels increases in comparison to boundary pixels. Though it is generally felt that for agriculture survey, resolution better than that of MSS is necessary, an optimum resolution is yet to be established.

Spectral Band Selection

There are three aspects to the spectral band selection: (i) the location of the central wavelength, (ii) the bandwidth, and (iii) the total number of bands. Let us first briefly review the reflection characteristics of the vegetation. From a leaf, only a part of the incident energy is reflected. The remainder is either absorbed or transmitted. Figure 1 shows the reflectance, absorptance and transmittance spectra for a typical plant leaf. We shall first consider the reflective region (0.35 - 2.5 micrometers) of the electromagnetic spectrum. This region can be divided into six parts, based on the physical processes involved in the interaction of electromagnetic radiation.

- 1) 0.35-0.5 micrometer region is characterised by strong absorption by chlorophyll.
- 2) 0.5-0.62 micrometer region which results in a higher reflectance than the adjacent blue and red which our eyes perceive as 'green'.
- 3) 0.62-0.7 micrometer region characterised by a strong chlorophyll absorption.
- 4) 0.7-0.74 micrometer region characterised by the transition from the strong chlorophyll absorption to the high levels of reflectance in the IR.
- 5) 0.74-1.3 micrometer region is characterised by high levels of reflectance. The high IR reflectivity of leaves appears to be caused by their internal cellular structure, which allows about 40-60% of the incident radiation to be

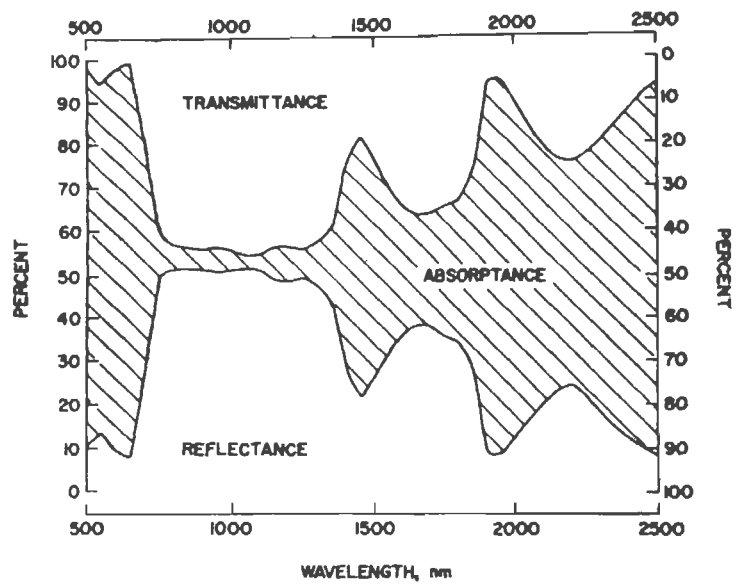


Fig. 1 Amount of transmittance, reflectance and absorptance from healthy green foliage (Gausman et al 1971)

scattered upwards as reflected radiation, whereas the remainder is scattered downwards.

- 6) 1.3-2.5 micrometer region is characterised by strong absorption by water present in the vegetation.

In summary, reflectance from green leaves typically shows in the visible part of the spectrum (0.4 to 0.7 micrometer) a low reflectance (about 10%) with a peak at about 0.55 micrometer in the green region, thereafter the reflectance increases to about 50% in the infrared region (0.7 to 1.3 micrometer) and then it decreases to a low value at about 2.7 micrometers.

Reflectance properties of single leaves, though basic to understanding the reflectivity of the vegetation canopy in a field situation, cannot be applied directly, without modifications for a vegetation canopy. There are both quantitative and qualitative differences between the data obtained from a single leaf and that observed from an agricultural field. This is because when we look at the gross effect of an agricultural field, reflectance pattern is modified by the variation in leaf orientation, shadows, illumination angle and soil background. Work of Jackson et al (1979) on the wheat field shows that the spectral reflectance can be highly dependent on solar elevation and azimuth, and even row direction. In addition to all these variabilities, the atmosphere modifies the reflectance pattern. Keeping all these factors in mind, we have to select spectral bands of the sensor at the appropriate place within the electromagnetic spectrum.

Apart from the position of the bands the bandwidth also plays an important role. It is felt that the agricultural classification accuracy can be enhanced by using narrow spectral bands. For example, a study shows a 0.02 micrometer bandwidth around 0.75 micrometer will be able to discriminate the alfalfa and wheat.

Repetitivity

It is generally felt that for proper identification of crop species, it is not adequate to look for distinct spectral characteristics of the crop under cultivation. Since spectral reflectance differences among healthy crops seem to be quite small at least in the visible and near infrared regions, the crop can be distinguished better if data are acquired at adequate intervals, establishing the time history of the spectral reflectance of the crop at various growing stages. In addition, crop condition assessment requires frequent observations. The revisit interval varies from a few days to a couple of weeks, depending on the specific application.

There are many other parameters to be defined for a sensor system, the above three parameters, namely spatial resolution, spectral bands selection and repetitivity seem to be most

crucial for agricultural remote sensing. Let us now consider some of the remote sensor systems which have been used in the past and planned for the future.

SENSOR SYSTEMS

Photographic Cameras

Photographic cameras are the oldest and probably the most widely used sensors. They have been successfully used from aircraft, balloons, and from manned and unmanned spacecrafts. Though there are different types of cameras, frame cameras are used most commonly as remote sensors. Among frame cameras, multiband camera plays the most important role for resources survey. Multiband camera enables simultaneous photography of a ground scene in more than one spectral band. This can be achieved generally by using different single band cameras and very accurately aligning them so that all the images are geometrically registered. In this case, each band will have its own lens, film magazine and the appropriate filters. Alternately multiple optics transfer images in different spectral bands onto a single large photographic film. Films are available with different spectral sensitivity and resolution. The response of black and white film is from about 0.4 to 0.7 micrometer. For infrared imagery films with response extending upto 0.9 micrometer are available. Infrared false colour film has been extensively used for remote sensing. The three emulsions are sensitised to green, red and infrared radiation instead of the usual blue, green and red wavelengths. Thus when the film is exposed, the resulting colour display is different from the natural colours and hence called false colour.

As remote sensors, photographic cameras have a number of limitations. Cameras have a limited spectral response extending only upto 0.9 micrometer. The middle IR and thermal IR regions which are of great interest cannot be covered with photographic cameras. The dynamic range of the camera, which essentially depends on the film is also limited. Reproducibility of the quality of the imagery depends on the processing of the film which, unless controlled very carefully, renders it difficult to compare different images quantitatively. The data, since not available directly in the electronic form, is not immediately amenable to digital processing which is essential when one wants a large throughput of resources information. In addition, for an unmanned spacecraft, the film has to be ejected out for recovery which complicates the system.

Television Cameras

The first electronic system to take imagery of earth from space is television camera. Starting from TIROS-1 in 1960, vidicon cameras were used in a number of meteorological satellites for routinely viewing the earth for world's weather

studies. The best example of high resolution TV cameras operated in space for resources survey is the Return Beam Vidicon (RBV) used in the LANDSAT series. The Indian experimental remote sensing satellite, Bhaskara-I and II carried a two-band television camera system. Of the two bands, one operated in the 0.54 - 0.65 micrometer region and the other in the 0.75 - 0.85 micrometer wavelength region. Each picture frame covers about 400 x 400 km with a spatial resolution of about 1 km.

Multispectral imagery is produced in LANDSAT and Bhaskara by using separate camera tubes for each band and selecting the spectral band using appropriate filters. The principle disadvantage for such a system is the difficulty of registration in all the bands. Even if one can optically align them accurately, difference in electro-optics and possible drift in the scanning electronics produce misalignment. For large number of spectral bands, the total system becomes very cumbersome with large size and volume.

TV camera has serious limitations as a useful remote sensor. The limitations of TV cameras include limited spectral response, low resolution, poor dynamic range, poor radiometric accuracy and geometric distortions. On the whole, it is unlikely that TV imaging systems will be able to satisfy the user requirements for multispectral imaging. It is worth noting that in LANDSAT-3, the RBV is used in a panchromatic mode.

Optical-Mechanical Scanners

Most of the limitations seen with photographic and TV imaging system are overcome in optical-mechanical scanners, though they have their own limitations. Typical examples of airborne MSS include the 11-channel M²S developed by Bendix (USA) and the six-channel MSS developed at ISRO (India). ISRO MSS has a combination of beam splitters and filters for spectral selection. This has the advantage that any set of desired spectral bands can be selected with appropriate filters and detector combinations.

The most widely used sensor for remote sensing is the MSS on board LANDSAT series. LANDSAT-1 MSS has four spectral bands in the 0.5 to 1.1 micrometer region. LANDSAT-2 and 3 MSS have an additional band in thermal IR.

MSS on-board LANDSAT consists of an RC telescope with 23 cm aperture. The cross-track scan is achieved by an oscillating mirror at a frequency of 13.6 Hz. In order to reduce the scan rate (thereby increasing the dwell time) 6 detectors are used in one band, for the visible and near infrared. Thus for each scan, 6 lines are generated per spectral band. The IFOV is defined by the ends of optical fibres arranged in a 6 x 4 matrix at the focal plane of the telescope. The light conducted through the fibres are detected by photomultipliers/photodiodes with appropriate filters. The fifth band covering the

thermal-infrared is relayed from the telescope focal plane and reimaged onto a mercury-cadmium-telluride detector which is cooled by a radiation cooler. The detector outputs are suitably amplified, multiplexed and either transmitted or recorded on a high density tape recorder. MSS provides a spatial resolution of about 80 x 80 m with a swath of 185 km from the 904-km altitude. The important parameters of MSS are given in Table 1.

Due to various technical problems, there is a limit to which the spatial resolution, spectral resolution and sensitivity of an optical-mechanical scanner can be improved. The best improvements one can achieve with the line scanners have been probably achieved with the thematic mapper (TM) carried on-board LANDSAT-4. Thematic Mapper provides 7 narrow spectral bands covering visible, near infrared, middle infrared and thermal infrared spectral regions. TM provides 30 m resolution in the visible, near and middle infrared bands and 120 m resolution in the thermal-infrared from the orbiting altitude of 705 km. Apart from the improved spatial and spectral resolutions, TM provides a factor of two improvement on the radiometric sensitivity for which TM uses 16 detectors per band (against 6 per band in MSS), and weight and power consumption is about 4 times that of MSS. The principal applications of TM spectral bands and the radiometric resolution are given in Table 2.

ADVANCED REMOTE SENSORS

Linear Imaging Self Scanning Sensors (LISS) are planned for most of the future high-resolution OIR systems. Unlike the mechanical scanning system, these sensors use an array of solid state devices. The array may be made of photodiodes, phototransistors or Charge Coupled Devices (CCD). In a remote sensing system using LISS, the optics focusses a strip of terrain in the cross-track onto the sensor array. The image from each detector is stored and shifted out sequentially to get a video signal, corresponding to one line in the cross-track direction. The motion of the spacecraft produces successive scan lines, thereby giving a two-dimensional picture. The resolution primarily depends on the number of photodetectors available in a linear array and the required swath. Remote Sensing Satellite planned by France, Japan and India will carry such solid state sensors.

The French satellite called SPOT will carry two high resolution instruments designed to operate either in the panchromatic mode or multispectral mode. Each instrument has a swath of 60 km. They are mounted on the satellite to give a combined swath of 110 km. In the multispectral mode the instrument has three spectral bands with a spatial resolution of 20 m. In the panchromatic mode the instrument operates in the 0.51 to 0.73 micrometer with a spatial resolution of 10 m. One of the unique features of the SPOT instrument is its

Table 1
LANDSAT MSS Specifications

Optics	229-cm Ritchy-Chretien with 10.16 cm secondary f/3.8		
Scan Method	Oscillating mirror $\pm 2.9^{\circ}$ at 13.6 Hz with 45% active scan		
No.of bands	5		
No.of detectors	6 per band for bands 1 to 4, and 1 for band 5		
Performance characteristics/detectors			
Band	Wavelength (micrometer)	S/N(mw/cm ² /sterad)	Detector
1	0.5 - 0.6	113 at 2.48	PM
2	0.6 - 0.7	86 at 2.00	PM
3	0.7 - 0.8	72 at 1.8	PM
4	0.8 - 1.1	123 at 4.60	Si PD
5	10.4 -12.5		HgCd(Te)
IFOV	86 micro-rad (bands 1-4) 276 micro-rad (band 5)		
MTF	0.42		
Band-to-band registration	50 m (with ground processing)		
Data rate	15 MBPS		
Weight	64 kg		
Power	55 W		
Calibration	Halogen lamp, skylight		
Quantisation	6 bits		

Table 2
TM Spectral Channels

Band	Spectral range (micrometer)	Radiometric resolution NEΔρ (%)	Principal applications
1	0.45 to 0.52	0.8	Coastal water mapping, soil/ vegetation differentiation, Deciduous/coniferous differentiation
2	0.52 to 0.60	0.5	Green reflectance by healthy vegetation
3	0.63 to 0.69	0.5	Chlorophyll absorption for plant species differentiation
4	0.76 to 0.90	0.5	Biomass surveys, water body delineation
5	1.55 to 1.75	1.0	Vegetation moisture measurement, snow/cloud differentiation
6	10.4 to 12.5	0.5 K NETD	Plant heat stress measurement Other thermal mapping
7	2.08 to 2.35	2.4	Hydrothermal mapping
NEΔρ	=	noise equivalent reflectance	
NETD	=	noise equivalent temperature difference	

capability for offnadir viewing. This off-nadir viewing capability covers a range of $\pm 27^\circ$ relative to the vertical in steps of 0.6° . This allows the instrument to image a point within a strip extending 475 km to either side of the satellite ground track. Without off-axis nadir viewing capability, the revisit time for any given region is 26 days. However, because of the off-nadir viewing a specific region can be observed with a period ranging from 2 to 5 days, thus enabling more repetitive observations than possible with any of the earlier satellite missions. Another important possibility of off-nadir viewing capability is that of recording stereoscopic pairs of images of a given scene. This is possible since the same region of the earth can be viewed with different view angles on different days by appropriately tilting a front mirror. The main specifications of the HRV instrument are given in Table 3. The SPOT satellite is scheduled for launch by end 1985/early 1986.

Japanese Marine Observations Satellite (MOS-1) developed by NEC for the National Space Development Agency of Japan (NASDA) carries a CCD camera. The camera is capable of providing a spatial resolution of 50 m in the four spectral bands of the visible/NIR with a swath of 100 km. Two such identical cameras give a combined swath of about 200 km.

Indian Remote Sensing Satellite (IRS-1) is planned to have two types of CCD cameras; one with a spatial resolution of 73 m (called LISS-I) and the other with a spatial resolution of 36.5 m (called LISS-II). LISS-I camera has a swath of 148 km and each LISS-II camera has a swath of 74 km. The two LISS-II cameras are aligned on the spacecraft so as to provide a combined swath of 145 km. The characteristics of IRS cameras are given in Table 4. In choosing IRS spectral bands, experience gained from the joint experiments with various users have been taken into account. The IRS bands have been chosen so as to avoid, as far as possible, atmospheric absorption regions in the pass band of the cameras. Main characteristics of IRS cameras are given in Table 4.

FUTURE OPTICAL INFRARED SENSORS

Most of the future sensors planned, use CCDs because of their unique capability to provide better spatial, spectral and radiometric resolution. However, currently CCD cameras are limited for use in the visible and in the near infrared. A lot of research is on the way to develop CCDs whose operations can be extended upto thermal infrared.

Some of the future systems under study include Automatic Mapping Satellite System which has got a stereo capability with high spectral and spatial resolution. The experimental LISS camera called Multispectral Resources Sampler (MRS) being developed by NASA for an earth-orbiting spacecraft will provide

Table 3
SPOT Camera Specifications

	Multispectral mode	Panchromatic mode
Spectral bands (micrometer)	0.50-0.59 0.61-0.68 0.79-0.89	0.51-0.73
Instrument field of view	4.13°	4.13°
Ground sampling interval (nadir viewing)	20 m x 20 m	10 m x 10 m
Number of pixels per line	3000	6000
Ground swath width (nadir viewing)	60 km	60 km
Pixel coding format	3 x 8 bits	6 bits DPCM(1)
Image data bit rate	25 M bits/s	25 M bit/s

(1) DPCM (digital pulse code modulation) is a mode of data compression that does not degrade the radiometric accuracy of the image data (256 grey levels).

Table 4
IRS Camera Characteristics

	LISS-I (LRC)	LISS-II (MRC)
Geometric resolution (m) (from 904 km)	73	1/2 LRC
Swath (km)	148	74
Spectral bands (micrometers)		
1.	0.45 - 0.52	0.45 - 0.52
2.	0.52 - 0.59	0.52 - 0.59
3.	0.62 - 0.68	0.62 - 0.68
4.	0.77 - 0.86	0.77 - 0.86
Quantisation (bits)	7	7
Signal to noise ratio	128	128
Sensor MTF		
Band 1	0.40	0.40
Band 2	0.40	0.40
Band 3	0.30	0.30
Band 4	0.20	0.20
Band-to-band registration (pixel)	$\pm 1/4$	$\pm 1/4$

new unique earth survey research capabilities beyond those possible with current sensor systems. The sensor will have a ground resolution of 15 m over a swath of 15 km in 4 bands or 30 km in 2 bands. The MRS can be pointed at $\pm 40^\circ$ in the across-track direction and $\pm 50^\circ$ in the along-track direction. Along-track pointing permits stereo coverage with high resolution and atmospheric correction experiment while across track will provide repeat coverage for every one to three days. In addition the sensor will have very narrow spectral band (20 nm). The desired set of spectral bands can be selected by ground command. MRS also plans to study another dimension in the optical imaging, that is polarisation.

Remote sensing from geosynchronous altitude promises to yield many advantages over sensing from low altitudes. A sensor in geosynchronous orbit extends the scope of remote sensing measurements due to its capability to repeatedly look at a specific region of interest. The difficulty in realising such a system is primarily because of the complexity of having a large telescope system to provide the required ground resolution. Studies are being funded by NASA to design a Synchronous Earth Observation Satellite (SEOS). The SEOS is planned to have three operating modes - earth resources imaging, meteorological imaging and meteorological sounding. A total of 18 spectral bands are planned covering the visible to far-infrared with spatial resolution varying from 100 m to a few km. Such a system, when realised, could collect data on transient phenomena not otherwise observable from a reasonable number of near-earth orbiting satellites or by aircraft. Such a system is expected to set a new trend in optical remote sensing.

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MICROWAVE REMOTE SENSING FOR AGRICULTURAL APPLICATIONS

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ABSTRACT

Remote Sensing of earth resources using airborne and spaceborne sensors is being considered today as one of the major sources of inputs to the National Natural Resources Management System. Though most of the data being used to date is from the optical sensors, active research and experimental projects are being undertaken to make use of the unique capabilities of the microwave sensors for the remote sensing of natural resources. One of their major advantages is the capability to see through the clouds. They can also penetrate the soil and are very sensitive to moisture. These qualities particularly make them attractive for agricultural applications.

The paper briefly reviews the various types of microwave sensors available, brings out the parameters of interest concerning applications in agriculture and highlights the present status of the research and experimental studies being conducted in India and elsewhere in the world in this field.

INTRODUCTION

Remote sensing of the earth resources, using the airborne and spaceborne sensors, is being now considered as a major component of the natural resources monitoring and management system. Though most of the data used to date is from the optical sensors, in the recent past sensors operating in the millimetre wave and centimetre wave regions of the electromagnetic spectrum have also been extensively used for a variety of applications. With the advancement of the technology of signal processing, the resolution achieved at these frequencies is comparable to that of the optical sensors, even from the spaceborne platforms. Further they have the advantage of propagating through the clouds, vegetation and soil cover and are highly sensitive to moisture in the soil and vegetation. They are now being experimented extensively in the fields of agriculture, geology, hydrology, oceanography, meteorology and environmental studies. The ability to collect data at any time of the year makes the microwave sensor highly suitable for

agricultural resources survey.

The present paper briefly describes the various microwave sensors, highlights the results of the several experimental studies (including those conducted at SAC) for agricultural applications and brings out the present status.

MICROWAVE SENSORS

Microwave sensors have certain unique capabilities due to the wavelengths used. The unique capabilities are: propagation through cloud cover, independent of sun's illumination, sensitive to moisture and penetration of soil and vegetation. Table 1 gives the unique capabilities of microwave sensors and compares them with that of the optical sensors for different applications.

Microwave sensors can be classified into two broad categories viz. passive and active sensors. The passive sensors measure the microwave radiation emitted from the target while the active systems provide their own illumination and measure the scattered signal.

Passive Sensors

All natural surfaces emit electromagnetic radiation which is a complex function of the physical properties of the emitting surface. Microwave radiometry is the measurement of this electromagnetic radiation. A passive microwave radiometer is a highly sensitive receiver capable of measuring low levels of radiation. When a scene, such as terrain, is observed by a microwave radiometer, the radiation received by the antenna is partly due to the self emission by the target and partly due to the reflected radiation originating from the surroundings. Through proper choice of radiometer parameters (wavelength, polarisation and viewing angle), it is possible to establish useful relation between the energy received and specific terrestrial or atmospheric parameters of interest. Typical example is the radiometric response in 2-30 cm wavelength range which is strongly influenced by soil moisture content.

Active Sensors

In the case of an active sensor, the sensor illuminates the target with its own energy and receives the back-scattered energy from the target. The scattering parameter of a target or terrain is influenced by the operating frequency, polarisation, look angle, dielectric and conductive properties of the target etc. In addition, the basic property of radar to produce high resolution image and capability to precisely measure the range or altitude, further enhance the capability of the active sensors.

Table 1
Comparison of Active Microwave Sensor and Visible
Region Sensors

Application	Unique capabilities of active sensors	Unique capabilities of visible region sensors	Capabilities shared by both sensors
1. Crop identification and assessment	Plant moisture recordable Soil moisture condition may be recordable Temporal behaviour can be recorded on timely basis	Spectral reflectance data	Canopy cover Areal extent Computer compatible data
2. Soil moisture determination	Vegetation and surface can be penetrated Moisture changes on diurnal cycle may be recordable Temporal behaviour can be recorded on timely basis	No quantitative capability	Vegetation response to soil moisture change Computer compatible data
3. Soil type and property	Vegetation and surface can be penetrated Dielectric characteristic may be recordable Soil moisture retention characteristics may be recordable Temporal behaviour on vegetation can be recorded on timely basis	Soil colour	Vegetation identification for soil type mapping Computer compatible data

There are different types of active sensors for different applications. The active sensors used for agricultural applications are: 1) Side Looking Radar, and ii) Scatterometer

Side Looking Radar (SLR)

Side Looking Radar (SLR) is an imaging radar used traditionally for reconnaissance applications. However, it has tremendous application potential for remote sensing of natural resources. Though real aperture SLR has fine resolution in the across-track direction, the resolution in the along-track direction is limited by antenna dimensions, specially at very high ranges. In order to overcome this limitation, synthetic aperture concept is used. In this case, the amplitude and phase information of the target, as they traverse the beam in the along-track direction, is received and processed to achieve very fine along-track resolution. By this technique, the along track resolution achievable is $L/2$ where L is the length of the antenna and the resolution is independent of the range.

Scatterometer

A radar scatterometer is a class of radar used to measure precisely the scattering coefficient of the targets. They operate either in pulse or Frequency Modulated-Continuous Wave (FM-CW) mode. Also they are calibrated to make absolute radar cross section measurements.

Scatterometers operating at short ranges from platforms can be used for fundamental studies and to provide ground truth data for airborne and spaceborne systems. By carrying out controlled measurements of scattering coefficients of various targets like crops, vegetations, soil etc. at different frequencies, polarisations and incident angles, it is possible to arrive at appropriate sensor parameters.

PARAMETERS OF INTEREST

In remote sensing of vegetation and soils, the important factor is the region of the electromagnetic spectrum to be used. Green vegetation absorbs strongly the blue and red wavelengths primarily because of its chlorophyll content.

The microwave return from vegetation is primarily influenced by the roughness (crop morphology) and dielectric properties rather than the cellular and molecular structure of the plants. Thus the determination of crop species, crop cover, leaf area and crop vigour by microwave remote sensing depends on the effects of these factors on the crop structure and/or dielectric properties. Crop vigour can be affected by many factors e.g. overgrazing, nutrients, drought, flooding, disease

and insects. One of the primary factors affecting agronomic production is the plant-water deficit. Slight changes in plant-water content can cause significant decreases in growth and production. Some plant species change leaf orientation and hence basic geometry during periods of water deficit. Such changes in structure may be more readily detected by microwave than by visible or near-IR sensors. Dielectric properties of the crops depend primarily on water content. Therefore, if small changes in dielectric properties of the crop can be detected, microwave sensors may prove valuable in detecting water deficits and the onset of disease and insect damage. Extreme drought, disease and insect damages would certainly be detectable because of leaf loss and consequent large changes in both crop morphology and dielectric properties. The most important advantage of microwave sensing for agriculture is the all-weather capability and so data can be gathered in time at specific growth stages of plants.

Further the unique penetration capabilities of microwave systems has made it possible to carry out applications related to soil moisture. Measurement of soil water content would allow the development of a soil moisture index that could be used as input to watershed, runoff and crop-yield models. The primary need for soil-moisture measurement over large areas stems from a desire to improve prediction models for water resources and crop yield. Crop yield models are vital to improving timely estimates of world food production.

PRESENT STATUS OF APPLICATIONS

Several studies have been conducted using both passive and active sensors for a variety of applications in the field of agricultural sciences. It has been fairly well established by these studies that measurement of soil moisture could be effectively carried out by microwave sensors and optimum radar parameters for this application has been derived by Ulaby et al (1983). However, these experiments have been conducted under controlled conditions. Demonstration in an operational situation is yet to be established. ERS-1, the European Remote Sensing satellite to be launched in 1989 with C-band SAR will provide an opportunity to do that. Similarly, crop classification and crop growth monitoring also has been demonstrated by many experimenters. Certain optimum radar parameters also have been derived. This, once again, needs to be demonstrated in an operational situation. The major plus point is that the data could definitely be gathered at the desired time, which is very important for agricultural applications by microwave sensors, as they are not affected by weather conditions. Following sections will briefly describe the typical studies conducted and summarise the conclusions drawn.

PASSIVE MICROWAVE REMOTE SENSING

The first satellite-borne microwave radiometer for agricultural applications was flown on-board SKYLAB by NASA, USA. This experiment was designed to determine the feasibility of using the microwave sensors on the SKYLAB satellite for determining the moisture content of the soil. Microwave sensors on SKYLAB made measurement at two different wavelengths in the passive and active modes. Data was collected with an L-band passive radiometer (at 21 cm wavelength) and at 2.1 cm wavelength in both the active and passive modes. For the soil moisture experiment, the L-band radiometer, S194 sensor, obtained measurements from an area 115 km in diameter centred around nadir. Fig. 1 shows the brightness temperature versus soil moisture curve at 21.1 cm wavelength. The relationship between the S193 radiometric temperature and the soil moisture content and scattering coefficient as a function of soil moisture content are shown in Fig. 2. The results of the study using the SKYLAB microwave sensors indicate that it is indeed possible to measure soil moisture over relatively large areas with reasonable precision by the use of microwave radiometers (Engleman et al 1975).

An experiment on remote sensing of soil-moisture content was conducted by Wang et al (1983) over bare fields with radiometers at the frequencies of 1.4, 5 and 10.7 GHz during July-September period of 1981. Three bare fields with different surface roughnesses and soil textures were prepared for the ground-truth acquisition of soil temperatures and moisture content for 5 layers down to the depths of 15 cm. The radiometric measurements were made concurrently. The experimental results show that the effect of surface roughness is to increase the brightness temperature and to reduce the slope of regression between brightness temperature and moisture content. Excellent correlation coefficient of 0.95 was found between brightness temperature and soil moisture content for two smooth fields at all the three frequencies. The slope of regression line for rough fields is appreciably smaller showing the effect of roughness. These results were found to be consistent with the laboratory measurements of dielectric permittivity of soil.

The measurements on wet smooth bare fields give lower brightness temperature at 5 GHz than at 1.4 GHz. However, the real part of dielectric permittivity for a soil-water mixture is somewhat smaller at 5 GHz than at 1.4 GHz which is in contradiction with the measured results. Thus, improvement in the present radiative transfer models call for more experimental observations in order to understand this phenomenon.

The reduction in sensitivity of the microwave brightness temperature to soil moisture content due to vegetation cover was analysed by Ulaby et al (1983), using airborne observations

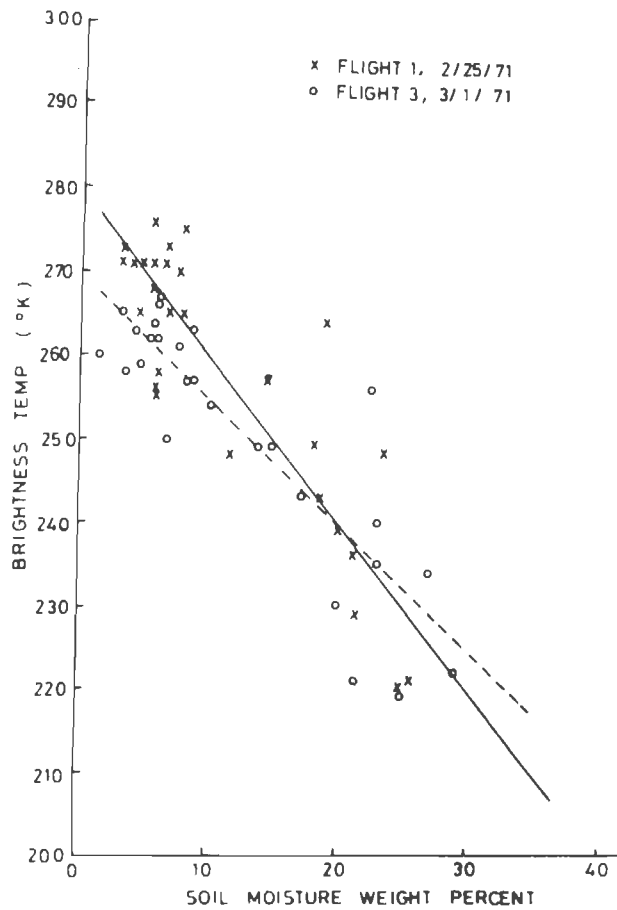


Fig. 1 Brightness temperature at 21.1 cm wavelength vs soil moisture from Phoenix, Arizona (After Engleman 1975)

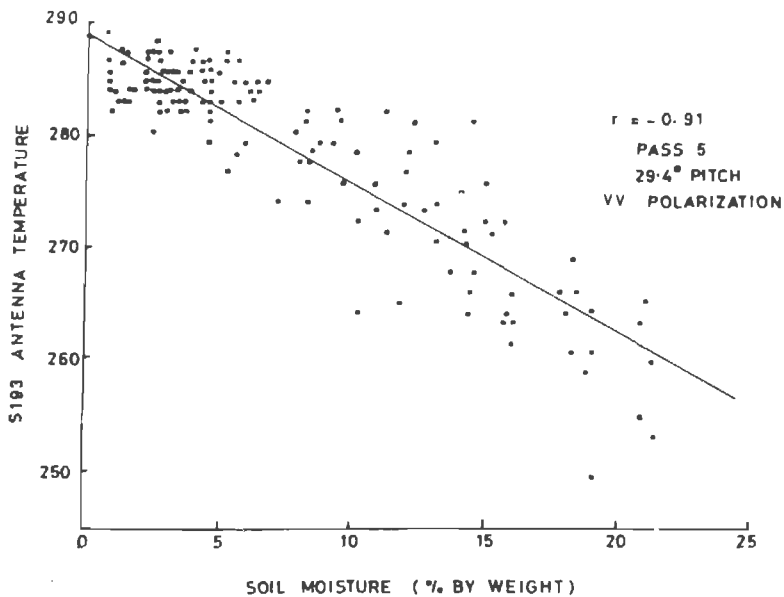


Fig. 2 The S193 antenna temperature as a function of soil moisture content (After Engleman 1975)

made at 1.4 GHz and 5 GHz. The data was acquired during six flights in 1978 over a test site near Colby, Kansas. The test site consisted of bare soil, wheat stubble and fully mature corn fields. The results for wheat stubble fields indicate that the radiometric sensitivity to soil moisture decreases in magnitude with increasing frequency as shown in Fig. 3. The sensitivity reduction factor, defined in terms of the radiometric sensitivities for bare soil and canopy-covered conditions was found to be equal to 0.65 for normal incidence at 1.4 GHz and it increases to 0.89 at 5 GHz. These results confirm previous conclusions that the presence of vegetation cover may pose a serious problem for soil moisture detection with passive microwave sensors.

The radiometric measurements over bare fields and fields covered with grass, soybean, corn and alfalfa were made with 1.4 and 5 GHz radiometer during August - October 1978 at the Agricultural Research Centre test site in Beltsville, MD by Wang et al (1983). The measured results are compared with radiative transfer theory treating the vegetated fields as a two-layer random medium. It is found that the presence of vegetation cover generally gives a higher brightness temperature than is expected from bare soil as shown in Fig. 4. The amount of this excess in brightness temperature increases with increase in the vegetation biomass and in the frequency of the observed radiation. The results of the radiative transfer calculations, which include a parameter characterizing the ground surface roughness, generally match well with the experimental data.

Recent advances in remote sensing of soil moisture include a method for estimating the dependence of the dielectric constant of the soil on its texture; the use of percent of field capacity to express soil moisture magnitudes independently of soil texture; experimental and theoretical estimates of the soil moisture sampling depth; models for describing the effect of surface roughness on the response, verification of the ability of radiative transfer models to predict the microwave emission from soils, and experimental and theoretical estimates of the effects of vegetation on the microwave response to soil moisture.

ACTIVE MICROWAVE REMOTE SENSING

Side Looking Radar

The SEASAT Satellite, launched by NASA in 1978, presented the first opportunity for evaluating some potentially important applications of a satellite-borne SAR system, like monitoring of soil moisture and crop state for crop yield forecasting. The L-band SAR imagery used in the land use studies was acquired by SEASAT in August and September 1978. Only broad crop groupings (i.e. ground crops, root crops and vegetables, grass etc.)

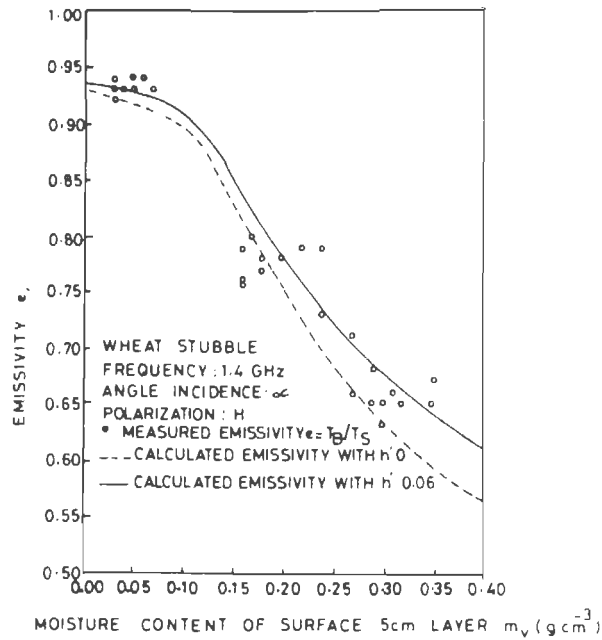


Fig. 3 Measured and calculated emissivity of soil surface covered with wheat stubble at 5GHz

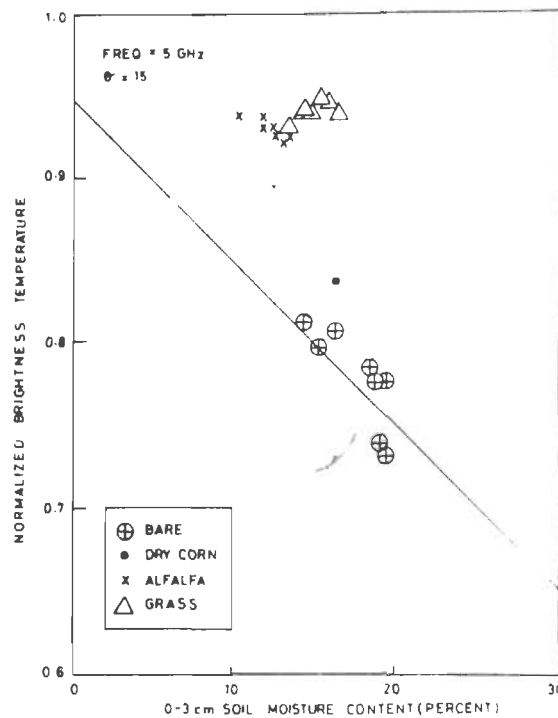


Fig. 4 The normalized brightness temperature vs soil moisture content in the top 0 - 3 cm layer (Schmugge 1983)

could be distinguished from the SEASAT imagery. It has been concluded that a total of six tone/texture units could be consistently recognised on SEASAT imagery (Allan 1983).

For crop classification, the first systematic experiment with airborne SAR systems working in X, C and L bands took place during the European Convair SAR 580 experiment in 1981. One of the major studies carried out by Sleber et al (1983) was the use of SAR images to analyse their potential for agricultural applications including crop identification.

The results from the analysis of images taken over two German test sites prove that differences of the backscattering behaviour of crops are mainly related to the dielectric property of the plants. Similarly, in 1980 a radar measurement campaign was organised in the Flevopolder area in Netherlands by Hoozeboom (1983) using the X-band calibrated radar. Ground measurements were also carried out, and at certain prefixed times, flights were conducted. The optimum flight times had been derived from a simulation study, based on previous measurement. The one-dimensional case, consisting of one flight over the test area at a previously derived optimum flight time gives only 35% correct classification in 7 classes. Multidimensional cases with flights at different dates improve the classification results to over 85%. Table 2 compares the relative backscatter coefficients (relative to sugarbeets) with the ground-based measurements. The small differences in backscatter between the various types of crops clearly demonstrate the need for an accurate radar system which does not show too much speckle.

The results of SAR measurements over Kershaw county, South Carolina, using HH, VV and HV polarisation and two-incidence angle X-band airborne SAR system and over Baldwin County, Alabama, using HH polarisation L-band Shuttle Imaging Radar (SIR-A) have been extensively analysed by Wu (1984). The X-band data indicate higher HH than VV radar return for cypress forest with standing water. Multipolarisation data (HH, HV and VV) help delineate several land-cover types that are difficult to delineate by the single polarisation (HH) data. The L-band data indicate that radar return signal strength is highly correlated with tree height or age for three types of pine forest. The results are summarised in Table 3 and 4.

Scatterometers

A large number of experiments using ground-based, airborne and satellite-borne scatterometers have also been conducted for a variety of applications, primarily to study the variation of backscattering properties with physical characteristics of the targets. Bradley (1981) et al conducted an experiment in 1978, using a partially irrigated area near Colby, Kansas, using NASA C-130 aircraft equipped with two frequency scatterometer operating at 1.6 and 4.75 GHz and radiometers operating at 1.4 and 5.0 GHz. These experiments show that there is an

Table 2
Comparison of Backscatter coefficient in DB for Ground-based
and Airborne Measurements at Horizontal Polarisation and
15 Grazing Angle

		date: 10-6-1980		date: 11-7-1980		date: 12-8-1980	
Crop type	Ground-based measurements	SLAR ground-based measurements		SLAR ground-based measurements		SLAR ground-based measurements	
	absolute	relative to S-beets	absolute	relative to S-beets	absolute	relative to S-beets	absolute relative to S-beets
Sugar beets	-8.0	0.0	0.0	0.0	0.0	0.0	0.0
Potatoes	-9.0	-1.0	-2.6	-8.3	-7.1	-3.5	-4.2
Wheat	-8.0	0.0	-1.7	-10.4	-4.7	-12.0	-5.3
Onions	-7.5	0.5	-1.9	-5.1	-3.7	-3.4	-2.4
Oats	-9.0	-1.0	-0.2	-5.5	-5.1	-6.6	-4.0
Peas	-4.5	3.5	-0.9	-4.1	-4.4	-4.3	-5.0
Barley	-9.5	-1.5	-3.0	-7.4	-2.2	-6.2	-4.6

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Table 3
Land Cover Classification Accuracy of X-band SAR and
LANDSAT MSS Data

Land cover class	MSS 4 band	3 Pol X-band SAR data	Data set used SAR & MSS bands 5,7
Deciduous forest	79	79	89.9
Pine forest	60	44	67
Pine forest with slash	65	22	68
Clearcut	63	39	79
Pasture/fallow field	64	35	77
Cropland	84	59	91
Wet Field	70	67	86
Water	98	92	99
Overall accuracy	72	59	82

Table 4
Land Cover Classification Accuracy of L-band
SIR-A and LANDSAT MSS Data

Land cover	SIR-A data	LANDSAT MSS data	SIR-A and MSS data
Urban/inert	6.7	35.7	72.5
Mixed pine hardwood	77.9	24.5	83.3
Native pine	83.0	78.4	91.0
Pine regeneration	66.4	41.0	78.8
Cropland/pasture	74.4	82.8	93.1
Water	64.9	98.5	99.8
Overall	67.0	68.0	89.2

improvement in moisture estimation accuracy of vegetation covered soil by combined active/passive microwave remote sensing. Comparison of an L-band radar shows the two systems to be complementary in terms of accurate soil moisture sensing over the extreme range of naturally occurring soil-moisture conditions. The L-band radiometer yields a significantly lower moisture-estimate error at low soil moisture, while the C-band radar is found to be significantly more accurate at soil moisture greater than approximately 70% of the field capacity. Fig. 5 gives the brightness temperature variations at 1.4 GHz backscattering coefficient variations at 4.25 GHz for corn, bare soil and general models as a function of per cent field capacity. The combination of both L-band radiometer and C-band radar is expected to yield soil-moisture estimates that are accurate to better than 30% of true soil moisture, even under vegetation cover. Also the experiment brought out the effect of vegetation on the backscattering characteristics as a function of incident angles at 5.1 GHz.

Backscattering measurements were acquired with airborne radar scatterometers over a test site in Cass county, North Dakota on four days in the summer of 1981 (Mehta 1984). Data were acquired at three frequencies (L, C and Ku band), two polarisations (like and cross) and at ten incidence angles (5° and 50°). Crop separability was examined using a two-class separability measure, which compares within class to between class variability. Based on this separability measure, a scatterometer channel most suited for separating each pair of crops was selected by choosing a subjective decision boundary to separate the two crops. Within the small-grains class, higher frequencies were found to be more useful, with good to very good separability in most cases. Both L and Ku bands were helpful for separability within the non-small-grains class, with mostly very good to excellent results. By discarding mixed pixels, substantial improvement was obtained in both the two-class separability and the separability errors for various crops.

RESULTS OF THE INDIAN EXPERIMENTS

Microwave Remote Sensing related studies are being carried out at SAC, ISRO. Significant work is also being done by NRSA, Hyderabad and at academic institutes like Banaras Hindu University, Gujarat University, and IIT, Bombay.

The microwave remote sensing activity in ISRO was initiated during the mid-seventies when the development of Satellite Microwave Radiometer (SAMIR) for Bhaskara Satellite was initiated. Subsequently a large number of studies were conducted using X-band SLAR, 19 GHz and 31 GHz radiometers and ground-based scatterometers for a variety of applications.

The first experiment was a temporal study on paddy carried

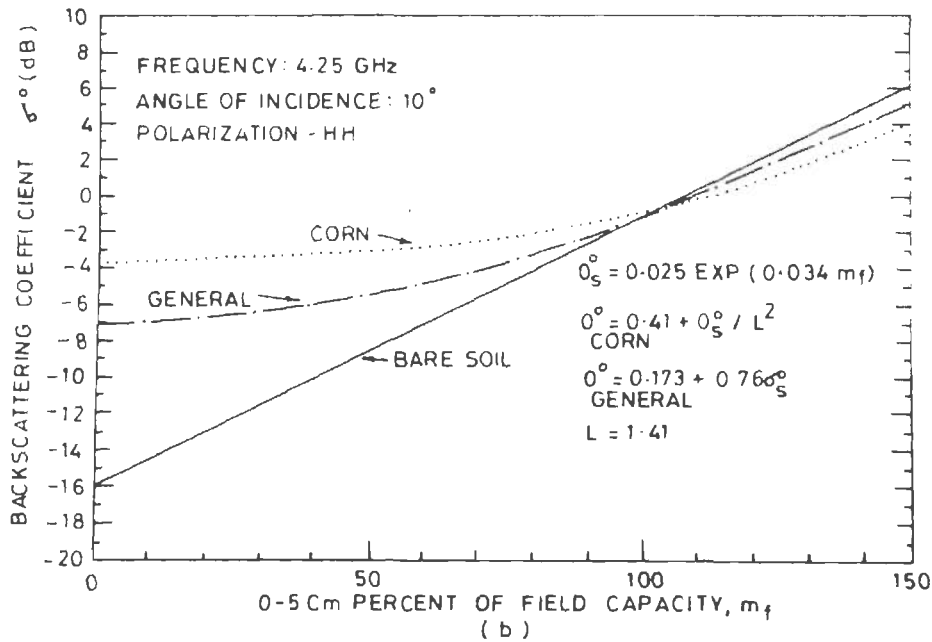
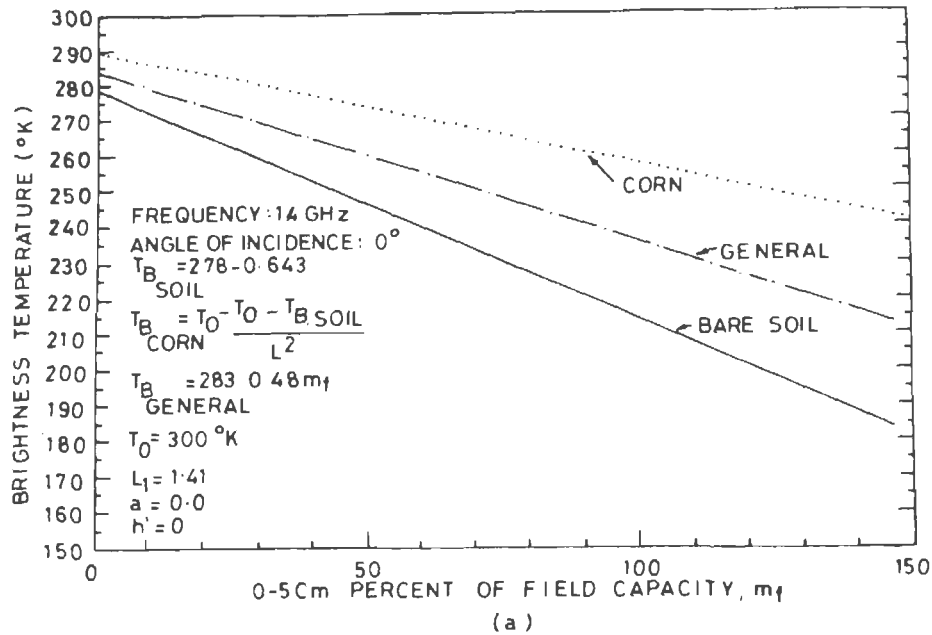


Fig. 5 Variation of the corn canopy model, the bare soil model and the generalized blind moisture classifier with soil moisture content for (a) 1.4 GHz radiometer at 0 incidence angle (b) 4.25 GHz radar at 10 incidence angle (after Ulaby et al 1985)

out by Calla et al (1979) using an X-band scatterometer. The study indicated the feasibility to monitor crop growth stages. Figure 6 gives the variation of scattering coefficient of paddy as a function of time for different polarisations.

Subsequently an experiment was also conducted (at Water Technology Centre, IARI) during December 1982 to April 1983 to study the temporal variation of scattering coefficient of wheat crop at 9.4 GHz by Kamat et al (1984). A simple scatterometer system (ground-based) was used with VV polarisation. The measurement of scattering coefficients was done at an interval of 15 days for look angles from zero to fifty degrees in step of ten degrees. Fig. 7 shows the variations of scattering coefficient over a crop cycle for look angles of 0° , 20° and 40° . Figure 8 shows the measurement made over the entire crop cycle for parameters such as leaf area index, dry weight, plant moisture and soil moisture for an irrigated plant. It was observed that there was a poor correlation between leaf area index and scattering coefficients (σ_0). Also it was observed that scattering coefficient decreased with increase of dry biomass. The correlation between wheat plant at 9.4 GHz (VV) and physiological parameters of wheat indicates the potential of radar remote sensing for wheat crop monitoring.

Soil moisture studies have also been conducted at SAC, using a ground-based calibrated FM-CW scatterometer operating over 8-18 GHz, range mounted on a 20 m high mobile platform (Calla et al 1984a). The plot of scattering coefficient at different look angles for bare ground under different moisture conditions at 9.6 GHz is shown in Fig. 9. The scattering coefficients at varying look angles show better separability between different soil moistures at like polarisation than at cross polarisation. Also maximum separability is seen to be at the lowest look angle around 10° .

In another experiment conducted by SAC, measurements for soil moisture at 19.35 GHz and 31.4 GHz were conducted by a radiometer system by Calla et al (1984b). Measurements were made at look angles varying from 0° to 70° for both horizontal and vertical polarizations. The soil type was bare sandy loam soil with surface irregularities of about 4 cm.

Typical results are shown in Fig. 10.

Following conclusions can be drawn from these results:

1. Sensitivity to moisture is more at lower look angles.
2. Significant discrimination exists between H and V polarisations.
3. 19 GHz has more moisture sensitivity than 31 GHz.
4. At lower moisture range ambiguity is more.

Similar experiments have also been conducted by the Gujarat University in collaboration with the Space Applications Centre using the 19 and 31 GHz radiometers (Vyas et al 1985).

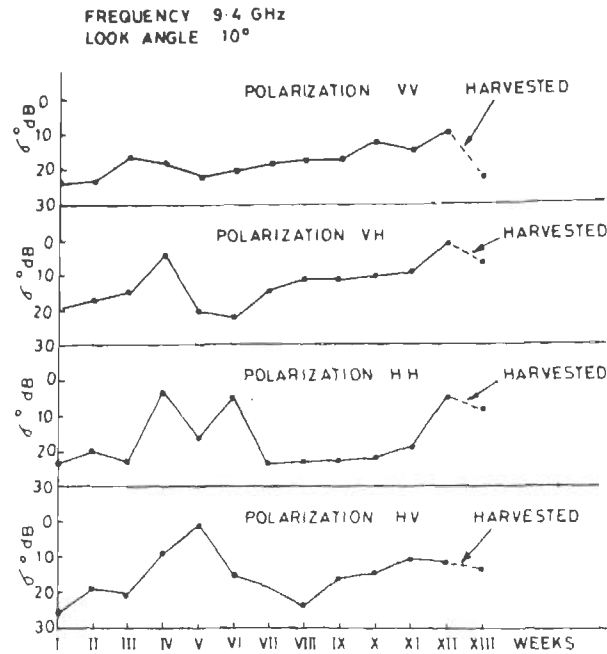


Fig. 6 Temporal plot of scattering coefficient (σ°) for different polarization (After Calla et al 1979)

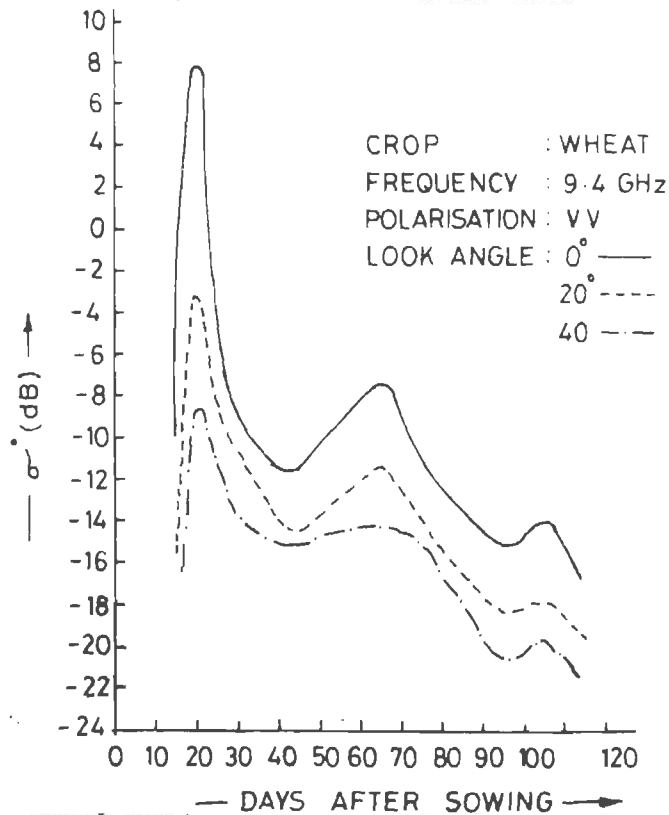


Fig. 7 Temporal variation in scattering coefficient (σ°) for wheat crop (After Kamat and Sinha 1984)

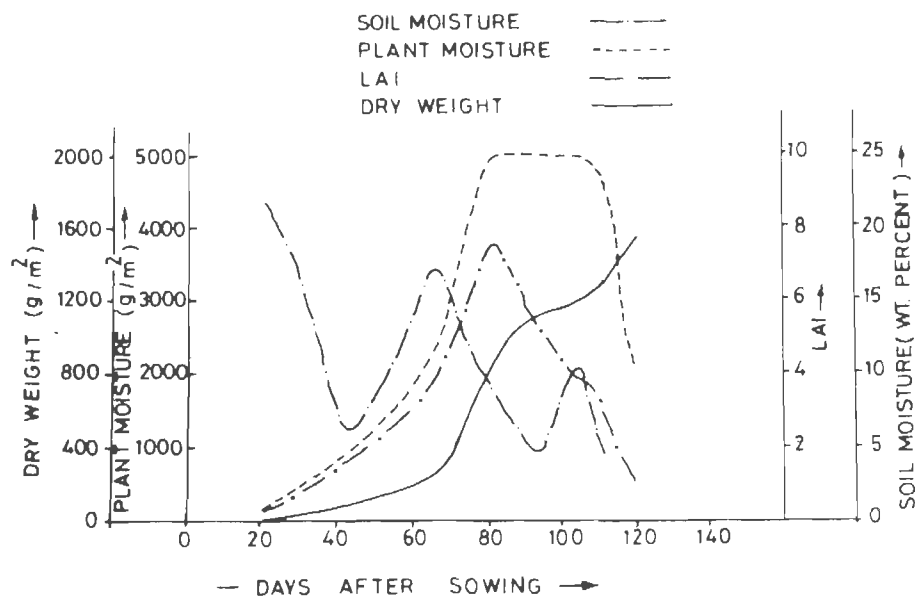


Fig. 8 Temporal variation in soil and plant moisture and dry weight of wheat (After Kamat and Sinha 1984)

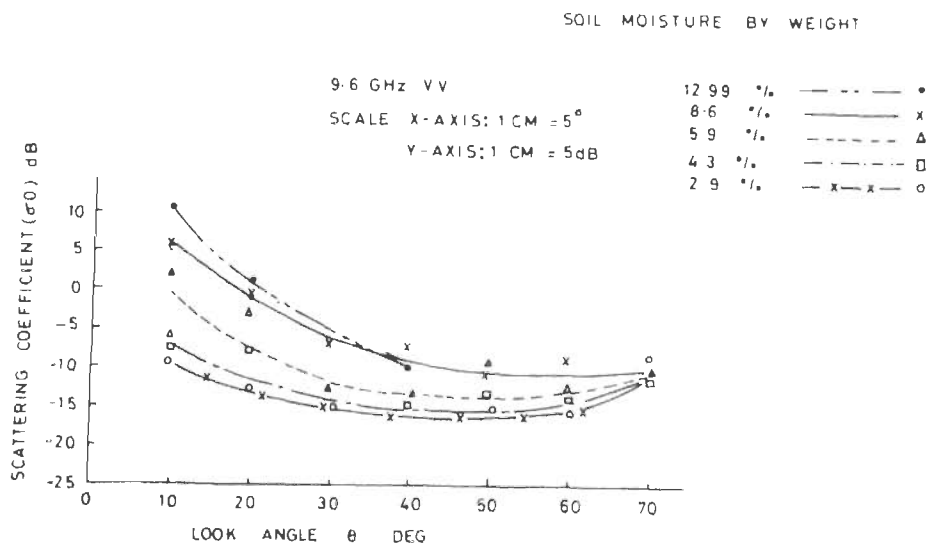


Fig. 9 Scattering coefficient at different look angles for bare ground under different moisture conditions at 9.6 GHz (After Calla et al 1984a)

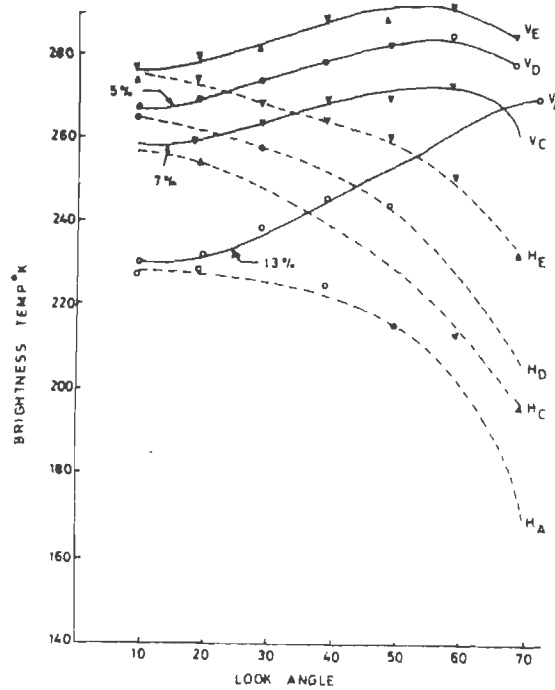


Fig. 10 Response of 19 GHz to soil moisture at different look angles (After Calla et al 1984b)

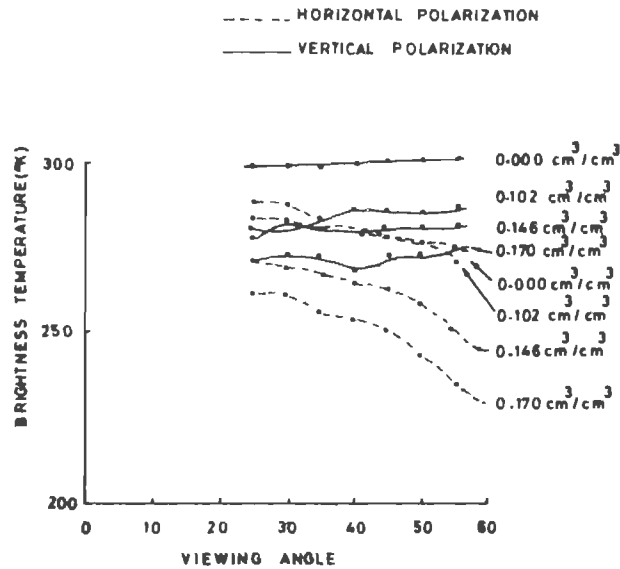


Fig. 11 Brightness temperature measured at varying look angles for both horizontal and vertical polarization (After Vyas et al 1984)

Fig. 11 shows the typical results of this experiment.

CONCLUSION

The experimental results obtained by the various groups demonstrate amply the potential of the microwave sensors for agricultural applications. Better understanding of the scattering and emission mechanisms, study of the factors which will influence the data in operational situation, evolution of the theoretical models and advancements in the sensor technology in the near future, will definitely take these applications to operational status.

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DATA PRODUCTS FOR INDIAN REMOTE SENSING SATELLITE

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ABSTRACT

The Indian Remote Sensing Satellite System will be launched in 1987. It will carry two camera systems, one having 36 m ground resolution and the other with 72 m ground resolution. The satellite will be placed in a sun synchronous orbit and the data will be collected at 10 AM local time. It will have a repetitivity cycle of 22 days.

The data products system is presently under design at Space Applications Centre/ISRO and at National Remote Sensing Agency/Hyderabad. The necessary software for generation of data products is being developed indigenously at SAC which will be transferred to NRSA for operational use. The basic products for users is called the standard data product which will have a location inaccuracy of ± 2.2 kms with respect to tick marks derived from the satellite ephemeris data. However, the local distortion within the imagery will be limited to about 5 pixels.

The other major product is called the precision product which will have a location inaccuracy of about 100 m. This will be generated using a ground control point library which is under development. There is another product called Special Product which is user oriented product and this will be operationally supplied to users after performing enhancement on the data. This note highlights the critical areas of development in the aspects of data processing software, data products generation and data dissemination of the IRS data products system. This also discusses the future directions for similar work.

INTRODUCTION

The Indian Remote Sensing Satellite (IRS) is proposed to be launched in 1987 and will carry two camera systems, one having a ground resolution of 73 m and the other 36.5 m. The satellite is a 3-axis stabilised platform with high stability (0.1 deg accuracy). The camera has 4 bands and uses linear CCD arrays, each having 2048 detectors.

The data reception will be carried out at the National

Remote Sensing Agency (NRSA), Hyderabad and the data products will be operationally generated both at NRSA and at SAC. The Tables 1 to 5 give the specifications of the camera system, the specifications of the orbit, the specifications of the platform stabilities, the type/formats and accuracies of the data products to be generated and the volume of data products to be generated per day and their turn-around time during normal operations respectively.

THE DATA PRODUCT SYSTEMS DESIGN

This discusses the major highlights of the IRS-DP system design.

1. To carry out user services efficiently, a path row referencing scheme has been designed.
2. An Information Management System (IMS) around the computer is organised to handle user requests and to generate catalogues for users.
3. The cloud cover information is planned to be given for 16 equal segments of the LISS-I image and in 4 equal segments for the LISS-II image.
4. Browse products are intended to serve as quick turn-around time products for use in emergency situations.
5. One band of the image will be made available to the Regional Remote Sensing Service Centres routinely on microfiche for all the useful data acquired over Indian Region. This will help the regional users to look at the imagery and satisfy themselves before placing an order.
6. The precision products are introduced as a user product. This will have a ground location accuracy of about 100 metres. This product is expected to help in the generation of accurate resource maps.
7. There are special products such as ratio imagery, principal-component imagery, edge-enhanced imagery, contrast-stretched imagery etc. which form part of user-oriented products in the IRS-DP system. All the products will be available in photographic formats (black and white and colour) or in the computer-compatible-tape (CCT) format.

STATUS OF THE DATA PRODUCTS SYSTEM

The software for generating the data products is under development at SAC and will be transferred to NRSA for

Table 1
Payload (Sensor) Parameters

	LISS-I	LISS-II
1. No.of cameras	1	2 (A & B)
2. No.of spectral bands	4	4
3. Central wavelengths	485, 555, 650 & 815 nm	
4. Spectral bandwidth	70, 70, 60 & 90 nm	
5. Geometric resolution (m)(corr.to 904 km. altitude)	72.5	36.25
6. Swath width (km) (Corr.to 904 km altitude)	148.48	74.24 (Combined swath:145.48)
7. Quantization levels (bits)(radiometric resolution:128 levels)	7	7
8. No.of gain settings (1:low gain; 4: high gain)	4	4
9. Noise equivalent reflectance NE $\Delta\rho$	<1%	<1%
10.Band to band registration	± 0.25 pixel	± 0.25 pixel

Table 2
Platform (Attitude) Parameters

1. Pointing accuracy (3 limits)	Roll : $\pm 0.4^\circ$ Pitch : $\pm 0.4^\circ$ Yaw : $\pm 0.5^\circ$ ($\pm 0.1^\circ$ with star sensor)
2. Determination accuracy (3 limits)	Earth sensor Star sensor + Gyro Roll : ± 0.1 $\pm 0.02^\circ$ Pitch : ± 0.1 $\pm 0.02^\circ$ Yaw : ± 0.3 $\pm 0.02^\circ$
3. Drift rate (worst case) (3 limits in all the 3 axes)	$\pm 3 \times 10$ deg./sec
4. Jitter (worst case) (3 limits in all the 3 axes)	$\pm 3 \times 10$ deg.

Table 3
Orbit Parameters

Sr. No.	Parameter	Value corresponding to nominal orbit
1.	Semi-major axis	7282.277 km
2.	Eccentricity	0.002
3.	Inclination	99.028
4.	Nodal period	103.192 min.
5.	Altitude+	904 km
6.	Local time for descending node	10.00 AM
7.	Repetitivity cycle	22 days

+ Nominal value. Due to eccentricity of orbit, it may vary from 890 km to 940 km.

Table 4
Product Types, Formats and Location Accuracies

Sr. no.	Type	Format	Scale		Location accuracy (3-sigma) in km
			LISS-I A & B	LISS-II	
1.	QL film	70 mm	-	-	-
2.	Browse	65mm x 65mm (9 band scenes in 240mm)	1:2.9m	1:1.45m	± 10
3.	Stand- ard	240mm 70mm	1:1m -	1:0.5m -	±2.2 ±2.2
4.	Preci- sion	240mm	1:1m	1:0.5m	±0.1
5.	Special (enhanced/enlargements)	240mm to 100 mm	1:1m to 1: 250,000	1:500,000 1:100,000	As above for different types of products

Computer Compatible Tapes for these will be available in 1600 BPI (6250 BPI Optional)

Table 5
Volume of Products Per Day and Turn-about Time

Type	Requirements in band scenes		Turn-around time in days+
	Master	Copies	
I. Photographic			
Browse	225	75	2
Standard	75	184++	7
Precision	40	40	15
FCC	20	20	15
Enlargements			
B/W	-	3	15
Colour	-	1	15
Special products	4	4	15
Microfische	2	20	2
II. CCT	6	6	15

+ Time for product generation and despatch. For
 browse despatch not included.

++ 184 Copies of standard products for IRS-UP only.

operational use. The design of the software is completed and the testing of the software will be carried out during the next six months. A dedicated computer system is under procurement at NRSA for generating the IRS data products. The photographic data products laboratory at NRSA and SAC are augmented to take care of the users' needs. The system is expected to be operational by the second quarter of 1986. The data products will be released to users after stabilising the products generation and their quality during the initial phase of operations of IRS system. The initial phase operation is expected to last for 2/3 months and then the data products will be given routinely with the specified turn-around time. The standard products is planned to be sent to the users within seven days of receipt of an order. The precision and special products will have a turn-around time of 15 days. User catalogues will be routinely generated and sent to primary users for helping them in placing orders after checking the quality specifications of each of the product.

The special products software is undergoing tests. The users will be involved in evolving its utility for applications before the schemes are finalised.

FUTURE SCOPE

IRS-DP system is expected to give operational insight into problems associated with quality products generation with specified turn-around time. If the precision processing work is successful and operationalised, the quality of products will help in making cartographic quality resource maps at least upto 1:250,000 scale.

INDIAN REMOTE SENSING SATELLITE UTILISATION PROGRAMME FOR AGRICULTURE

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ABSTRACT

Agricultural resources are among the most important renewable dynamic natural resources. Comprehensive, reliable and timely information on agricultural resources is very much necessary for a country like India whose mainstay of the economy is agriculture. Indian Remote Sensing Satellite (IRS) and its utilisation programme have been conceptualized, designed and planned with maximum emphasis on agriculture. The choice of spectral bands for the payload on IRS-1A is largely determined by agricultural applications. In formulating various projects under the IRS Utilisation Programme (IRS-UP) in the field of agriculture, information needs and problem areas as identified at the national level have been taken into account. Although several areas of agricultural applications are projectized under IRS-UP, degree of operationalisation of remote sensing technology is at different levels in different application areas in the country. Land use survey, land degradation studies, disaster assessment in case of natural calamities like floods and drought, and soil mapping are some of the application areas wherein remote sensing technology has already attained operational or quasi-operational status. Thrust in the IRS-UP would be to make all these operational. Crop Production forecasting is another important area of application considered under IRS-UP which is deemed to be at an experimental stage because of problems like field sizes, mixed cropping pattern, confusion crops and large variability in crop calendars. Detection of crop stress and crop yield modelling are two projects at 'Techniques Development' stage. Agriculture-related applications account for more than fifty per cent of the total effort involved in the IRS-UP applications projects. State of the art in the country, problems involved and approaches being adopted in some of these application areas are discussed in this review paper.

INTRODUCTION

Agriculture plays a vital role in the Indian economy. Its contribution to the net national product is about 40 per cent. This sector provides livelihood to about 67 per cent of the

total working force (14.8 out of 22.25 crores). The contribution by the agricultural sector to the total value of exports is about 35 per cent. This sector has been quite dynamic. During the 1951-1983 period the foodgrain production has tripled from 50.8 million tons to 151.5 million tons. During the same period the population has grown by more than 90 per cent. However, the per capita availability of foodgrains has increased only marginally (from 430 gram/day in mid-fifties to 483 grams in 1983). Thus, there is a tremendous pressure on land. With a projected population of 1 billion by the year 2000 A.D., the requirement of foodgrains is estimated at 240 million tons which is further increasing this pressure.

The agriculture sector depends heavily on the vagaries of the monsoon. The area under rainfed crops is about two-thirds of the total area of the country. In fact, 79 per cent area of the country is drought-prone. Upto June 1983, only 63.3 Mha area of the country had been provided irrigation facilities.

If the challenge of feeding, clothing and providing other necessities of life to the growing population is to be met, better management of our land and water resource is required. Improved management will only enable maximising productivity of our land.

Remote sensing techniques have demonstrated their potential in furnishing information on the character, distribution, productivity, and use of our natural resources. It is in this context that the country embarked upon the operationalisation of remote sensing technology for aiding the management of our natural resources through the National Natural Resources Management System (NNRMS). The predominant importance of agriculture to the country naturally led to the highest importance being given to applications in the area of agriculture while formulating the Indian Remote Sensing Satellite Utilisation Programme (IRS-UP). This programme has been drawn up for the optimal utilisation of the first operational/semi-operational Indian remote sensing satellite, IRS-1A, planned for launch during 1987/88

APPLICATIONS IN AGRICULTURE

In the Indian context, the possible applications in the broad area of agriculture are:

- i) Land use/land cover surveys and monitoring
- ii) Soil mapping
- iii) Crop production forecasting including crop stress detection and yield modelling.
- iv) Disaster assessment i.e. assessment of damage to crops etc due to floods, drought etc.
- v) Appraisal and monitoring of land degradation due to erosion, salinity/alkalinity, waterlogging,

desertification etc.

- vi) Water management; as for example, monitoring of surface water bodies, estimating availability of water in irrigation systems, estimation and monitoring of irrigated, cropped areas, scheduling of irrigation, exploration of ground water resources, watershed management etc.

The IRS-UP identified 16 applications for operationalisation keeping in view the experience of the Dept. of Space (Space Applications Centre (SAC), National Remote Sensing Agency (NRSA)), various user agencies and academic institutions in the country in all the possible disciplines like agriculture, land use, forestry, mineral resources, water resources, environment, marine resources etc. The choice of agriculture-related projects was based on the information needs and problem areas identified by the National Commission on Agriculture (1975).

However, the status or degree of operationalisation is apparently different for different applications. One of the yardsticks for assessing this degree of operationalisation was the recent experience in the Joint Experiments Programme (JEP) carried out by the DOS in collaboration with various ministries and departments of the Central Government. Hence, it was considered expedient to categorise various application projects on the basis of the status of the technology and the Indian experience. The 16 application projects thus fall in the following four categories:

- a) Operational Applications Projects (OAP)
- b) Quasi-Operational Application Projects (QAP)
- c) Experimental Application Projects (EAP), and
- d) Techniques Development Projects (TDP).

For an application, the operationalisation proceeds through three steps:

- a) The techniques development phase
- b) The experimental phase
- c) The quasi-operational phase.

One develops a remote sensing technique for a possible application (TDP), tests its feasibility experimentally (EAP), and establishes it by a pilot-scale project (QAP). It is then ready for operational use by a user agency. The following is the categorisation of the 16 application projects.

- A. Operational Application Projects
 - 1. Regional Geological Mapping
 - 2. Groundwater Exploration
 - 3. Flood Mapping
- B. Quasi-Operational Application Projects
 - 1. Land Use/Land Cover Survey and Monitoring
 - 2. Land Degradation including Desertification

- 3. Snow Mapping
- 4. Drought Monitoring
- 5. Soil Mapping
- C. Experimental Application Projects
 - 1. Crop Production Forecasting
 - 2. Forest Mapping and Damage Detection
 - 3. Water Quality Monitoring
 - 4. Watershed Characterisation
 - 5. Monitoring of Coastal Environment
 - 6. Marine Fisheries
- D. Techniques Development Projects
 - 1. Crop Stress Detection
 - 2. Crop Yield Modelling

It is obvious that atleast 10 out of 16 projects are directly related to agriculture. These are: i) Groundwater Exploration, ii) Flood Mapping, iii) Land Use/Land Cover Survey and Monitoring, iv) Land Degradation including Desertification, v) Drought Monitoring, vi) Soil Mapping, vii) Crop Production Forecasting, viii) Watershed Characterisation, ix) Crop Stress Detection and x) Crop Yield Modelling. Even Snow Mapping project has a bearing on the availability of water in irrigation systems developed on snow-fed rivers from the Himalaya. Similarly, water quality monitoring project is at this stage of development, obliquely related to irrigation. Thus, it is quite evident that IRS-UP is heavily tilted in favour of agriculture. It is also apparent that most of the agriculture-related applications are on a quasi-operational or operational level and thus meet the information needs of these areas.

It is not feasible to discuss all these projects in this review. Land use survey and land degradation are covered by another review (Sahai 1985) in this volume. In this review, we shall have a brief description of IRS-1A for the sake of completeness and discuss the major application in agriculture i.e. crop production forecasting.

IRS-1A SATELLITE

IRS-1A is planned to be 3-axis-body-stabilised polar-orbiting sun-synchronous satellite at an altitude of 904 km. Some of the salient feature of the IRS-1A system are given in Table 1. Important payload parameters of relevance to the discussion on applications are spatial resolution, spectral domain and bandwidth, radiometric sensitivity as well as repetition cycle.

- i) Spatial resolution: The spatial resolution needs for some of the broad agricultural applications in the country have been assessed to be in the range of 40-70 m. However, identification of contiguous areas under a single crop would require effective spatial resolution at least of the

order of 30 m. Keeping this in view and the technological constraints, payloads with two different spatial resolutions viz. 73 m and 36.5 m have been considered for the IRS-1 mission.

- ii) Spectral bands: Choice of the spectral bands on IRS-1 payload has been done considering that applications in agriculture have a higher priority.
- iii) Radiometric resolution: Based on the studies conducted so far either 128 or 256 quantization levels appear optimum for orbital monitoring of terrestrial vegetation. Quantization at 128 levels has been chosen.
- iv) Repetition cycle: The repetition cycle of 22 days for IRS-1 based on the trade-off between orbit choice considerations and payload swath represents a compromise between the needs of dynamic resource applications such as agriculture and hydrology and those relating to applications to not-so dynamic applications as in geology, land use and ground water exploration. 22 day repetition rate is not particularly suitable for crop production forecasting. However, with the launching of subsequent IRS satellites, one may be able to get repetition rate of 11 days (Navalgund and Kasturirangan 1983).

A variety of data products such as high density digital tapes, 70-mm film, microfiche, 240-mm black-and-white as well as colour prints, computer compatible tapes, and false colour composites generated by four different levels of processing are going to be available. NRSA is identified as the agency to disseminate the data products in the country. SAC will produce precision products for selected scenes and applications.

CROP PRODUCTION FORECASTING

Crop production forecasting is of vital importance to the country as the agricultural production is highly susceptible to vagaries of the monsoon. Out of a total geographical area of 329 Mha, 260 Mha i.e. 79 per cent area of the country is drought-prone though the intensity of drought varies from region to region and from year to year. Two-thirds cropped area of the country is rainfed and provides 42 per cent of our foodgrains besides other agricultural commodities like coarse grains, pulses, oilseeds, cotton etc. Pre-harvest crop production forecasts can go a long way in enabling the country to adopt suitable measures to meet shortages, if any, and also to enable the Government to implement suitable support and procurement policies, if surplus is likely to be generated in a particular season/year so that the prices do not crash.

Important steps involved in forecasting of crop production (acreage x yield) are:

- i) Identification of crops.
- ii) Evaluation of crop quality (vigour, density, maturity and disease).
- iii) Measurement of acreage under different crops/crop qualities.
- iv) Evaluation of the yield of crops per unit land area.

Adoption of remote sensing techniques in India faces the following major problems in the country.

- i) Small land holdings and hence small fields in which crops are grown.
- ii) Mixed crops e.g. wheat and gram.
- iii) Confusion crop e.g. wheat and barley.
- iv) Different cultural practices.
- v) Large variability in crop calendars.
- vi) Large areas under rainfed crops having generally poor growth.
- vii) Cloud cover during the Kharif season - the major crop-growing season in India.

The IRS-UP projects entitled Crop Production Forecasting (CPF), Crop Stress Detection (CSD) and Crop Yield Modelling (CYM) have been taken up to tackle these problems and develop appropriate techniques. CPF is aimed at establishing methodology for step (i) and (iii) mentioned above, CSD for step (ii) and CYM for step (iv) i.e. evaluation of the yield per unit area.

State of The Art in India

India is fortunate to have an ongoing system for forecast of production of major crops. As early as in 1884, forecast of wheat yield was made. Acreage statistics are gathered by village level officials and are compiled, collated by the tehsil/district level agencies and further by the State Bureau of Economics and Statistics and by similar organisations at the central level. Timely Reporting Scheme is also in vogue. Pre-harvest estimates of yield are obtained on the basis of visual observations and assessment from the land revenue and agricultural officials. National Sample Survey Organisation conducts crop-cutting experiments to determine yield per unit area at selected places. Directorate of Economics and Statistics (DES), Govt of India, issues 80 forecasts in respect of 38 field crops, besides plantation crops such as tea and rubber.

Besides DES, various institutions are also engaged in evolving reliable yield models, following different approaches, such as the use of biometrical parameters, weather factors and agricultural input etc. India Meteorological Department is engaged in developing agrometeorological models using multiple regression techniques.

Studies directed towards development of remote sensing technology for crop production forecasting in India have been carried out for the last few years. Space Applications Centre has played a pioneering role in this area. Studies conducted can be divided into two main categories:

- i) Crop inventories including acreages - aircraft and satellite based
- ii) Spectral response of crops

In the first category are the studies carried out using airborne sensors since 1974 and more recently, using LANDSAT data. The second category comprises essentially ground-based studies carried out in agricultural farms to build up agromet-spectral yield models.

The first systematic attempt in India directed towards crop inventorying through remote sensing techniques was carried out under a joint ISRO-ICAR experimental project - Agricultural Resources Inventory and Survey Experiment (ARISE). The experiment was conducted in Anantapur district of Andhra Pradesh, primarily a groundnut and paddy-growing area in October-November 1974 (Sahai 1975; Sahai 1976; and Sahai et al 1977) and in Patiala district of Punjab, primarily a wheat-growing area, during February-March 1975 (Dhanju and Shankaranarayan 1978). Detailed crop inventories were prepared and acreages under various crops were estimated. In another experiment, involving multiband photography through multitemporal aerial flights during 1975-76, an attempt was made to identify and classify paddy and sugarcane crops at different growth stages (Sahai and Venkatesh, 1978). Sugarcane affected by the leaf blight disease could be identified on CIR imagery at 1:60,000 scale (Parihar et al 1977).

In an experiment conducted in Karjan (Gujarat), it was not only possible to identify four varieties of cotton but also to assess qualitatively four vigour classes on CIR imagery on 1:20,000 scale (Sahai and Patel 1977; Sahai 1977). Other experiments have been conducted in Bharuch district during 1977-78 for making a cotton inventory, in Ahmedabad district during 1978 for wheat inventory and in Vijapur taluka (Mehsana district) during 1979 for inventorying wheat, cotton, mustard and castor crops.

In Vijapur experiment, stratified sampling technique was successfully tried and estimates on expected wheat production could be made prior to the harvest. Crop inventories were also attempted in the Idukki district of Kerala (Sahai et al 1985) and Ukai Command area (Sahai et al 1985).

Ayyangar et al (1980) conducted an experiment in the Mandya district of Karnataka and showed that it was possible to distinguish three classes of paddy based on varietal, vigour or

crop growth differences and two classes of sugarcane.

Approach Under IRS-UP

Three major crops of India wheat, paddy and groundnut are considered for experimentation under the Crop Production Forecasting (CPF) project. Project sites for each of these are selected in the major regions of the country growing these particular crops as follows:

Wheat: Punjab, Haryana
Paddy: Orissa
Groundnut: Saurashtra

The CPF project is being carried out in close collaboration with actual user agencies so that the methodology and know how developed could be transferred smoothly.

The collaborating agencies with whom memoranda of understanding (MOU) have been signed or are in the process of being signed are:

Wheat:

- i) Punjab Agricultural University, Ludhiana
- ii) Haryana Agricultural University, Hisar

Paddy:

- i) Orissa Remote Sensing Applications Centre

Groundnut:

- i) Gujarat Co-operative Oilseeds Growers Federation, Bhavnagar

The actual mode of analysis is being evolved in this project. However, possible methodology that may be adopted using IRS-1 data in conjunction with aircraft and ground data employing multistage stratified random sampling technique is as follows.

- i) The cropped area may at the first step be stratified into homogeneous areas on the basis of high resolution satellite data. Apart from IRS-1A LISS-II data, data available from SPOT and other contemporaneous satellites, will be used. This is quite essential since the repetitive cycle of IRS-1A is 22 days, rather infrequent from the point of view of this application.
- ii) In each of these homogeneous areas, sample segments may be chosen for conducting aerial surveys with sensors compatible with sensors on board the satellite.
- iii) Detailed ground truth data collection
- iv) Signatures of crops at different growth stages to be

extracted for multispectral analysis and unique identification of crops.

v) Using clustering algorithms to estimate acreage

As part of this project, yield estimates are to be obtained on the basis of crop-cutting experiments done on a sample basis since the development of yield models using spectral data is still in its infancy.

As part of this project some analysis of satellite data (LANDSAT-MSS) collected over wheat-growing regions of Karnal area of Haryana has been carried out. Based on the detailed ground truth collection, training sets were identified. Spectral signatures corresponding to these training sets (windows) were extracted and used in supervised classification of the LANDSAT MSS data covering that area. Wheat classification was found to be 82% of the estimate by the Bureau of Economics and Statistics.

CROP STRESS DETECTION

Inadequate supply of nutrients and water, pest attack, diseases and abnormal weather are some of the factors which adversely affect the crop growth and often create 'stress' in plants. Such a stress ultimately results in the reduction of crop yield. The physiological changes that occur due to stress may result in changes in the spectral reflectance/emittance characteristics hence making the detection of stress amenable to remote sensing techniques.

Status in India

The first modern remote sensing experiment in India carried out in 1970 was to detect coconut-wilt disease (Dakshinamurti et al. 1971). Colour infrared aerial photographs on 1:60,000 scale have also been used to detect leaf-blight disease in sugarcane in Mandya district of Karnataka (Parihar et al. 1977). Disease severity of cotton crop was detected on CIR photographs at 1:20,000 scale in Vijapur taluka of Mehsana district.

Quite a few ground-based experiments have also been carried out to see the effect of moisture-stress and different fertilizer treatments on the spectral response of crops and their ultimate effect on the final yield. Experiments conducted on wheat plots subjected to different irrigation schedules showed that the ratio of reflectance in near-infrared to red is a good indicator of moisture stress (Sahai et al. 1981, Patel et al. 1982, Singh et al. 1982). It was also demonstrated that the plants grown under moisture stress have higher crop canopy temperature compared to the normal ones which could be utilized by remote sensing techniques. It has also been conclusively

shown that the accumulated stress degree days over some critical period (where stress degree day is defined as the difference between the canopy temperature and the ambient temperature) has an inverse relationship with grain yield (Singh et al. 1982, Patel et al. 1983, Saha et al. 1984).

Although feasibility of detecting stress has been demonstrated using both ground-based and aircraft experiments, identification of specific stress has not been so far possible. Quantification of stress and its effect on yield needs to be further examined. Studies using satellite imagery in this direction have been very few.

In a recent study (Nagarajan et al. 1984), LANDSAT multispectral data for two years were analysed using computer aided techniques to detect changes in the wheat growing regions of West Punjab (Pakistan) affected by yellow-rust. The Kauth-Thomas greenness was used for the change detection. The greenness difference transformation could identify disease affected areas quite clearly.

Approach Under IRS-UP

It is envisaged to conduct this project in collaboration with agricultural research and academic institutes, this being still at the technique development stage. The likely collaborating agencies are:

- i) Indian Agricultural Research Institute, New Delhi
- ii) Central Rice Research Institute, Cuttack
- iii) Gujarat Agricultural University, Anand.

The two major crops considered are paddy and wheat. Systematic ground experiments would be conducted to study the spectral response of the plants undergoing induced

- i) moisture stress,
- ii) nutrient stress, and
- iii) stress caused through diseases.

Efforts would be made to see if specificity of stress can be established through spectral parameters and its quantification. In addition to the ground experiments, aircraft surveys would be mounted, if the incidence of large scale stress are reported from any place in India. In parallel, efforts would be made to develop techniques to derive information on stress from spacecraft imagery.

CROP YIELD MODELLING

Reliable crop yield estimates are an important component of any crop production forecasting system. The crop growth and yields are determined by the soil base, technological inputs and weather elements. Mathematical formulation of relationships between various physical observables, yield-affecting

parameters and the yield and subsequent modelling is a complex task but very important.

Status in India

Yield estimates are made either on the basis of visual observations or on the basis of crop-cutting experiments. These methods do not involve any mathematical modelling but statistical concepts for sampling. India Meteorological Department has developed agrometeorological models using multiple regression techniques (Sarkar 1977). These models incorporate only the weather factors, whereas technological trend is taken into consideration through a dummy variable. However, certain inherent drawbacks of agromet models arise from the fact that they use long historical data base, are area specific and lack the sensitivity to account for abnormal weather conditions. There are also other models which are based on the use of biometric parameters of plants.

Efforts made to combine spectral information of crops alongwith weather data to develop models known as hybrid agromet-spectral models have been a few. The advantage with this approach is that the crop reflectance data, being a manifestation of the integrated effects of weather, soil and cultural factors make it possible to avoid parameterising of the technology trend. The other important aspect of this approach is that reflectance data would be available for all the regions with almost equal accuracy.

Many field experiments on two major crops, paddy and wheat, have been carried out to study the relationships between agronomic parameters like leaf area index, wet biomass, dry biomass and plant water content and spectral parameters (Singh et al 1983, Patel et al 1983, Kamat et al 1983). Linear relationship was observed between the maximum leaf-area-index attained by the crop and final grain yield. Leaf area index has also been shown to be related to spectral parameters. Near infrared to red radiance ratio and the normalized difference were also shown to be linearly related with grain yield. As mentioned earlier, accumulated stress degree days (SDDs) over a period starting after the heading stage is reached to the maturity stage, is also shown to have a high inverse relationship with grain yield. The results have thus indicated that agrospectral models have a great promise in predicting crop yields. Of course, high correlation observed between biometric parameters and spectral variables in field experiments needs to be verified using airborne and spaceborne spectral radiance data.

Approach Under IRS-UP

It is envisaged to carry out this project in close collaboration with agricultural research institutes. The collaborating agencies are likely to be the same as those for CSD project. This would ensure that the expertise required for

understanding problems of physiology of crops that contribute to yield and the manifestation of this physiology in spectral parameters and mathematical techniques is available. Since the tasks to be performed are enormous, it is also felt necessary to encourage many institutes to take up parallel work in this direction. It is also necessary to carry out experiments and subsequent yield modelling exercise in different agroclimatic zones. It is planned to take up work initially on two crops, namely paddy and wheat; Groundnut may be taken up subsequently.

It is envisaged to design and execute field experiments in at least two agroclimatic zones for each crop. Experimental plots would have planned variation in sowing dates, fertilizer treatments, irrigation schedules, seed rate etc. Replication of plots would also be taken into account for statistical significance.

Analysis of spectral data of different plots, alongwith their agronomic parameters would be carried out and yield models in terms of spectral data and weather parameters at critical growth stages would be developed. Such an exercise would be repeated at least for two years to test the reproducibility.

Similar experimentation would be carried out with aircraft data to validate the relationships and models thus developed.

Concurrent to the above-mentioned tasks, available satellite data would be analysed to extract yield related parameters like leaf-area index from spectral data. Whereas methodology would be developed using currently available satellite data, it is envisaged to use IRS-1 data to do similar analysis once the data from IRS-1 become available.

CONCLUSIONS

With the launching of the Indian Remote Sensing Satellite and availability of various data products with quick turn-around time, applications in agriculture would gain momentum. Various approaches/techniques suggested in this paper would get developed during the pre-IRS phase using currently available satellite data and their validation shall be done using IRS data. Methodology for crop acreage estimation using RS data would have reached semi-operational phase for the major crops of the country. The two technique development projects related to crop yield modelling and stress detection would have made sufficient progress and be ready for experimentation on a regional scale. All these efforts put together would pave way for evolving a RS-based crop inventory system in the country. With the major application areas in agriculture having reached operational/semi-operational status, the National Natural Resources Management System would become a reality.

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NATIONAL NATURAL RESOURCES MANAGEMENT SYSTEM -AN OVERVIEW

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ABSTRACT

There are many practical applications of the remote sensing technology of which many are heading towards operational status with the present sensors and data collection systems. The future plans with microwave remote sensing including Synthetic Aperture Radar (SAR), cartographic large format cameras, other high resolution and stereo sensors and the American Polar Platform hold many promises for establishing many more operational systems for generation of information for the resources management. Considering the various studies carried out during the last few years, a Planning Committee (PC) constituted by Planning Commission, Government of India had taken an overall stock of the studies carried out in India and organised a National Seminar in May 1983. Member, S&T, Planning Commission is the Chairman and Secretaries of the Departments of Space (DOS), Science & Technology (DST), Environment (DEN), Ocean Development (DOD), Agriculture & Cooperation, Agricultural Research & Education (DARE), Mines (DOM), Forest & Wild Life (DOFWL) and Member Finance of DOS are members of the Planning Committee. A Standing Working Group constituted by PC-NNRMS assists the Planning Committee in various matters related to NNRMS. The Planning Committee conceptualised the evolution of National Natural Resources Management System (NNRMS) where the conventional techniques and the modern remote sensing techniques would be suitably integrated towards the generation of a system for the required information for the management of the natural resources. The Indian Remote Sensing Satellite System (IRS) and the IRS Utilisation Programme (IRS-UP) is the preamble towards the evolution of NNRMS.

Five Regional Remote Sensing (Data Processing) Service Centres (RRSSC) are being established in the country, where computer systems and visual data interpretation facilities would be established in about a year. They would also serve as a limited training facility. The location of these Centres are Dehra Dun (funded by DOS); Nagpur (funded by ICAR); Kharagpur (funded by DST); Bangalore (funded by DOM); and Jodhpur (funded by DST & DOS). It has been considered by PC-NNRMS that one Centre each in the north and north-eastern region also should be established during the 7th Five-Year-Plan period. Department of Space has been identified to handle all the five Regional

Centres and subsequent Centres that may be added to the same for an initial period of five years. The procurement of computers as well as all other activities like civil works and software required for RRSSCs have begun.

The PC-NNRMS also constituted nine separate Task Forces to study the details of the information needs in the management for different resources. These Task Forces are on Agriculture, Forestry, Geology, Oceanography, Soils and Land Use, Urban and Rural Studies, and Water Resources. These Task Forces have studied the details and recognised the potentials of remote sensing technology. The other two Task Forces are for studying the details of Cartographic Representation of Data (CARD) and Natural Resources Information System (NRIS).

INTRODUCTION

Over the past 12 years, in India, the remote sensing techniques have been experimented for the resources and environmental monitoring studies by the Department of Space at its main application centres, Space Applications Centre (ISRO) and the National Remote Sensing Agency (DOS). The techniques involve measurements of the electromagnetic radiation from the earth's surface that give clue to the type of the feature, its state, and other details. The basic measures in remote sensing are: radiant flux; reflectance; albedo; absorptance; irradiance; exitance; radiance; thermal inertia; thermal diffusivity; dielectric constant depending on the spectral region. Another important aspect in the remote sensing measurements is the resolution. There are four different resolutions: spectral, radiometric, spatial, and temporal. Multidimensionality increases greatly with various combinations of the above.

The specific distinctive contributions of remote sensing in providing resources data are:

- Spatial comprehensiveness
- Accessibility
- Flexibility of aggregation
- Comparability of data
- Synoptic view
- Monitoring
- Historical record capability

The major technology elements that need consideration in the design of the remote sensing system are:

- All weather data for timely applications
- Near-real or real-time data delivery and data continuity
- Consistent data coverage with reliable data format
- Image quality
- Integration of existing ground data and airborne data

- Data registration from multiple sources
- Use of multiple spectral bands
- Evolving geographic information system
- Research & development
- Joint and pilot experiments.

There are also some present obstacles that include:

- Data continuity problems
- Costs
- Communication gap between researchers & users
- Lack of coordination, lack of expertise and institutional problems.

The Remote Sensing techniques proved very valuable in the meteorological applications for inferring the clouds and their movements for predicting the weather conditions. Many land-related applications have been experimented with remote sensing data, with both aircraft and satellite data in different disciplines world-over viz. agriculture, water resources, geological mapping, cartographic applications etc. There have been many US satellites launched for land applications - Landsat 1, 2, 3, 4 and the recent one Landsat 5 launched in the month of March 1984, which has a high resolution sensor - the Thematic Mapper with 30 m spatial resolution and seven spectral -bands.

THE BHASKARA UTILISATION

In India since 1970 the remote sensing techniques have been tested with a modest beginning involving aerial surveys followed by experimental Bhaskara satellites 1 and 2, and small-size experimental satellites Rohini 1 and 2. The Bhaskara satellites carried two types of sensors: (i) Microwave radiometers and (ii) TV cameras. The frequencies for microwave radiometers were 19 GHz, 22 GHz and 31 GHz. The TV cameras had visible band (0.54 - 0.66 micrometer) and the near IR band (0.75 - 0.85 micrometer). The Bhaskara-I was launched on June 7, 1979 while Bhaskara-II was launched on November 20, 1981. The SAMIR data (19 GHz, 22 GHz, 31 GHz) was used for meteorological and oceanographic applications and experimental studies viz:

- Sea-state (sea surface temperature, winds)
- Water vapour and liquid water content
- Rainfall rate

The broad applications experimented with TV Camera data are on:

Land cover mapping	1:2 M scale (10 maps)
	50% of the geographical
	area of the country.

Forest mapping	Sunderbans (West Bengal) Chotanagpur, Cuddapah (Andhra Pradesh)
Snow mapping	Beas-Sutlej basin
Geological studies	Varanasi & Calcutta, Bombay, Kanyakumari (broad lithological units)
Vegetation & drought mapping	Karnataka, West Bengal, Orissa, Gujarat Different vegetation density classes
Flood plain mapping	Gangetic plains

The Bhaskara experience has paved the way for planning the semi-operational satellite - Indian Remote Sensing Satellite IRS-1, scheduled for launch in 1987/88. It would have the state-of-art sensors - Charge Coupled Devices (CCDs) and the payloads would provide data with two spatial resolutions of 73 m and 36.5 m at 4 spectral bands tuned for various applications. The IRS Mission objectives are:

- o Design develop and deploy three axis stabilised sunsynchronous satellite with multiple solid state push broom cameras
- o Establish and operate ground based system, spacecraft control, data reception and recording, procesing, data product generation, analysis and archival
- o Use IRS and other satellite data for evolving National Natural Resources Management System (NNRMS) for survey and management of natural resources (agriculture, hydrology, geology etc.)

An IRS-Utilisation Programme has also been planned with the following objectives:

- o Use IRS-1 Data in selected areas of resources viz., Agriculture, Hydrology, Geology and Environment
- o Technology transfer to user agencies
- o Infrastructure to support remote sensing based information
- o Inputs to IRS-1 follow on

In the above programme 16 projects have been formulated and would be conducted in the next few years.

EARTH OBSERVATION SYSTEMS PROGRAMME OFFICE

Considering the overall programme of the Department of Space in Earth Observations, and the main thrust areas of the

Department of Space for the indigenous development of Indian Remote Sensing, and all future satellites, an Earth Observation Systems/NNRMS Office has been set up at ISRO Headquarters.

Evolution of NNRMS

Considerable infrastructure for data collection, data processing and analysis has been built up at the two main nodal Centres of the Department of Space - Space Applications Centre (SAC), Ahmedabad and National Remote Sensing Agency (NRSA), Hyderabad. The regular training activities are concentrated at the Indian Institute of Remote Sensing (NRSA), Dehra Dun. There are many user departments (central/state government organisations/departments and academic institutions) that conduct experiments with the remote sensing data. In the recent past, the process of integration of the remote sensing data with the conventional data is being studied for evolving the National Natural Resources Management System (NNRMS). After many discussions with user ministries/departments, a Preparatory (Planning) Committee (PC-NNRMS) has been constituted with Member (S & T), Planning Commission as Chairman and Secretaries of Department of Space, Department of Agriculture and Co-operation, Dept. of Agricultural Research and Education; Department of Science & Technology, Dept. of Mines, Department of Environment, Department of Ocean Development, Department of Forest & Wild-life, and Member (Finance), Space Commission as members. There are 10 members with Secretary to PC-NNRMS from Department of Space (Table 1A).

The Planning Committee constituted a Standing Working Group (SWG) with Convenor from DOS and other members from various Central Government Ministries/Departments. The details of SWG are given in Table 1B. While PC-NNRMS gives the broad guidelines on the various tasks towards the operational use of Remote Sensing, the SWG organises the modalities of operationalisation and experimentation.

Among the various experiments and studies carried out by different organisations, keeping the end-to-end concept and the role of remote sensing in generating the required information, sixty experiments were selected for evaluating the role of remote sensing for resources management.

NATIONAL SEMINAR ON NNRMS: END-TO-END EXPERIMENTS; SALIENT

RESULTS

Scientists belonging to different organisations have thoroughly reviewed these experiments and also prepared a set of 20 review papers and summary reports. These review papers, summary reports and the end-to-end experiments were presented by the concerned scientists at a National seminar organised by the Preparatory Committee (The Preparatoy Committee has been

Table 1A
The Members of the Planning Committee: NNRMS

1. Members (S&T)	
Planning Commission	Chairman
2. Secretary, Dept. of Space	Member
3. Secretary, Dept. of Science & Technology	Member
4. Secretary, Dept. of Mines	Member
5. Secretary, Dept. of Agriculture & Cooperation	Member
6. Director General, ICAR & Secretary, Dept. of Agricultural Research & Education	Member
7. Secretary, Dept. of Environment, Forests and Wildlife	Member
8. Secretary, Dept. of Ocean Development	Member
9. Member (Finance) Space Commission	Member
10. Director, Earth Observation Systems Programme Office, Dept. of Space	Secretary

Table 1B
Members of Standing Working Group for NNRMS

o Scientific Secretary, ISRO/Director EOS Department of Space	Convenor
o Representatives from Department of Space	
- Space Applications Centre,	Member
- ISRO Satellite Centre,	Member
- National Remote Sensing Agency	Member
o Representatives from Department of Science & Technology	
- Department of Science & Technology	Member
- Survey of India	Member
- National Atlas & Thematic Mapping Organisation	Member
o Representatives from Ministry of Agriculture	
- Economic & Statistical Adviser	Member
- All India Soil & Land Use Survey Organisation	Member
o Representative from Indian Council of Agricultural Research	
- National Bureau of Soil Survey & Land Use Planning	Member
o Representative from Dept. of Mines	
- Geological Survey of India	Member
o Representative from Dept. of Forest & Wildlife	
- Forest Survey of India	Member
o Representative from Dept. of Ocean Development	
- Dept. of Ocean Development	Member
o Representative from Dept. of Environment	
- Dept. of Environment	Member
o Representative from Planning Commission	
- Planning Commission	Member
o Representative from Ministry of Irrigation	
- Central Water Commission	Member

renamed as Planning committee after the National Seminar at NRSA - Hyderabad during 10 - 12 May, 1983. In the 3-day Seminar on National Natural Resources Management System about 500 delegates from various organisations coming from different parts of the country participated. A 16-point resolution has been passed by the participants after the seminar (Appendix I). Table 2A shows an overview of the papers presented at the seminar. The salient details of the presentation made conclude that for:

Macrolevel planning	Satellite data is adequate.
Landuse mapping	is operational with satellite data.
Snow survey, surface water mapping, and flood mapping	is operational with satellite data.
Ground water resources	modelling is required.
Base metal mineralisation	Combination of data of multi-sensors is required.
Agriculture	High resolution data and modelling are main requirements.
Ground truth and spectral signatures	A great requirement is felt in the data analysis.
Training and digital analysis	are felt as very important components in the data utilisation.

The present status of the major application themes is given in Table 2B.

REGIONAL REMOTE SENSING DATA PROCESSING SERVICE

CENTRES (RRSSC)

The Planning Committee (PC-NNRMS) discussed the requirements of Regional Remote Sensing Data Processing Service Centres for Remote Sensing. It was decided that it would be essential to have five regional facilities in the country to generate necessary trained manpower for machine processing of the remotely sensed data and also collateral data which will be used in resource management. It was decided by PC-NNRMS that this facility should be a service facility for various users while the host institution could also use it for its remote sensing work, strictly on queue basis. Considering the complexity of user requirements, the essential infrastructure support for such facilities and the need for some dispersal of the facilities in various regions of the country to maximise

Table 2A
Overview of Papers Presented at NNRMS - National Seminar

Theme no.	Theme name	Number of end-to-end experiments	Number of review papers
I	Agriculture/forestry/soils	15	4
II	Water resources	9	2
III	Geology, mineral & petroleum	8	2
IV	Cartography/land use	6	2
V	Environmental monitoring & protection	1	1
VI	Marine resources, oceanography & coastal engineering	6	3
VII	Disaster warning	-	1
VIII	Basic sciences/research	4	1
		49	16

Table 2B
Status of the Major Application Themes

o Forestry, agriculture and soil	Broad categories/classes demarcated High-resolution data at frequent intervals for crop classification/species identification Modelling for yield prediction (to be developed)
o Water resources: Surface water mapping, snow survey, snowmelt runoff, flood mapping	Operational
Ground water targetting in hard rock areas	Operational Modelling required for estimation
o Geology	Geological mapping/structures at regional level: operational
Mineral & petroleum resources	Combination of data with multisensors is required
o Cartography/land use	Operational
Macro-level planning:	Operational to the scales of the satellite resolutions
Land use planning:	Semi-operational; multi-sensor data required
o Environmental monitoring & protection	
o Marine resources oceanography and coastal engg.	Potential areas of application need more experimentation
Sediment movements, littoral process, chlorophyll mapping	New areas of work and emerging applications
o Disaster warning	Cyclones operational; others need more experimentation

utilisation, the locations of the facilities were decided. The details of the locations in different regions and the funding agencies for the Centres are given below:

Region	Location	Funding agency
Northern India	Dehra Dun	Dept. of Space
Central India	Nagpur	ICAR, Min. of Agriculture
Eastern India	Kharagpur	Dept. of Science & Technology
Southern India	Bangalore	Dept. of Mines
Western India	Jodhpur	Dept. of Science & Technology/ Dept. of Space.

It was decided that these units would be initially run by the Department of Space and there would be a common user Committee which will issue guidelines for training, software development, identifying the priorities etc. so that a roughly uniform service to remote sensing and resource management users is provided. A Committee was constituted by the Department of Electronics to study the technical aspects in the requirements of the digital interactive computer system and other related facilities for the regional centres. The broad details of the facilities that would be available at each of the RRSSCs are given in Table 3. The work on establishment of the different Centres is progressing well and the staff for these RRSSCs include resource scientists, computer specialists and other administrative staff. These staff would be working for rendering services in the Regional Centres to all its users/user departments.

IRS-UP JOINT EXPERIMENTS OF DOS WITH USER DEPARTMENTS

Considering the various studies carried out earlier, and particularly considering the IRS-Sensor specifications, which include 2 different types of sensors at two different resolutions of 73 m and 36.5 m at 4 narrow spectral bands, the application thrust has been on the agriculture-related studies. A set of 16 projects are planned under different categories. They are proposed to achieve a gradual operationalisation of the applications. However, all the applications may not become operational within the IRS-1 time-frame because of the difference in the level of maturity of these applications. Some of these applications have advanced to a level of near-operationalisation while some others are still at the proof-of-concept stage. On this basis the sixteen projects have been categorised into the four groups OAP, QAP, EAP and TDP.

Table 3
Facilities at RRSSCs

INTERACTIVE IMAGE PROCESSING SYSTEM

Computer Configuration

- o CPU - 32 bit processor
- o Main memory - 2 MB (expandable to 8 MB)
- o Add-on array processor
- o On-line storage
 - 2/3 disk drives (600 MB)
 - Expandable to 8 drives (1.8 B)
- o Tape Units
 - 2 drives
 - 800/1600 BPI, 125 IPS, 9 track
- o Printer plotter
- o Map digitizer
- o Intelligent image graphics terminal
 - 3 imported, 3 indigenous
 - 19" screen
 - 512 x 512 viewable matrix
 - 1024 x 1024 addressable matrix
 - 250 colour/gray levels
 - Colour pallet - 4096
 - Zoom, PAN, SCROLL
 - Multi-Image capability
 - Split screen display
 - Graphic overlay
 - Superimposition of images
 - Graphic tablet

- Software** - Operational system
 multi-user, multi-programming,
 - FORTRAN - 77, COBOL - 80, PASCAL
 - Networking software
 - Sort/merge, PERT/CPM, DBMS
 - Statistical and scientific library

Visual Interpretation Aids		Stereoscopes
Stereoscopes	...	6
B-2 Image enlarger	...	1
Densitometer	...	1
Optical pantograph	...	2
Diazo printer	...	1
Stereo zoom transfer-scope	...	1
Electronic planimeter	...	1
X-Ray film viewers	...	4
Audio-visual training kit	...	1

- A. Operational Application Projects (OAP)
 - 1. Regional Geological Mapping
 - 2. Ground Water Exploration
 - 3. Flood Mapping
- B. Quasi-Operational Application Projects (QAP)
 - 1. Land use, Land Cover Survey and Monitoring
 - 2. Land Degradation including Desertification
 - 3. Snow Mapping
 - 4. Drought Monitoring
 - 5. Soil Mapping
- C. Experimental Application Projects (EAP)
 - 1. Crop Production Forecasting
 - 2. Forest Mapping and Damage Detection
 - 3. Water Quality Monitoring
 - 4. Watershed Characterisation
 - 5. Monitoring of Coastal Environment
 - 6. Marine Fisheries
- D. Technique Development Projects (TDP)
 - 1. Crop Stress Detection
 - 2. Crop Yield Modelling

Proposals on the various requirements for the above studies are drawn up and the required infrastructure/manpower is worked out. Active user involvements would be there for these studies. User departments are identified for each of the projects.

REQUIREMENTS PROJECTED BY THE NATIONAL TASK FORCES FOR EVOLUTION OF NNRMS

One of the resolutions of the NNRMS - National Seminar recommended setting up of National Task Forces for specific applications addressing themselves to questions of technical suitability, cost effectiveness, accuracy and integration of remotely sensed data with data obtained through traditional techniques. Accordingly the Planning Commission constituted the following nine task forces in February 1984 on:

- 1) Agriculture (TF-A)
- 2) Cartographic Representation of Data (TF-C)
- 3) Forestry (TF-F)
- 4) Geology (TF-G)
- 5) Natural Resources Information System (TF-N)
- 6) Oceanography, Marine Resources & Coastal studies (TF-O)

- 7) Soil & Land Use (TF-S)
- 8) Urban & Rural Studies (TF-U)
- 9) Water Resources (TF-W)

The terms of reference for the above task forces are:

- To study the present activities of the existing information systems (IS), data processing and management aspects in the natural resources and identify the
 - o Elements amenable to remote sensing,
 - o Areas of operational systems,
 - o Support required,
 - o Estimate average information generation and turn over,
 - o Training programme,
 - o Improvements for technology transfer,
 - o Application of IS to management system,
 - o Role of remote sensing to substitute/complement/supplement the conventional methodology,
 - o Manpower/finance/time/equipment, and
 - o Support/coordination requirements to achieve maximum results cost-effectively.

The Task Forces on the resources themes have conducted comprehensive studies of the tasks involved in each discipline for operationalisation of Remote Sensing technology to evolve an NNRMS. The major recommendations of the Task Forces included the details on:

- o Setting up of remote sensing cells/units in the concerned department(s)
- o Strengthening the existing facilities at national/state level organisations
- o Liberalisation of the security classification of aerial and other remote sensing data
- o Data supply including special surveys and map making facilities
- o Preparation of nation-wide status maps for different themes (such as 1:1M, 1:250,000, 1:50,000 etc).
- o Training at different levels
- o Higher education
- o Research and development studies
- o Pilot studies/joint experiments at different levels (district/state/national).
- o Uniform quantitative definitions and terminology of the attributes in different themes
- o Role of remote sensing - supplementary/complementary
- o Digital cartographic data base/geographic information system (GIS)
- o Improve working conditions and promotional opportunities
- o Symposia/workshops - literature dissemination (bulletins)
- o NNRMS house - as an information centre

The Task Forces on Cartographic Representation of Data (CARD) and Natural Resources Information System (NRIS) are studying the details of the reports of the Task Forces on

resource themes, to evolve the basic details of the information system and its associated organisation of the necessary data base systems.

The information needs, the existing system of information for different resources and the gaps in the existing system of information are given in the Task Force Reports. Considering the various applications and the elements amenable to remote sensing, the infrastructure and facilities required for setting up of remote sensing cells, units and State Centres are considered. The requirements of satellite data (present and future) are also considered. The remote sensing cells and units would be equipped with low-cost equipment and other conventional interpretation facilities. The requirement of aerial photography for various studies particularly to develop methodology for integrating the satellite and aircraft data with ground data to evolve an NNRMS Information System are also considered.

Elements Amenable to Remote Sensing

The elements amenable to remote sensing have been identified on the basis of present use of remote sensing in India, the capabilities of systems which may be available in the near future and the present research trends in India and abroad.

The amenable elements have been classified under the heads "presently operational", "operational in the next five years" and "experimental". This classification gives a good guideline for the directions in which NNRMS should progress.

The main plank on which considerable experience has been gathered is the LANDSAT and the aerial remote sensing surveys. Hence, most of the operational applications are based on this experience. These are:

- i) Broad land use/land cover delineation and changes in the same due to natural causes and human intervention.
- ii) Mapping geology on a regional scale for applications in mineral exploration, ground water exploration (inclusive of targetting), engineering projects (irrigation and power), and monitoring of environmental aspects related to geology;
- iii) Mapping of soils at rapid reconnaissance level and land degradation at regional level;
- iv) Delineation of water bodies and flood-affected areas;
- v) Mapping snow-covered areas over land;

Applications which are likely to become operational over the next five years based on availability of data from future satellites (Indian Remote Sensing Satellite (IRS), Landsat Thematic Mapper, Systeme Probatoire d'Observation de La Terra (SPOT), Metsats etc.) and present research directions are:

- i) Mapping drought - affected areas
- ii) Mapping of forest types, classifying degraded forests
- iii) Assessing damages in forests due to fires, cyclones, landslides, etc;
- iv) Preparing semi-detailed land use maps including urban and regional land use;
- v) Monitoring waterlogged and saline areas
- vi) Coastal vegetation and monitoring, shoreline change monitoring, near-shore shallow water bathymetry, sediment movement etc.

Applications which are considered to be experimental and require considerable research efforts using advanced technologies and sensors such as microwave sensors, high resolution sensors, special models combining multistage stratified random sampling strategies etc., are:

- i) Crop inventory, agrometeorological models for yield, crop production estimation, crop stress studies etc.;
- ii) Delineating pure stands of forest species, site condition and identification, damage assessment in forests due to pests and diseases;
- iii) Reconnaissance level and semi-detailed soil and land use maps using multistage stratified remote sensing models;
- iv) Estimation of areal precipitation, mapping snow and estimating water equivalent of snow, estimating soil moisture, developing rainfall run-off models;
- v) Mapping chlorophyll in oceans, ocean fronts, currents, pollution, wave structures, fish schools, precipitation over ocean, air-sea interaction, climate, ocean topography, mapping land and sea ice (this is very specific to Antarctic research) etc.

While the above gives a brief resume of the recommendations of the various task forces, specific details related to setting up of Remote Sensing Cells/Units, augmentation of facilities at the national institutes, data supply, map making and liberalisation procedures, training & higher education requirements including R & D, joint experiments including pilot studies, information systems and geographical information system (GIS), NNRMS-House etc. are given in the TF Reports. Most of the task forces have gone into great depth in classifying the applications by data source, stages of survey, level of details and type of information required.

The Task Force on Urban and Rural studies has identified its special requirements of large scale aerial surveys for cadastral mapping as well as urban land use. For this purpose, it has specifically stated the inadequacy of satellite remote sensing data and therefore suggested the application of large scale rectified aerial photographs as base maps.

The Task Force on Forestry also recommended aerial surveys at the required times at scales suited for forest applications.

Required Remote Sensing Facilities

All the Task Forces have brought out the need to set up Remote Sensing Cells/Units. However, the conceptual framework slightly differs from task force to task force. As a general guideline, the following definitions are used for the Cells/Units.

Remote Sensing Cell: A Remote Sensing Cell would have facilities for interpretation of the data, based on visual/manual analysis of the imagery.

Remote Sensing Unit: A Remote Sensing Unit would have, apart from visual interpretation facilities, a small stand-alone interactive digital image processing system.

Remote Sensing Centre: A Remote Sensing Centre (as a State level facility) would have full-fledged facilities for visual and digital analysis of the remotely sensed data. The centre would have a major interactive image analysis system.

All the three types of facilities would have other essential facilities viz. (photographic facilities, ground truth data collection etc).

Training

A three-tier programme has been envisaged and recommended by various Task Forces, that is for decision makers/resources managers, resources scientists and technical personnel, respectively.

The training for the resources managers/decision makers would be typically at the appraisal level only, which could be 3 to 5 days. The training of resources scientists/Technical personnel could be for 3 months or more.

The training would be imparted by Indian Institute of Remote Sensing Dehra Dun, National Remote Sensing Agency, Hyderabad, Space Applications Centre, Ahmedabad and all the NNRMS Regional Remote Sensing Service Centres. These training programmes, however, will be supplemented by the training facilities being provided by the Centre of Studies in Resources Engineering (CSRE), Indian Institute of Technology, Bombay; Institute of Remote Sensing, Anna University, Madras and other Universities and academic institutions.

It was also recommended by some task forces that a certain number of scientists should be sent for advance training abroad. It has also been suggested that the Department of Space should act as the nodal agency for arranging the advanced training in remote sensing in developed countries.

The general assessment is that 300 persons (resources

scientists and technical personnel) will have to be trained in each major discipline to cater to the needs of National Natural Resources Management System (NNRMS) in the next five years. In all about 2,000 people will have to be trained in the next five years for all levels including the decision makers/resource managers and resource scientists and technical personnel. The levels of training are at 3 different levels as mentioned earlier. These figures are typical estimates from the trends that have been noticed. So far in the country about 1,850 people have been trained (at the various institutes in the country including the DOS Centres) in different disciplines such as remote sensing (general), photo-grammetry, image processing, water resources, agriculture and earth sciences. This includes the people trained at Indian Institute of Remote Sensing, Dehra Dun (formerly IPI) and other academic institutions. About 60 per cent of this training was done in the VI Five Year Plan period. However, quite a few of these trainees were given training only at appraisal level lasting for less than a week.

It has been recommended that Remote Sensing education should form a part of the curricula of all the Post-Graduate Courses in the universities and technological institutions. Academic research programmes leading to Master's Degree or Ph.D. should be encouraged in all the universities and technological institutions.

STANDING COMMITTEES

While the Task Force deliberations are going on, 8 Standing Committees have been constituted. They are:

Standing Committee	Chairman
i) Agriculture & Soils (SC-A)	Secretary, DARE & DG-ICAR
ii) Bio-resources & the Environment (SC-B)	Secretary, DOEn.
iii) Cartography & Thematic Maps (SC-C)	Secretary, DST
iv) Geophysical & Mineral Resources (SC-G)	Secretary, DOM
v) Ocean Resources (SC-O)	Secretary, DOD
vi) Remote Sensing Technology including space segment & data products (SC-R)	Secretary, DOS
vii) Training & Manpower (SC-T)	Secretary, DOS
viii) Water Resources (SC-W)	Chairman, CWC

The terms of reference for these committees are to:

- o Advise on the methods of using remote sensing technology for operational use and integrating with existing system.

- o Identify key issues in the management.
- o Study the national requirements and identify improved methods and data sources.
- o Identify supporting research, training, joint experiments and technology transfer.

These standing committees would specifically deal with the major issues on behalf of PC-NNRMS and advise on the methods of using the remote sensing technology for operational use for the management of the natural resources in the country.

They would identify the improved methods for the management of resources by integrating conventional surveys and remote sensing techniques and generate specific national programmes/projects.

Considerable effort is involved in bringing out the impact of use of remote sensing in the departments where concerted efforts would be done in the course of next few years. Besides the technical competence, there are many other organisational matters involved in this venture. There are focal points named in many central/state government departments.

RESPONSIBILITY OF EVOLVING THE JOINT PROJECTS OTHER THAN IRS-UP AT DIFFERENT LEVELS FOR EVOLVING NNRMS

One of the resolution elements of the National seminar is on evolving the Joint Experiments (other than IRS-UP) at different levels district/state/regional/national. Many studies related to crop signatures, ecological monitoring, etc. have been studied as joint projects for defining the sensor parameters of Indian Remote Sensing Satellite (IRS). The experience of these studies has given enough insight on the approach of the problem particularly at user departments/academic institutions/government laboratories etc.

There are some joint projects that are initiated between Department of Space - Department of Forest and Wild Life on updating of forest maps in a few states. This is one of the typical examples of a large scale study under NNRMS. This particular example of mapping of forest areas in a few states, would be giving many lead steps in the overall system management for forests. It is expected that with improved resolution/spectral/multidate data many other applications in the forestry sector would slowly grow from experimental stage to operationalisation. Many such studies have to be experimented and studied at various levels before the Information System could be generated for NNRMS (NNRMS-IS).

The various application themes that are at various stages of maturity and for which the information is required in the resources management by different central/state government

departments are on the following topics:

- Agriculture/soils
- Cartography and mapping application
- Disaster warning and assessment
- Environment/ecology studies
- Forest management including wildlife protection
- Geology and mineral resources
- Land use mapping and urban development studies
- Oceanography and marine resources
- Rangeland management
- Water resources

In addition there is an urgent requirement of training the required manpower for executing the various studies/projects in different central/state government departments.

In the different 10 major themes of applications in the resources management, various studies have to be conducted at district/state/regional/national levels before the information systems could be conceived towards NNRMS.

To organise the various studies, expert scientists and knowledgeable persons have to evolve the themes and projectise the requirements and coordinate with the concerned organisations. The projects have to be inter-departmental, multi-theme oriented so that maximum utilisation of the data could be achieved with the remote sensing techniques. Such projects have to be evolved for the Indian conditions particularly where applications have been proven and more so for those applications where considerable research effort is involved. A prioritisation could be done for each of the themes for arriving at a few core projects (5 to 7) that could be undertaken in each of the themes.

LOW COST EQUIPMENT

One of the important items that was discussed by PC-NNRMS was on Low-Cost Equipment (LCE) required for the analysis of the remote sensing data. Secretary, DOS had constituted a Committee for studying the technology transfer of remote sensing equipment/aids, developed/under-development in ISRO/DOS. The committee has studied the matter in detail and considering the requirement and status of development, the following equipment have been recommended to be given priority for technology transfer to industry.

Equipment developed by DOS for which the technology is transferred to industry are as follows:

INSTRUMENT	DEVELOPED BY	TECHNOLOGY TRANSFERRED TO
1. Spectroradiometer	ISAC	Hind High Vacuum Ltd., Bangalore. National Instruments Ltd., Calcutta
2. Optical Reflecting Projector	NRSA	Optomech Engineers, Hyderabad
3. Dual Densitometer	NRSA	Doschen India (P) Ltd., Bombay
4. Illuminating Magnifier	NRSA	Dynascan inspection systems Co., Bangalore
5. Analog Image Analyser	NRSA	Speck Systems, Hyderabad
6. Large Format Optical Enlarger	SAC	Optomech Engineers, Hyderabad
7. Diazo Printer	SAC	Optomech Engineers, Hyderabad
8. Multiband Ground Truth Radiometer	SAC	Optomech Engineers, Hyderabad
9. Agro-Photometer	ISAC	Optomech Engineers, Hyderabad
10. Variable incident angle spectro- photometer	ISAC	To be Decided
11. Multispectral Colour Additive Viewer	NRSA	Remote Sensing Instruments, Hyderabad
12. Light Table with coordinate measur- ing system	NRSA	Remote Sensing Instruments, Hyderabad

NNRMS ACTIVITIES

A Bulletin of National Natural Resources Management System (NNRMS) is being published (presently twice a year) as an information medium for exchange of suggestions and ideas among the different scientists, planners and decision makers. The details on the following are included in the Bulletin:

- NNRMS Activities
 - Evolution of the System (Task Forces, Standing Committees and their progress)
 - Regional Remote Sensing Service Centre (RRSSC)
 - Low Cost Equipment (LCE)
- ISRO/DOS Activities
 - Indian Remote Sensing Satellite (IRS)
 - Indian Remote Sensing Satellite - Utilisation Program (IRS-UP)
 - Data Supply and availability

- Projects/Studies carried out
 Data Utilisation of other satellites
 Digital processing facilities being developed in the country
- o Remote sensing activities in State Centres and User Cells/User Departments
 - o International scene in Remote Sensing
 - o Special articles on specific themes related to NNRMS
 - o Highlights of the Symposia held on Remote Sensing and Publications
 - o Short courses and forthcoming symposia/workshops/seminars
 - o Training and other opportunities

The bulletin is presently issued twice a year in the months of February and August. It is envisaged that this bulletin is useful for various scientists, planners, decision makers, resources management personnel.

APPROVAL FROM GOVERNMENT OF INDIA FOR IMPLEMENTATION OF NNRMS BY DEPARTMENT OF SPACE

Considering the progress made in NNRMS and recognising all the efforts made by Department of Space so far, Government of India has approved the following:

- i) The Department of Space (DOS) will be the nodal Department of the Government of India charged with the responsibility of establishing the National Natural Resources Management System. The Department of Space will be responsible for the generation of integrated data for the NNRMS mainly based on remote sensing. The Department of Space will also assist in the analysis and dissemination.
- ii) The responsibility for utilising the analysis and information for executive action will continue to be with the respective Central and State Government agencies.
- iii) The Department of Space will speedily install and initially manage, on behalf of the different funding organisations of the Government of India, a set of five Regional Remote Sensing Service Centres as Service Facilities for various users in the geographic region being served, and also a few other Centres as may be decided upon by the Planning Committee of National Natural Resources Management System (PC-NNRMS) subsequently.
- iv) All Ministries/Departments and other agencies of the Government of India will take action to implement the various points indicated in the Resolution passed at the National Natural Resources Management System - National Seminar (NNRMS) - copy enclosed as Appendix 1 - as efficiently and rapidly as possible.
- v) The State Governments/Union Territories and their agencies will be requested to contribute similarly, especially in view of the Indian Remote Sensing Satellite (IRS) series, the first satellite of which is scheduled for launch in

Table 4
Overview of State Centres/Cells

- Already established:
1. Remote Sensing Applications Centre - Uttar Pradesh 1981
 2. Indian Institute of Remote Sensing - Anna University 1983
 3. Centre for Resources Studies - Visakhapatnam 1984
 4. Centre for Studies in Resources Engineering,
Indian Institute of Technology, Bombay 1976
- o Other States Planning for establishing State Centres are:
Karnataka, Rajasthan, Orissa, West Bengal, Madhya Pradesh
- User cells: Many user cells are established in the country
viz. in Departments of Geological Survey of India, Central
Ground Water Board, Indian Institute of Technology
(Kharagpur), Ministry of Agriculture, Central Water
Commission. The typical costs of a user cell ranges from
Rs. 5 lakhs-45 lakhs
while the State Centre would be around Rs.100 lakhs.

1987/88.

- vi) The Planning Committee of NNRMS (PC-NNRMS) is empowered to supervise and coordinate the speedy implementation of the National Natural Resources Management System based on the broad principles indicated above, with a Natural Resources Information System as a part of NNRMS integrating conventional information system relating to natural resources with satellite and other remote sensing technology, for improved acquisition, analysis and Utilisation of data for national development.
- vii) All concerned will gear up the existing organisations and mechanisms for maximum utilisation of remotely sensed data for efficient study and integrated management of natural resources.
- viii) The Department of Space will provide secretarial and servicing support to the PC-NNRMS.

SOME IMPORTANT POINTS ON "INTEGRATIVE APPROACHES IN REMOTE SENSING IN EVOLVING NNRMS"

There is a great amount of work involved to understand the basic measurement processes in remote sensing for use as an operational tool for the majority of applications in evolving NNRMS. The following are some of the areas where considerable effort is needed:

- o Data integration methods from multi-sources need to be evolved.
- o In comparing and correlating images from different sources e.g.: LANDSAT, NOAA, METEOSAT, INSAT, SAR, etc., there are many problems. This is an important research area.
- o There is a great need of geocoded thematic data for any comparison of remote sensing and ancillary information.
- o Field observations/spectral signatures are very important to resolve the ambiguities and the cluster confusions.
- o Integration of data of NOAA and LANDSAT would be useful for land use applications. However, there are many problems in the integration of such data sets.
- o There are many problems in understanding the SMMR results of snow at 6.6 GHz, 18 GHz, 37 GHz etc.,
- o Only by accepting gross and unwarranted hypotheses the requirement for groundbased data can be overcome.
- o The potential application studies on crop diseases and diseased forest trees need more detailed spectral signatures.
- o Effects due to direction of the observations and sensor view angle are very significant and need special emphasis.
- o The chances of carrying out automated classification is less promising. Integrated methodology has to be worked out for each of the applications.
- o To use all data contained in the data base in a synergetic manner, the geometric relations have to be established and maintained. Imagery should be geocoded i.e. brought to a

unique cartographic projection with a resolution according to the image source.

- o The main questions in the next few years are:

Complementarity of data from visible, near infrared, thermal infrared and microwave regions.

Limitation of data flow - onboard processing, compression and selection.

Operational use of Space Camera.

WHAT FURTHER IS TO BE DONE

- o Assess the adequacy/inadequacy of the conventional measurements made on each of the parameters with regard to their spatial and temporal frequencies, accuracy and suggest improvements to be made in each of the themes in various resources management.
- o Develop the relationship between the identified parameters to elucidate the phenomena so that operational procedures could be evolved.
- o Develop forecasting models and simulate test results where applications are at experimental level.

REMOTE SENSING OF SOIL MOISTURE AND CROP-WATER STRESS VIA ALBEDO MEASUREMENT

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ABSTRACT

Albedo measurements show potentiality in determining soil water content and onset of irrigation initiation level of water stress in wheat (*Triticum aestivum* L.). During December 27, 1983 to March 12, 1984, normalized albedo of smooth bare sandy loam soil was 0.136 ± 0.004 on day 1 after irrigation and 0.249 ± 0.002 at air dryness. Normalized albedo was linearly related with water content of the surface 0-0.5 cm soil layer in the range of 0.28 to 0.04 $\text{cm}^3 \text{cm}^{-3}$. Results reveal that normalized albedos of 0.235, 0.215, 0.200, 0.195 and 0.193 near crown root initiation, late tillering, late jointing, flowering and milk stages of wheat crop may be considered as indicators of irrigation time. Significant correlations were obtained between normalized albedo and volumetric water content ($r = -0.99$), and between wheat yield and normalized albedo measured a week after the milk stage ($r = -0.98$).

INTRODUCTION

Knowledge of soil moisture and crop water stress is essential in timing irrigation (Jensen et al 1970, Jackson et al 1981, Tripathi et al 1983), pest incidence (Chauvin, 1967), persistence of pesticides (Messersmith et al 1971, Spencer and Cliath 1973), planting dates (Slayter 1969, Tyagi and Tripathi 1983) and water balance of a watershed. Parameters adaptable to remote sensing of soil moisture and crop water stress are albedo, colour infrared, thermal infrared and microwaves (Blad and Rosenberg 1976, Idso et al 1975).

Albedo (ratio of reflected to incoming solar radiation) measurements have been found valuable in determining soil moisture (Angstrom 1925, Brooks 1952, Bowers and Hanks 1965, Idso and Reginato 1974, Idso et al 1975) and water stress (Kalma and Badham 1972, Idso et al 1977) routinely over large areas. Simple solarimeters have been used to measure albedo for determining soil moisture in the range from air dry to field capacity (Idso and Reginato 1974). Reginato et al (1975) showed that a simple summation of the different band radiances

measured by a multispectral scanner flown at a 300 m height was as good as the pyranometer data. A linear relationship between normalized albedo and water content of the surface layer of soil has been obtained (Idso et al 1975). The relationship was dependent on soil type. Microwave region of electromagnetic spectrum (0.1 to 80 cm) has shown greater potentiality in determining soil moisture in the active root zone of most agricultural crops (Reginato et al 1975). The intensity of observed radiation in the microwave region is essentially proportional to the product of the temperature and emissivity of the soil-water system and is termed as brightness temperature (Schmugge et al 1974). The brightness temperature was linearly related with soil-water content (independent of soil type) from air-dry to near-saturation at wavelength of 21 cm (Reginato et al 1975). This paper describes the usefulness of albedo in characterizing bare soil water content and onset of water stress in wheat by a simple albedometer.

EXPERIMENTAL PROCEDURE

The experiment was conducted at the Crop Research Centre of the G.B. Pant University of Agriculture and Technology Pantnagar, Naipital in the winter season of 1983. Pantnagar is situated at 28° 26'N latitude and 79° 3'E longitude at an altitude of 244 m above mean sea level in the foothills of the Shivalik range of the Himalaya. The region enjoys humid to sub-tropical type of climate.

Albedo measurements were made from a height of 60 cm over the smooth bare field and wheat (*Triticum aestivum* L.) crop using Kipp and Zonen albedometer (0.3 to 2.5 μ m). Soil of the experimental area was sandy loam containing 1.9 per cent organic matter in the Ap horizon. Wheat variety RR-21 was planted on December 10, 1983 after a pre-sowing irrigation in 8 x 5 m plots separated by 2 m passage on all the sides. Treatments included rainfed (T0); irrigation at crown root initiation (CRI) stage (T1); CRI and late tillering (LT) stages (T2); CRI, LT and late jointing (LJ) stages (T3); CRI, LT, LJ and flowering (F) stages (T4); and CRI, LT, LJ, F and milk (M) stages (T5). Since the equipment was heavy (6 kg), measurements of albedo were made only in the plots with irrigation differences. Thus measurements were made in all the plots only after irrigation at the milk stage. The albedometer mounted on a triangular stand was directed vertically over the north-south rows of the wheat crop. The crop was fertilized as per the soil test value.

Measurements of bare soil albedo were made in the irrigated and unirrigated plots of 8 x 5 m size adjacent to the cropped plots. The plot was irrigated by surface flooding with 6 cm water and allowed to dry. Before starting regular observations, several diurnal measurements of albedo were made in the bare plots to determine the period during the day when

the instantaneous changes were small. As can be seen in Fig. 1, variations in albedo were small during 1130 to 1200 hours, and therefore this was chosen as the time of one's daily-observations on clear days in the cropped and bare plots. Regular measurements in the cropped plots were started from 12th day after sowing following a light rainfall of 10 mm. Diurnal values of albedo were monitored in the bare plots from December 27, 1983, January 18, February 4 and March 12, 1984 on 1, 3, 5 and 14 days after irrigation in the irrigated plot and on the 2nd day in the unirrigated plot drying since 24 days (water content $0.02 \text{ cm}^3 \text{ cm}^{-3}$ in the 0-0.5 cm layer). Measurements were made from sunrise to sunset at 30 minutes interval. Soil moisture was determined gravimetrically in the same plot concurrently from the surface 0-0.5 cm layer similar to those viewed by the albedometer. Surface characteristics of the bare soil did not change significantly during the experiment.

RESULTS AND DISCUSSION

Albedo VS Soil Moisture

Albedo of smooth bare soil at half-hourly intervals on 1, 3, 5 and 14 days after irrigation and in the dry plot (water content = $0.02 \text{ cm}^3 \text{ cm}^{-3}$ in 0-0.5 cm layer) during December 27, 1983 to March 12, 1984 on clear days against local standard time has been presented in Fig 1. General variation show maximum values of albedo at dawn and dusk and minimum during the 1130 to 1200 hours in response to changes in Sun's zenith angle (Fig. 2) at Pantnagar. Also, magnitude of albedo increased with days after irrigation as the soil moisture decreased. For example, on 14th day after irrigation, the bare soil albedo was 1.7 to 1.8 times greater than those on the day 1 (Fig. 1).

In order to remove the effect of Sun's zenith angle, albedo data in Fig. 1 were normalized as described by Idso et al (1975). The normalizing function was obtained by plotting albedo of wet and dry ranges of four months (Fig. 1) as a function of zenith angle (Fig. 3). Average of the two curves (Fig. 3) for wet and dry soil conditions was normalized to zero at zero zenith angle. The normalized values of albedo were obtained by subtracting the normalizing function (Fig. 3) from the raw albedo (Fig. 1) corresponding to the same zenith angle and plotted as a function of local standard time (Fig. 4). As shown in Fig. 4 with the exception to albedo values on the day 1 after irrigation, in the morning when surface soil moisture was relatively high because of dew (soil was darker), the albedo was low as compared to those at noon when the surface soil moisture reduced due to rapid diurnal drying. This is reverse of those presented in Fig. 1 but is in response to moisture changes due to evaporation during the day. Regression of normalized albedo of all the four months pooled together on volumetric water content between 0.04 to $0.28 \text{ cm}^3 \text{ cm}^{-3}$ showed

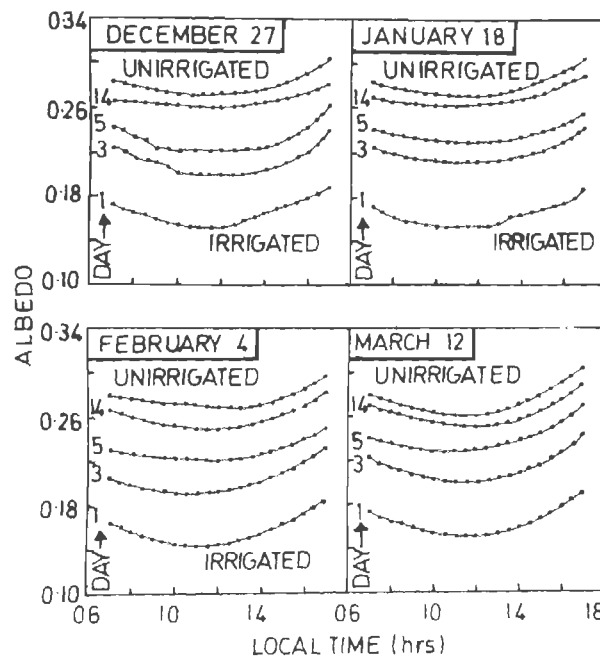


Fig.1 Diurnal variations of bare soil albedo on 1, 3, 5 and 14 days after irrigation and in unirrigated plot on Dec 27, 1983, Jan 18, Feb 4 and Mar 12, 1984.

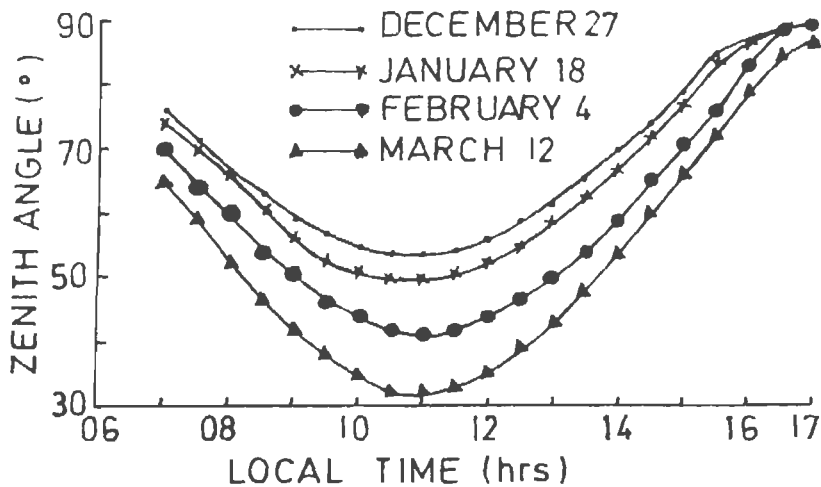


Fig.2 Diurnal variations of zenith angle of the Sun on Dec 27, 1983, Jan 18, Feb 4 and Mar 12, 1984 at Pantnagar.

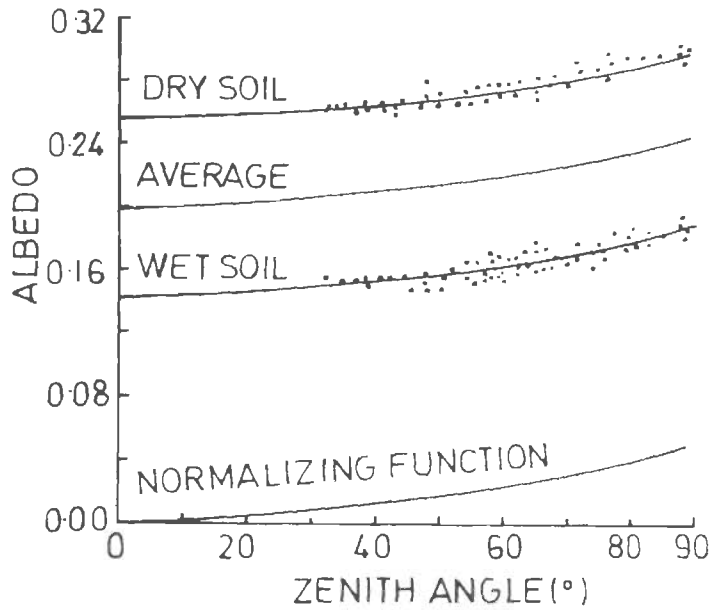


Fig.3 Wet and dry soil albedo as a function of zenith angle and the normalizing function derived therefrom.

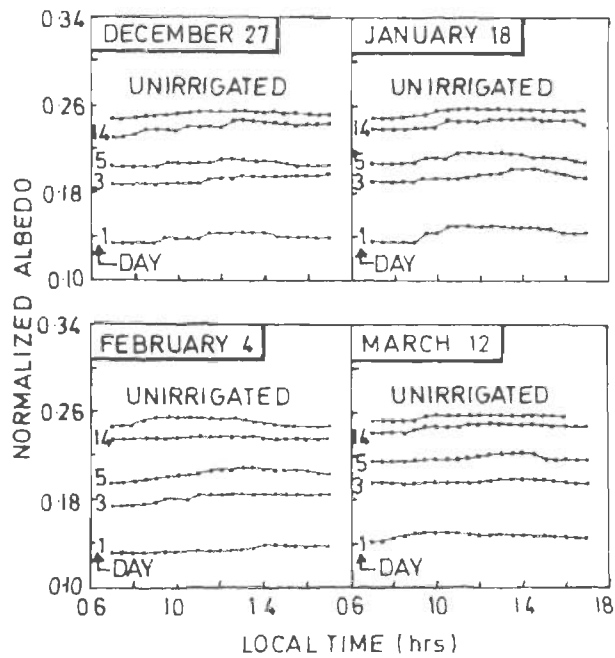


Fig.4 Diurnal variations of normalized albedo of bare soil albedo plotted in Fig.(1).

a linear relationship (Fig. 5). The correlation coefficient was highly significant ($r = -0.99$).

Albedo VS Crop Water Stress

Normalized albedo of wheat crop during 1130-1200 hrs on clear days from 12th day after sowing till maturity in different irrigation treatments has been shown in Fig. 6. Initially when seedlings were just coming up, albedo variations were similar to those in the bare plots. Each value in the figure represents an average of 3 measurements in the same plot at different locations. In the beginning all the treatments were alike and, therefore, only average albedo of the treatments has been presented. Independent values of the treatments are shown only after irrigation differentiations. Broken lines with arrows in Fig. 6 indicate drop in albedo following irrigations or rainfall. Large fluctuations due to rainfall or irrigations in the beginning of the season were reduced as canopy developed.

As shown in Fig. 6 albedo of crop surfaces has certain characteristic features. Initially, there was a sharp reduction in albedo till 70-75 day stage followed by a slow decrease/increase or a constant value upto flowering and thereafter a temporary decrease by irrigation or rainfall before a general rise. Idso et al (1977) showed that the initial decrease in albedo of cropped plots was due to vegetative growth (which progressively covered more and more of the high albedo soil) and later due to the growth of ear heads. The final increase in albedo was associated with senescence (which exposed high-albedo soil) and browning of the crop. Discontinuity in the general decreasing rate of albedo corresponded with 70-90 day stage which was the peak period of ear-head growth and flowering. Reduction of albedo after rainfall or irrigation was not as apparent after the late jointing stage as before.

Although experiment was too simple to reveal a definite value of albedo to signal the onset of water stress yet, some conclusions could be drawn. Figure 6 demonstrates that albedo values lying below the broken line 1 represent unstressed state of wheat crop and those above the line 2 represent overstressed state. The crop needs irrigation at normalized albedo values falling within the two lines. Also heavy rainfall during 69-70 day period brought T2 and T3 together but T0 and T1 were still behaving differently. This shows that T0 was subjected to water stress beyond the critical level during CRI, LT and LJ stages (Fig. 6) and therefore, could not respond to even such a heavy rainfall as T2 to T5 (Hsiao 1973). Similarly T1 was stressed beyond the critical value during 60-65 day stage. Thus values of albedo falling in the middle of the two broken lines 1 and 2 could be considered as upper limit of stress before which wheat crop must be irrigated. However, a more rigorous experimentation would be necessary in different soils and crops to determine the stress state from ground truth measurements

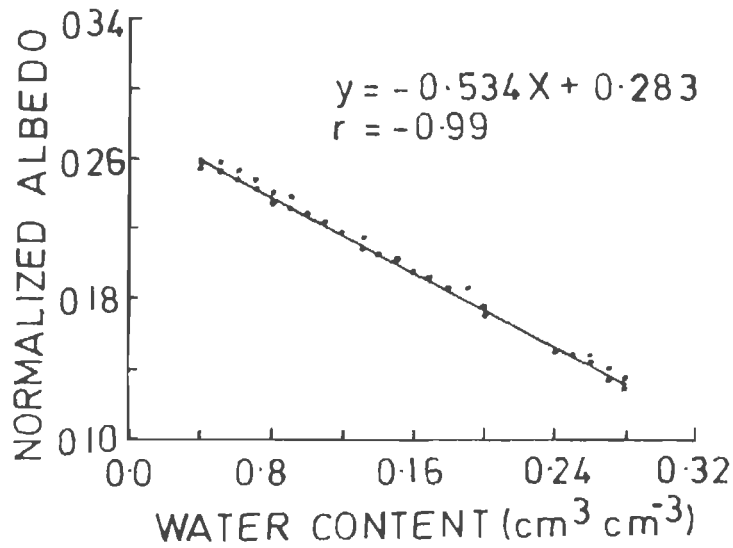


Fig.5 Regression of normalized albedo on water content of surface 0-0.5 cm soil.

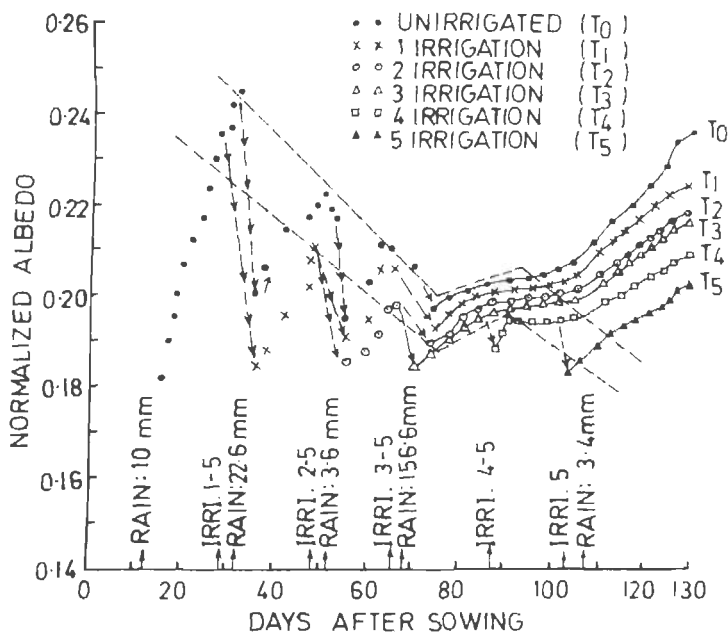


Fig.6 Seasonal progressions of normalized albedo on water content of suof wheat on clear days at different irrigation levels.

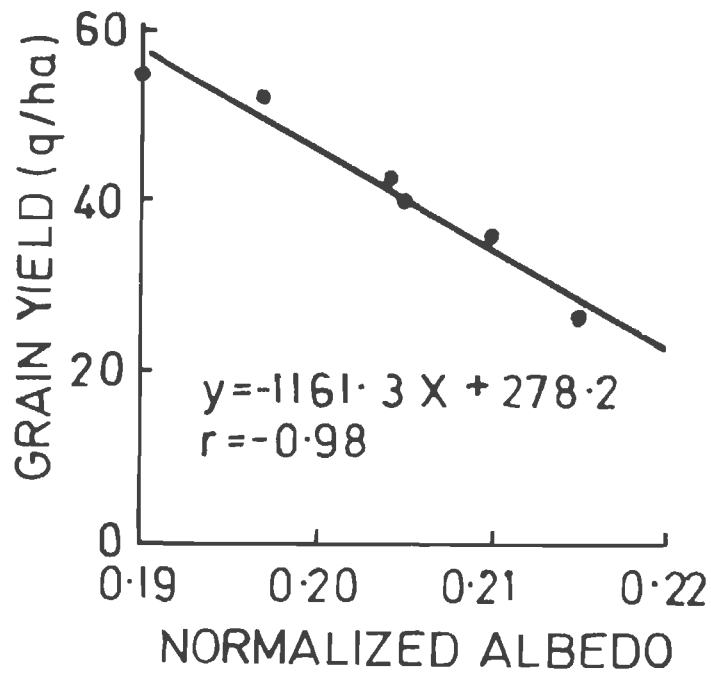


Fig.7 Regression of grain yield of wheat on normalized albedo measured a week after the milk stage.

before this technique could be used in a complete remote sensing context.

In order to test the usefulness of albedo for remote sensing of crop yields, grain yield was plotted against the normalized albedo measured a week after the milk stage (Fig. 7). As shown in Fig. 6, this is the period of sharp increase in albedo in all the treatments. The correlation coefficient was highly significant ($r = -0.98$). Lowest albedo prior to its final rise (Fig. 6) before the grain ripening was associated with highest grain yield.

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EXTRACTION OF TWO-DIMENSIONAL AND FOUR-DIMENSIONAL VEGETATION INDICES

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ABSTRACT

Analysis of remotely sensed data for vegetation studies requires understanding and quantification of the contribution of the soil background to the total vegetation canopy reflectance. Hence, development of techniques or transformations for separating soil effects from vegetation reflectance and for reducing the dimensionality of the feature space becomes very necessary. Analysis of ground-based reflectance data collected over many wheat plots with different soil backgrounds has been carried out to derive two-dimensional and four-dimensional 'soil line' and vegetation indices. Perpendicular vegetation index (PVI), a two-dimensional vegetation index, was determined for different wheat plots and correlated with leaf area index measured at maximum vegetative growth stages. Using Gram-Schmidt procedure of orthogonalization, the four-band spectral data was transformed to another set of four vectors viz., brightness, greenness, yellowness and non-such. Greenness was related to the leaf-area-index and final yield measurements of different plots. Such an analysis was carried out for two sets of four-band data, one set having spectral bands similar to those of LANDSAT MSS and the other similar to those proposed on IRS-1. Using available LANDSAT MSS data of the same region, brightness, greenness, yellowness and non-such vectors were also derived using Kauth-Thomas transformations.

INTRODUCTION

Analysis of remotely sensed data for vegetation studies requires understanding and quantification of the contribution of the soil background to the total vegetation canopy reflectance. This assumes greater significance in early growth stages of crops and for poor vegetation covers. Comparison of the same kind of vegetation grown on two different soil backgrounds requires that the contributions of the differing soil backgrounds be subtracted from the remotely sensed data. So development of techniques or transformations for separating soil effects from vegetation becomes very necessary. Such transformations have another important role to play. Generally, remotely sensed data is collected in a number of spectral bands

chosen on the basis of requirements of many, sometimes conflicting, applications. The information in respect of a specific application contained in different spectral bands of this set may be correlated. In such a situation, it is desirable to reduce the dimensions of the feature space and analyse data contained in the first few vectors of the new feature space which contain most of the information. Principal component transformation achieves this although it is highly scene dependent.

Various vegetation indices have also been used to segregate the vegetation information from that of soil (Rouse et al 1973). Ratios of reflectance data in bands such as LANDSAT multispectral scanner (MSS) bands 7 and 5 and normalised difference are known to correlate well with vegetation parameters (Tucker 1979). But even these are influenced by soil and atmospheric conditions. Kauth and Thomas (1976) in their study of LANDSAT MSS data showed that in a four-dimensional space obtained after the tasselled cap transformation all the soil points are confined to a 'plane' and the vegetation points grow perpendicularly out of this plane. The new 4-vector space was defined by the vectors termed as brightness, greenness, yellowness and non-such. These new vectors are linear combinations of the earlier four MSS bands and are orthogonal to each other. In such a space, soil and vegetation data occur along two orthogonal axes and the vegetation data is insensitive to soil variations.

Richardson and Wiegand (1977) developed a two-dimensional vegetation index called 'Perpendicular Vegetation Index (PVI)' based on LANDSAT MSS 7 and MSS 5. They established the concept of soil line in a two-dimensional spectral space. The PVI is the orthogonal distance of a vegetation point from the soil line. However, this index is found to be sensitive to variations in the soil background. Jackson (1983) has outlined a generalised technique for calculating different vegetation indices from any set of n-dimensional spectral data.

OBJECTIVES OF THE PRESENT STUDY

Space Applications Centre, Ahmedabad has been carrying out spectral signature studies of vegetation (mainly crops) under different growing conditions (Sahai et al 1981, Patel et al 1982, Singh et al 1982, Patel et al 1983a, Patel et al 1983b). Various radiance ratios and normalized differences using different spectral bands have been considered and are shown to be related to vegetation parameters like the Leaf Area Index (LAI), wet biomass, dry biomass etc. However, in all these investigations, segregation of soil contributions as mentioned earlier had not been considered. It was considered pertinent to see if existence of soil line could be established from the available data and also, if newly derived vegetation indices could be related to the vegetation parameters. The other

motivation for taking up this study was to develop techniques for extending such concepts to satellite data under Indian conditions. Techniques thus developed could then be used to analyse data to be available from the Indian Remote Sensing Satellite to be launched in 1987.

In particular, the study attempts to derive two-dimensional and four-dimensional 'soil line' from the ground based spectral data. Efforts are also made to relate PVI with LAI measured in earlier experiments. Brightness, greenness, yellowness and non-such parameters are derived using data of two sets of four spectral bands each, one similar to those of LANDSAT MSS and the other proposed on IRS-1A.

LANDSAT MSS data corresponding to a specific region of Gujarat has also been analysed using tasselled cap transformation and various vectors derived.

ANALYSIS OF GROUND-BASED DATA

Data Used

In order to have as much variability as possible in the soil reflectance data, data collected in different regions of the country have been used. The measurements had been made using an indigenously developed seven-band ground truth radiometer whose specifications are given in Table 1. The main data sources for soil reflectance are those collected in Chittoor region of Andhra Pradesh, Ukai Catchment and Command areas of Gujarat and Vijapur region of Mehsana district, Gujarat. However, vegetation data used are those collected over thirty five plots of wheat at the Wheat Research Station, Gujarat Agricultural University, Vijapur.

Data Analysis and Results

Data available in seven spectral bands covering the visible and near-infrared regions have been examined. Analysis was done using two sets of four spectral bands each, one nearly similar to IRS (Set 1) and the other similar to LANDSAT MSS (Set 2). The Set 1 comprised bands 1,2,4 and 6 whereas Set 2 comprised bands 2,4,5 and 6. Also two-band data was used to derive two-dimensional scatter diagrams.

Figures 1 to 3 show the plots of reflectance data of soil and vegetation for various band combinations. In Fig. 1 reflectance of soil and vegetation in band 4 is plotted against the reflectance in band 6. All of the data is mainly concentrated along a straight line and above that line. There is no data below the line. Data lying along the straight line belong to soils while the data lying above this line are those of vegetation. While Fig. 2 and 3 show that reflectance in the bands within the visible region viz. bands 1 and 4 (Fig. 2) and

also reflectance in the bands within the infrared region viz. bands 5 and 6 (Fig. 3) do not show significant displacement of vegetation points from those of soil. All the soil and the vegetation points lie along a straight line.

PVI and its Relation to LAI

As mentioned earlier PVI is a measure of vegetation development. Regression analysis was carried out for all the soil data and also for specific soil data of Vijapur to get the mean soil line and Vijapur specific soil line respectively (Figs. 4,5). Then PVI relations were derived using these two soil lines.

$$\text{PVI} = [(1.18 - 0.414 R_{V6} + 0.493 R_{V4})^2 + (-1.405 + 0.493 R_{V6} - 0.586 R_{V4})^2]^{1/2} \dots (1)$$

$$\text{PVI} = [(-2.12 - 0.252 R_{V6} + 0.435 R_{V4})^2 + (3.648 + 0.435 R_{V6} - 0.748 R_{V4})^2]^{1/2} \dots (2)$$

Equation (1) is derived using mean soil line relation and Eq. (2) is derived using specific soil line relation. R_{V4} and R_{V6} are reflectances of vegetation in band 4 and band 6 respectively.

PVI values were computed for the wheat at plots and correlated to LAI of these plots. Regression analysis was done to relate PVI and LAI using linear and a second order polynomial (non-linear) fit. Results of this analysis are presented in Table 3. It shows that non-linear function gives better correlation between LAI and PVI. Figure 6 shows that for small values of LAI (less than 3), a linear relation holds, whereas for LAI values greater than 3, there is a tendency towards saturation of PVI. It is also seen from Table 3 that PVI derived from specific soil line correlates better with LAI than the PVI from the mean soil line. It indicates that one would get better results using specific soil line but where it is not possible to get specific soil line, the mean soil line can be used to get fairly good results. These results are in agreement with the study of Huete et al (1984) where they have derived soil lines for 20 different soils and showed that the use of individual soil lines to measure greenness minimized soil background influence and improved vegetation assessment.

Four-Dimensional Scatter Diagrams

To extract maximum information from the data and to reduce the number of dimensions of data, principal component analysis along with Gram-Schmidt procedure of orthogonalisation (Jackson 1983) was used.

Reflectance values of soils obtained from Vijapur, Ukai

Table 1
Specifications of Ground Truth Radiometer

1. Field of view	15°
2. Spectral bands (micrometers)	i. 0.445-0.515 ii. 0.495-0.565 iii. 0.570-0.650 iv. 0.625-0.695 v. 0.692-0.788 vi. 0.805-0.885 vii. 1.004-1.076
3. Output	on digital panel meter in mW/cm ² /Sr/micro m

Table 2
Spectral Bands of IRS and LANDSAT

IRS bands (micrometer)	LANDSAT bands (micrometers)
1. 0.45-0.52	0.5-0.6
2. 0.52-0.59	0.6-0.7
3. 0.62-0.68	0.7-0.8
4. 0.77-0.86	0.8-1.1

Table 3
Coefficients of Determination between PVI and LAI

Relationship	PVI derived from	R ²
Linear	Mean soil line	0.83
Linear	Vijapur specific soil line	0.84
Non-linear	Mean soil line	0.86
Non-linear	Vijapur specific soil line	0.88

catchment, Ukai command and Chittoor areas were subjected to principal component analysis. The first principal component with the maximum variance was chosen as the direction of the line of soils and termed as brightness. For determination of other components viz. greenness, yellowness and non-such, reflectance values of wheat during heading stage and maturity stage which characterised green and yellow vegetation, respectively, were taken and Gram-Schmidt procedure of orthogonalisation was applied.

This analysis was done for both the sets of spectral bands mentioned earlier. Table 4 shows the eigen vectors, amplitudes and percentage variance explained by each component of soil. The first principal component which explains 81.5 per cent and 96 per cent of the total variance for the two sets, respectively, has been considered as the 'plane of soils' and termed as 'Brightness'. The rotation matrices obtained after applying Gram-Schmidt orthogonalisation procedure on vegetation data for both the sets are:

$$R1 = \begin{bmatrix} 0.3606 & -0.1508 & -0.3929 & 0.3933 \\ 0.3759 & -0.3329 & -0.6743 & 0.6749 \\ 0.5529 & -0.5546 & 0.6200 & -0.6191 \\ 0.6503 & 0.7476 & 0.0805 & -0.0810 \end{bmatrix}$$

$$R2 = \begin{bmatrix} 0.1879 & -0.4871 & -0.6763 & 0.6763 \\ 0.4056 & -0.7518 & 0.4333 & -0.4333 \\ 0.6128 & 0.2786 & -0.4694 & 0.4694 \\ 0.6517 & 0.3464 & 0.3668 & -0.3668 \end{bmatrix}$$

R1 is for the set 1, R2 is for the set 2. In these matrices the four columns represent coefficients of brightness, greenness, yellowness and non-such respectively.

Brightness has been plotted against greenness for both sets of bands (Figs. 7,8). The basic triangular shape is still evident from the data distribution but the triangle is now rotated so that the base of the triangle i.e. the soil line is parallel to the brightness axis.

Greenness values for both sets of bands were computed for ten plots of wheat at heading stage and were correlated to LAI of these plots. Results are presented in Table 5. Figures 9 and 10 show that greenness and LAI have a linear relationship for low LAI values (less than 3) while for LAI values greater than 3 greenness has a tendency towards saturation. These results are same as those for LAI and PVI. This is because at a certain value of LAI when the green cover is about 100 per cent, greenness is maximum and there is practically no contribution to the total reflectance of the canopy from soil. Any increase in vegetative growth will then not affect greenness.

Greenness has also been correlated to final grain yield of

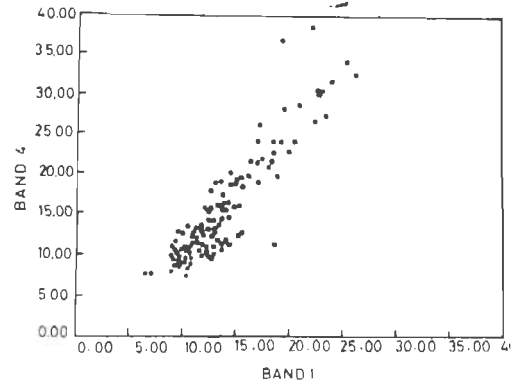
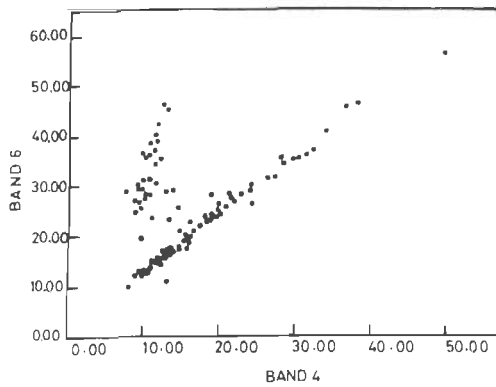


Fig. 1 (Left) Reflectance of soil and vegetation in bands 4 & 6
 Fig. 2 (Right) Reflectance of soil and vegetation in bands 1 & 4

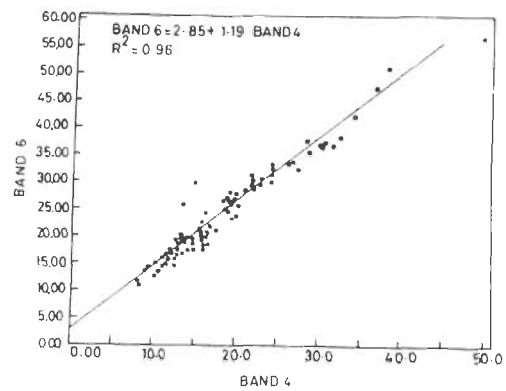
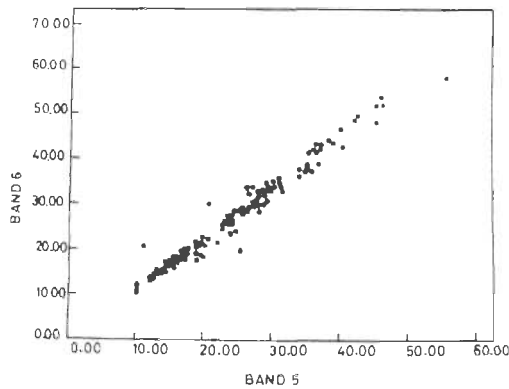


Fig. 3 (Left) Reflectance of soil and vegetation in bands 5 & 6
 Fig. 4 (Right) Mean soil line

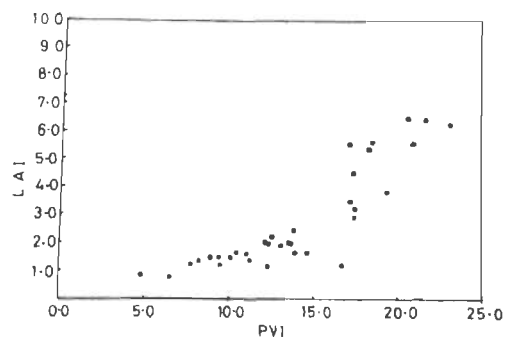
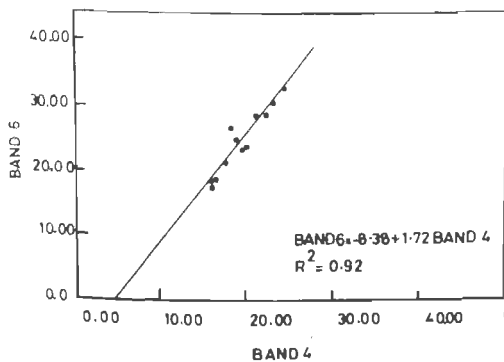


Fig. 5 (Left) Vijapur specific soil line
 Fig. 6 (Right) LAI as a function of PVI

the wheat plots. Figures 11 and 12 show greenness plotted against yield for two sets of bands. Greenness for both the sets are linearly correlated with yield ($R^2 = 0.92$). Apparently it means that in these limited investigations, greenness derived using two sets of bands are identical. Quantitatively, IRS greenness has a larger dynamic range (9.0-28.5) than that of MSS greenness (4.0-18.5). As IRS bands are more specific to vegetation, this is expected.

ANALYSIS OF SATELLITE DATA

Extraction of Soil and Vegetation Data

LANDSAT MSS data available in the form of CCT of January 26, 1982, path-row 160-044 of the area covered by $23^{\circ}20'N$ - $22^{\circ}50'N$ latitudes, $72^{\circ}E$ - $72^{\circ}30'E$ longitudes was extracted for all the four MSS bands. The sub-image extracted from the CCT was displayed on COMTAL and enhanced images were obtained by linear stretching. A false colour composite (FCC) of this enhanced image was prepared. With prior information about the features on ground the pixels were then identified as those belonging to soil, green vegetation and yellow vegetation. Grey values for these pixels were noted.

RESULTS AND DISCUSSION

The digital values of soil and vegetation have been plotted for different MSS band combinations (Figs. 13-15). As expected MSS 4 and MSS 5 data are highly correlated and MSS 6 and MSS 7 are also highly correlated. The plot of MSS 4 vs MSS 6 show that all the data points lie in a triangular shaped region, the base of which is formed by soil points and the vegetation points lie between the base and its vertex. This is due to high reflectance of vegetation in near-IR bands.

As the coefficients obtained by Kauth and Thomas for brightness, greenness, yellowness and non-such may not hold good for our region of study, we attempted tasselled cap transformation to get the new coefficients. The procedure for arriving at the transformed vectors was essentially the same as that for ground data. All the soil digital values were subjected to principal component analysis to obtain brightness vector and then using Jackson's procedure the remaining vectors were obtained.

Principal components of soil and the variance explained by them are given in Table 6. The amplitudes of four principal components give the dimensions of the ellipsoid in which the soil points lie. Soil points lie in an ellipsoid which is 4 times as long as it is wide, nearly 4-5 times long compared to its thickness and 1-2 times as thick as it is thin. The

Table 4
Principal Components of Soil Reflectance

Set Parameter no. component	PC 1	PC2	PC3	PC4
1. Eigen	0.1879	-0.0093	-0.980	0.0616
vectors	0.4056	0.9014	0.0774	0.1305
	0.6128	-0.1706	0.0708	-0.7683
	0.6517	-0.3979	0.1678	0.6336
% Var	81.53	8.39	8.21	1.86
AMP	14.67	4.71	4.65	2.21
2. Eigen	0.3606	-0.4874	0.2309	-0.7609
vectors	0.3759	-0.6119	0.2548	0.6475
	0.5529	0.0015	-0.8332	0.0082
	0.6503	0.6228	0.4330	0.0407
% Var	96.07	2.98	0.57	0.36
AMP	13.71	2.42	1.06	0.84

Table 5
Coefficient of Determination (R^2) between
Greenness and LAI

	Linear	Non-linear
First set	0.84	0.87
Second set	0.84	0.89

Table 6
Principal Components of Soil (MSS data)

	PC 1	PC 2	PC 3	PC 4
Eigen	0.2374	-0.4297	-0.265	-0.8298
vectors	0.4865	-0.1689	-0.724	0.4583
	0.6508	0.7138	0.128	-0.2246
	0.5324	-0.5265	0.623	0.2257
%Var	87.42	5.54	4.32	2.72
AMP	18.41	4.63	4.09	3.25

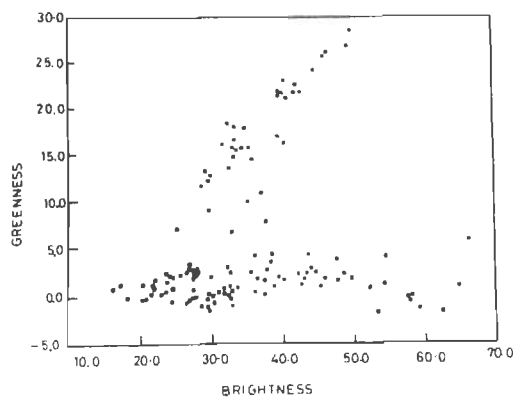


Fig. 7 (Left) Brightness versus greenness for set 1

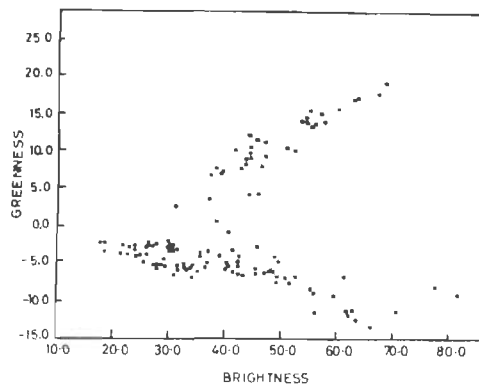


Fig. 8 (Right) Brightness versus greenness for set 2

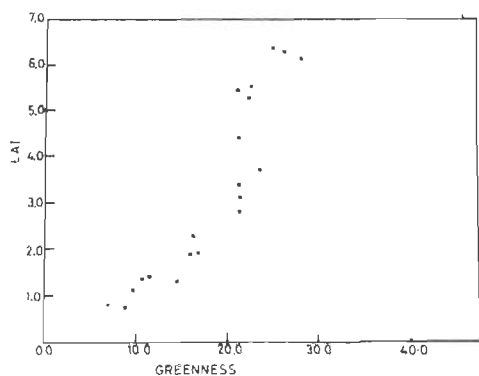


Fig. 9 (Left) greenness versus LAI

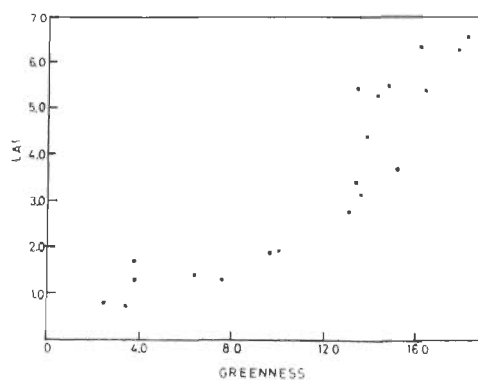


Fig. 10 (Right) Greenness versus LAI

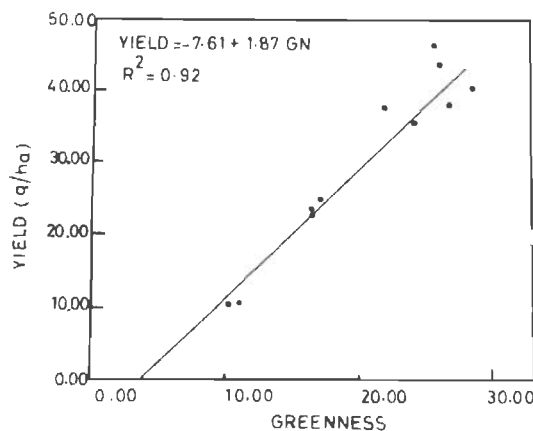


Fig. 11 (Left) Yield as a function of greenness for set 1

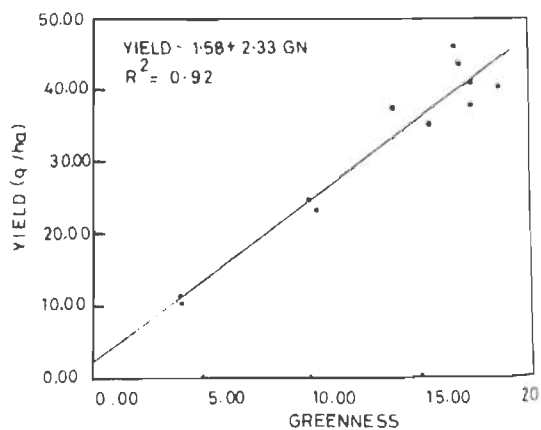


Fig. 12 (Right) Yield as a function of greenness for set 2

rotation matrix obtained for transforming MSS vector space into a new feature space is

$$R = \begin{bmatrix} 0.2374 & -0.3634 & -0.7899 & 0.4336 \\ 0.4865 & -0.7473 & 0.4452 & -0.0822 \\ 0.6508 & 0.3176 & -0.2928 & -0.6243 \\ 0.5324 & 0.4567 & 0.3034 & 0.6446 \end{bmatrix}$$

The Kauth and Thomas rotation matrix is

$$R = \begin{bmatrix} 0.3323 & -0.2832 & -0.8995 & -0.0159 \\ 0.6032 & -0.6600 & 0.4238 & 0.1307 \\ 0.6758 & 0.5773 & 0.0759 & -0.4519 \\ 0.2628 & 0.3883 & -0.0408 & 0.8823 \end{bmatrix}$$

As is seen here the coefficients obtained for brightness, greenness, yellowness and non-such are slightly different from those obtained by Kauth and Thomas. Although the signs of the coefficients of yellowness and non-such are different in both sets the overall contribution from the visible and infrared bands is same in both cases. The data distribution in the brightness-greenness plane (Fig. 16) shows the soil points lying on a line parallel to the brightness axis and the vegetation points growing perpendicularly out of this soil line. Due to insufficient data it could not be verified whether this MSS greenness was actually related to vegetation density or not.

This technique would be used for similar analysis using LANDSAT MSS data and subsequently using IRS data. With better spatial resolution, it may be possible in these cases to relate it to individual plot measurements of vegetation parameters.

CONCLUSIONS

Greenness in two-dimensional and four-dimensional space is a good tool for estimation of yield and related parameters. The two-dimensional transformation of spectral data to PVI is partially independent of soil background as we have seen that using specific soil line for a region gives better results than mean soil line for whole area. Development of region-specific soil lines will definitely enhance the discrimination of vegetation from soil background. But for some purposes such as broad vegetation classification, mean soil line can also be useful.

Tedious ground measurements of LAI can be avoided by estimating LAI from PVI with a fairly good accuracy. From the ground-based studies it has also been seen that though there is

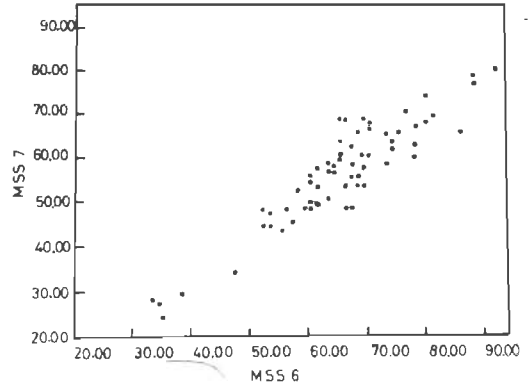
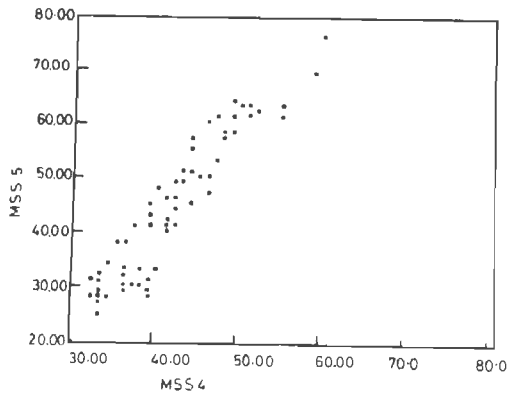


Fig. 13 (Left) MSS 5 vs MSS 4 digital counts of soil and vegetation
 Fig. 14 (Right) MSS 7 vs MSS 6 digital counts of soil and vegetation

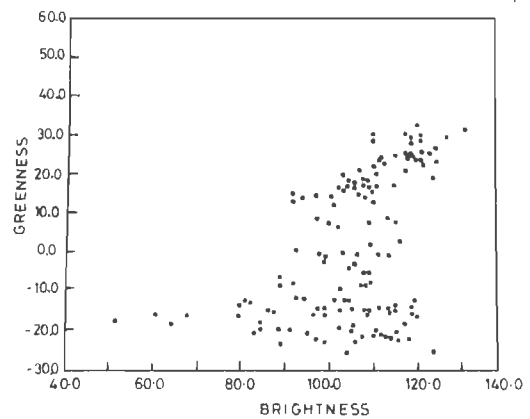
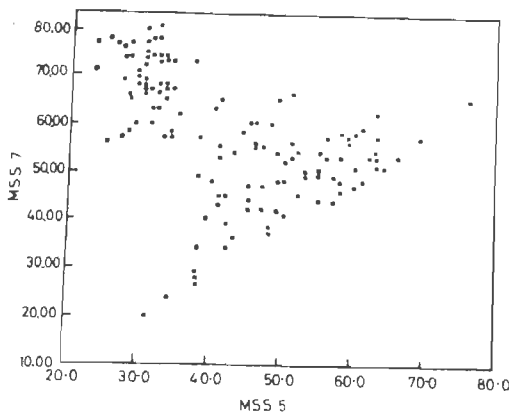


Fig. 15 (Left) MSS 7 vs MSS 5 digital counts of soil and vegetation
 Fig. 16 (Right) Brightness vs greenness for LANDSAT MSS bands

quantitative difference between the greenness obtained using data of LANDSAT MSS bands and IRS bands, both are good indicators of vegetation density and correlate well with crop yield.

No relationship could be established between the greenness obtained from satellite data and vegetation because at present the region of study contained small fields of crop which could not be identified on LANDSAT image and hence no measure of vegetation was available to us. But in future, it is planned to work on larger aggregates of fields which would be easy to identify on satellite images and for which we would have some ground-based measure of vegetation.

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NORMALIZED DIFFERENCE VEGETATION INDEX FOR DROUGHT MONITORING

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ABSTRACT

Normalized difference of LANDSAT-2 MSS band 7 and 5 has been found useful to monitor the change in crop/vegetation cover due to drought. The technique was tried for 1982 drought in parts of Karnataka State.

INTRODUCTION

The terminology defining drought is highly complicated. In very general terms, it is a rainless situation for an extended period of time leading to decrease in surface and subsurface water levels and causing a severe shortage of moisture availability to local vegetation and crops. A well-established method of drought monitoring based on aridity index exists under the auspices of India Meteorological Department (George 1972, Appa Rao et al 1979). However, when unbiased information on drought occurrence is required for taking quick relief measures, the modern technology of satellite remote sensing has additional advantages.

A general agreement between the LANDSAT derived greenness index number developed by Kauth and Thomas (1976) and ground based assessment of drought stress was reported by Thompson and Wehmanen (1979). Vegetation index defined in terms of crop reflectance in red and near infrared bands was found to be a sensitive parameter for monitoring vegetation in general (Tucker 1979) and to distinguish normal plants from soil moisture stressed plants (Tucker et al 1980, Patel et al 1982). Recently, Rao and Rao (1984) proposed an approach for agricultural drought monitoring wherein the advantage of combined use of NOAA/AVHRR and LANDSAT/MSS imagery was highlighted. In the present study an attempt has been made to quantify the effect of drought in terms of change in vegetation/crop cover by calculating the normalized difference vegetation index.

METHODOLOGY

LANDSAT-2 (L2) MSS scene (path-row 155-051) of October 16, 1979 and LANDSAT-4 (L4) MSS scene (path-row 145-051) of September 30, 1982 (drought year) were selected for this study. The scene covers a part of the drought-affected districts of Hassan and Tumkur in Karnataka State. The difference/sum value (normalized difference, ND) of 0.8 - 1.1 (MSS 7 on L2 or 4 on L4) and 0.6 - 0.7 micrometers (MSS 5 on L2 or 2 on L4) spectral bands was calculated on IMAGE-100 system taking the digital data of these two bands. A "training gate" of equal size was chosen positioned at the same ground control points in both the scenes of 1979 and 1982. Within this training gate area, different land cover types were identified with the help of ground truth data. ND values were calculated for each cover type using offset and gain values. The percentage of different land cover types having different ND values was calculated with reference to the gate area.

RESULTS AND DISCUSSION

Normalized difference (ND) values of each land cover and their percentage cover in 1979 (normal year for the area under study) and 1982 (drought year) are shown in Table 1. It can be observed from Table 1 that the land cover types having ND values greater than 0.47, namely, crops and forest, covered about 12 per cent of the training window area in 1982 and about 66 per cent in 1979. These values indicate that the area under study was affected by drought in 1982. In fact, subsequent consultations with local district authorities and news reports confirmed the above observations.

CONCLUSIONS

The study offers the scope of quantifying the drought effect on vegetation and crop cover and thus help in monitoring drought. Observations made in this study confirm the conclusions drawn from visual interpretation of LANDSAT false colour composites in the previous study of Rao and Rao (1984).

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Table 1
 Normalized Difference (Difference/Sum) Values
 of 0.8-1.1 and 0.6-0.7 Micrometers for Different Land
 Cover Types and Percentage Area occupied by Each
 Cover Type

Land cover	Normalized difference value	Percent area covered by each cover type	
		1982	1979
Water 1	-1.17 to -0.57		
Water 2	-1.34 to -1.02		
Water 3	0.0 to 0.03		
Bare soil	-0.15 to -0.10	] 87.06	32.85
Bare soil	-1.17 to -0.43		
Crops	0.47 to 1.47	9.36	58.68
Forest (sparse)	1.25 to 1.86	] 2.39	7.52
Forest (dense)	2.27 to 2.90		

Note: Bare soil and water bodies have almost same ND values.

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REMOTELY SENSED CANOPY TEMPERATURES OF BRASSICA GENOTYPES IN RELATION TO CROP GROWTH

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ABSTRACT

Field experiments were conducted to study the variations in canopy temperatures, leaf temperatures and transpiration rates during the growth of eight oilseed Brassica genotypes belonging to four species namely *Brassica campestris*, *B. juncea*, *B. napus* and *B. carinata*. Canopy temperatures were monitored with a portable infrared thermometer. During the early growth phase (85 days) the transpiration rates were higher in *B. campestris* and *B. juncea* species with a corresponding lowering of leaf temperature, canopy-air temperature differences (CATD) and cumulative stress degree days (SDD) as compared to *B. napus* and *B. carinata*. However, a reverse trend was observed during the later growth phase (85-125 days). The CATD and SDD were found highly and linearly correlated with leaf area index (LAI) and dry matter production (DM) during the vegetative phase. Varietal differences were evident among the different brassica species in respect of CATD and SDD values indicating the potentiality of screening brassica genotypes using canopy-temperature-based indices by remote sensing technique.

INTRODUCTION

Recent development of air/space borne spectral and thermal sensors has thrown new challenges to the agricultural scientists to monitor crop growth and evaluate its productivity by remote sensing techniques. The possibility of using remotely sensed environmental parameter such as canopy temperature for estimating evapotranspiration or water use and predict crop yields has been demonstrated by several workers (Bartholic et al 1972, Idso et al 1975, 1977, Jackson 1982, Singh and Das 1983, Saha et al 1984). It has been shown that transpiration reduces leaf temperature considerably thereby influencing canopy environment (Tanner 1963, van Bavel and Ehrlir 1968). Since a strong correlation has been found to exist between level of water stress in a plant and its leaf or canopy temperature, it was speculated that leaf or canopy temperature could be used as criteria to screen genotypes of a species for their crop yields or susceptibility to drought (Blum 1974,

Millard et al 1978, Singh and Kanemasu 1983). Based on canopy temperature measurement, Das et al (1984) reported varietal differences in transplanted and direct seeded rice.

Although the feasibility of using canopy temperature based remote sensing technique to monitor crop growth, water use and yield has been demonstrated, meagre quantitative data are available for screening varietal differences in crops, more so in brassica using this technique. The present investigation was, therefore, conducted with the objective of finding out differences, if any, in leaf and canopy temperatures (CT) of brassica genotypes and to correlate the latter with crop growth parameters.

MATERIAL AND METHODS

The results reported herein form a part of an experiment on varietal screening of brassica species conducted during the Rabi 1983-84 in a sandy loam soil (Typic Ustochrept) of the Experimental Farm of the Indian Agricultural Research Institute. Eight cultivars of four species of oilseed brassica namely, Brassica campestris (duration 140-150 days), Brassica juncea (120-140 days), Brassica napus (150-160 days) and Brassica carinata (160-180 days) were taken in the present study. While the first two species are widely grown in plains, B. napus and B. carinata are of longer duration but have good yield potential and hence suitable for colder and hilly regions. The crops were sown on October 25, 1983 with row-to-row and plant-to-plant spacings of 60 and 10 cm respectively. Fertilizers were applied at the rate of 40 kg each of N, P_2O_5 and K_2O per ha. The crops were irrigated only once on November 17, besides a pre-sowing irrigation.

Canopy temperature (CT) and canopy-air temperature differences (CATD) were monitored upto 125 days of crop growth with an infrared thermometer (Telatemp Model AG-42) having a spectral response 8-14 μ at 0.95 emissivity. Temperatures were recorded by pointing the sensor at the sunlit leaves on all days, care being taken to avoid interference by exposed ground surface. Observations on all days were recorded during 1300-1400 hrs as far as possible. Other physiological parameters like leaf temperature (LT) and transpiration (TR) rates were concurrently measured using a steady state diffusion porometer (Model LICOR 1600). The data on photosynthetically active radiation and atmospheric temperature were also measured with the diffusion porometer and are depicted in Fig. 1. The biophysical parameters such as green LAI and total above ground biomass were determined and correlated with the canopy temperature based indices.

RESULTS AND DISCUSSION

Transpiration Rate and Leaf Temperature

Data on TR and LT recorded at different stages of plant growth in respect of four representative brassica species are depicted in Fig. 2 and 3, respectively. The average values of TR for the periods from sowing to maximum tillering (upto 85 days and henceforth reported as phase A) and from maximum tillering upto maturity of *B. juncea* (upto 125 days and henceforth reported as phase B) for the eight cultivars are presented in Table 1. In general there were fluctuations in the TR and LT values during the period of crop growth (Fig. 2 and 3) which were in coincidence with the changes in atmospheric temperatures (Fig. 1). The four different species showed similar trends in the changes of TR and LT, although the magnitude of changes differed in different species (Fig. 2 and 3). During the vegetative growth phase (upto 85 days, A) average TR values were higher in *B. campestris* and *B. juncea* ($6 \mu\text{gm cm}^{-2} \text{sec}^{-1}$) than *B. carinata* ($5.3 \mu\text{gm cm}^{-2} \text{sec}^{-1}$) and *B. napus*, the latter having the lowest TR ($4.8 \mu\text{gm cm}^{-2} \text{sec}^{-1}$). During this period LT values showed opposite trend, *B. campestris* and *B. juncea* leaves being cooler (19.7°C) compared to the other two species (20.2°C). However, it could be observed that in the second phase (85-125 days) TR values in *B. napus* and *B. carinata* increased ($7.6 \mu\text{gm cm}^{-2} \text{sec}^{-1}$) and became comparable to that of the first two species, with a corresponding lowering of leaf temperature. Data in Table 1 further revealed that the cultivars within a particular species *B. juncea* also differed in TR and LT values as much as 0.9 to $2.0 \mu\text{gm cm}^{-2} \text{sec}^{-1}$ and 0.9 to 1.5°C respectively. The results were in agreement with the findings of Carlson et al (1972) and Ehrler (1973) who reported variation in leaf temperatures of soybean and cotton cultivars and attributed the same to differences in the genetic make-up of the plants.

Canopy Temperature-based Indices

Data on the variation in CATD during the crop growth period and the average CT and CATD values for the two phases are depicted in Fig. 4 and in Table 1. While the absolute values of CT did not differ much, statistically significant differences among the genotypes were observed in their CATD values. During the vegetative growth phase (A) average CATD values were found to be lower in *B. campestris* and *B. juncea* (-4.3 to -4.9°C) than in *B. napus* and *B. carinata* (-3.5°C). But during the second phase (B) the CATD values were much lower in the latter two species (-5.5°C). Thus genotypic differences in CATD reflected the differential transpirational cooling of brassica genotypes even under similar soil and climatic environment as was also observed by Singh and Kanemasu (1983) in pearl millet. The variation in CATD values during the crop growth (Fig. 4) almost followed the same trend as that of transpiration rate (Fig. 2).

Table 1
Average Transpiration Rate (TR), Leaf Temperature (LT), Canopy Temperature (CT), Canopy-air Temperature Difference (CATD) and Cumulative Stress Degree Days (SDD) of Brassica Genotypes.

A. Transpiration Rate and Leaf Temperature

	TR (gm/cm ² /sec)		LT (°C)	
	A	B	A	B
<u>B. campestris</u>				
1. Spān (Brown Sarson)	6.5	7.4	19.5	21.4
2. YID-1 (Yellow Sarson)	6.6	6.6	19.8	21.6
3. TCSH-3 (Toria)	5.7	6.6	19.8	21.0
4. DS-17 MD (Brown Sarson)	6.6	7.7	19.3	20.4
5. Ys-Pb-24 (Yellow Sarson)	6.1	5.7	18.9	19.5
6. <u>B. juncea</u> (Pusa Bold)	5.8	7.1	19.8	20.0
7. <u>B. napus</u>	4.8	7.6	20.2	19.8
8. <u>B. carinata</u>	5.3	7.6	20.2	19.3
CD (0.05)	1.02	NS	NS	NS

B. Canopy Temperature (CT), Canopy-air Temperature Difference (CATD) and Cumulative Stress Degree Days (ΣSDD)

Sr. No.	CT (°C)		CATD (°C)		(SDD)	
	A	B	A	B	85 days	125 days
1.	17.4	19.2	-4.9	-3.9	-241	-374
2.	17.7	19.6	-4.7	-3.3	-229	-343
3.	18.1	20.0	-4.7	-3.2	-226	-341
4.	17.7	18.9	-4.5	-3.7	-228	-361
5.	17.8	18.4	-4.5	-4.2	-225	-378
6.	18.3	19.6	-4.3	-3.1	-206	-311
7.	18.6	18.5	-3.5	-5.3	-174	-373
8.	17.6	18.0	-3.5	-5.7	-192	-403
CD (0.05)	NS	NS	-0.7	-1.46	--	--

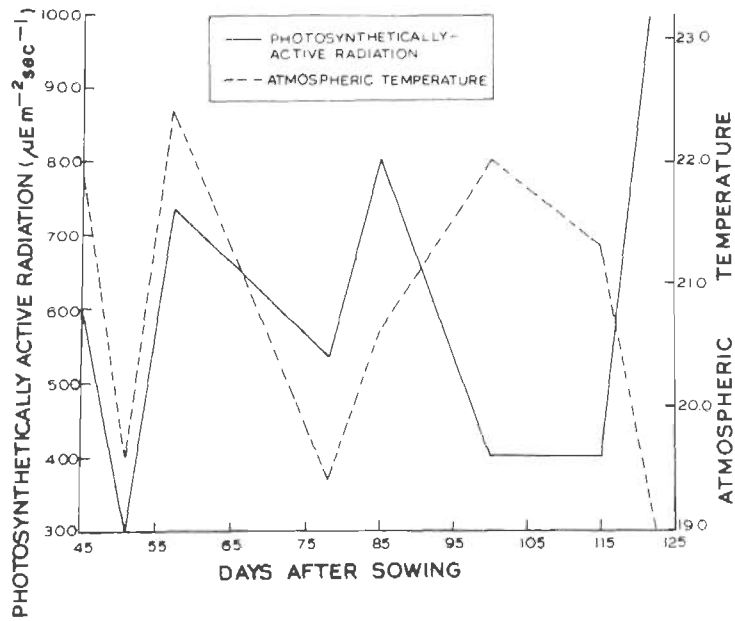


Fig. 1 Atmospheric temperature and photosynthetically active radiation during the growth period of Brassica species

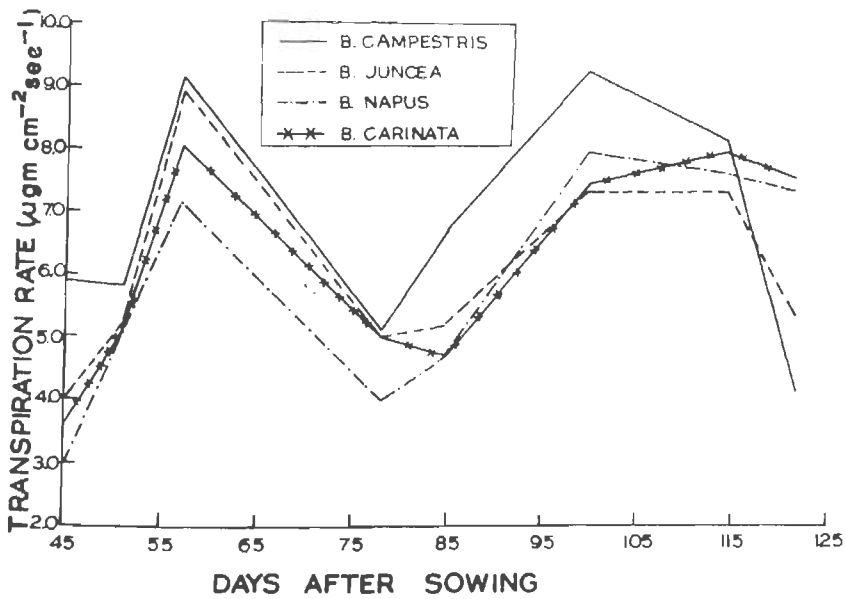


Fig. 2 Transpiration rate of four Brassica species at different stages of growth

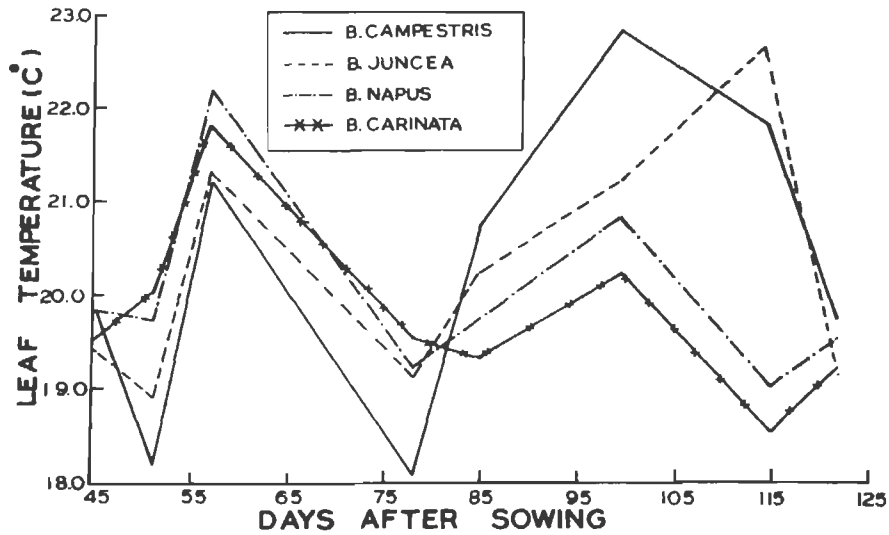


Fig. 3 Leaf temperature of four Brassica species at different stages of growth

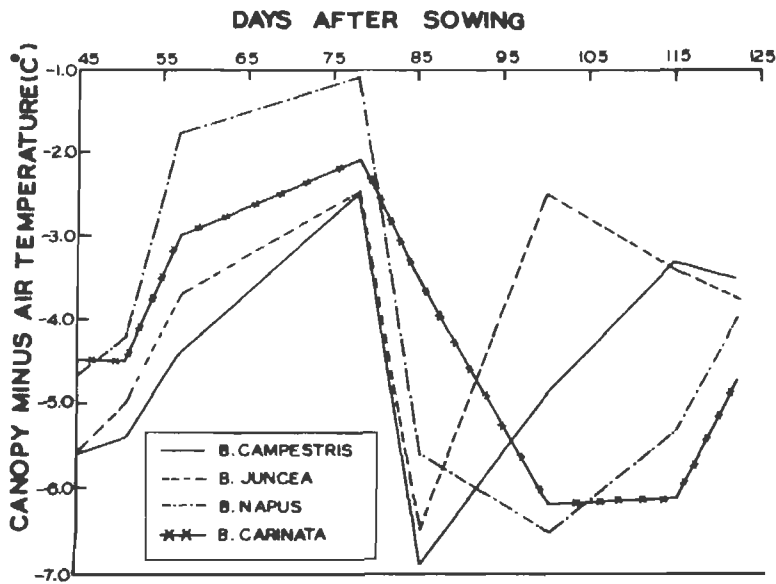


Fig. 4 Variation in canopy-air temperature differences (CATD) during the growth period of four Brassica species

The seasonal variation of stress-degree days (SDD) for four representative brassica species are depicted in Fig. 5 and the SDD values on 85 and 125 days are presented in Table 1. The results showed that cumulative SDD were much lower in *B. campestris* and *B. juncea* upto 105 days of growth. Thereafter there were changes and on 125th day *B. carinata* had the lowest SDD value (-403 °C-day). Consistently higher cumulative SDD were observed in *B. napus* throughout the growth period (Fig. 5). Among the different cultivars of *B. juncea* and *B. campestris*, the SDD values on 125 days varied from -311 °C-day to -378 °C-day indicating varietal differences within a species in canopy temperature variability.

Correlations across Genotypes Growth Parameters with Stress Indices

Data on correlation of LAI and dry matter production (DM) during the vegetative growth period (upto 85 days after sowing) with the stress indices, CATD and SDD are presented in Fig. 6 and 7, respectively. Leaf area indices were negatively and significantly correlated with average CATD ($r = -0.83$) and cumulative SDD ($r = -0.63$), although the correlation coefficient was much higher in the former. Similarly, DM during the vegetative growth period were also significantly correlated with average CATD ($r = -0.78$) and cumulative SDD ($r = -0.7$). However, in the present study no significant correlations could be obtained between the grain yield and the average CATD or cumulative SDD obtained upto the observation period. This is attributable to low and statistically non-significant differences in grain yields of genotypes and the genotypic differences in variation of CATD and SDD values during the later period of crop growth (Table 1, Fig. 5). The results suggest that detailed studies are required on the complex microclimatic conditions resulting from variation in crop geometry, density and duration and plant water relations to screen genotypes for their yield, based on plant canopy temperature. Similar observations have been reported by Singh and Kanemasu (1983) in pearl millet.

CONCLUSIONS

The present study shows that variability in transpiration rate, leaf temperature and canopy temperatures exists among the oilseed brassica genotypes. Canopy-air temperature difference and cumulative stress degree days were significantly correlated with leaf area index and dry matter production during the vegetative growth phase. It may be concluded that CATD and SDD could be successfully used as criteria for relating crop growth at different phenological stages. However, further studies are needed for using canopy temperature indices to screen brassica genotypes of different growth duration for their grain yields

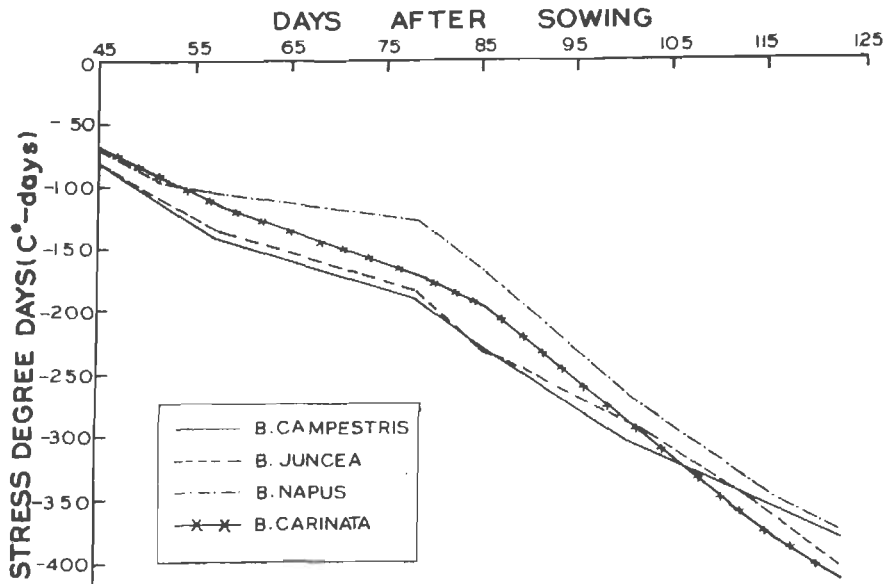


Fig. 5 Variation in cumulative stress-degree days (SDD) during the growth period of four Brassica species

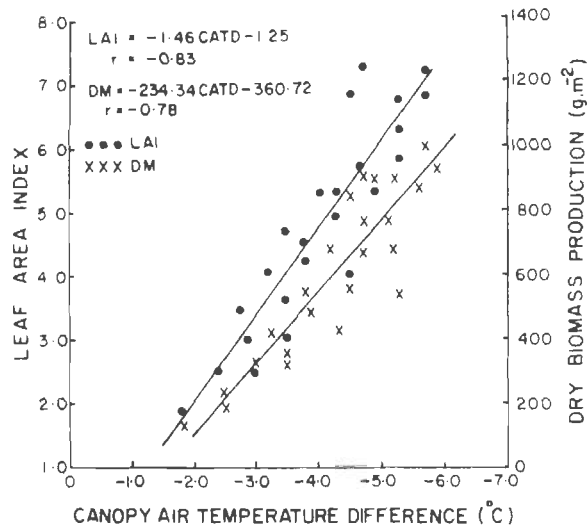


Fig. 6 Relationship of leaf area index and dry matter production of Brassica with canopy-air temperature differences (vegetative growth period)

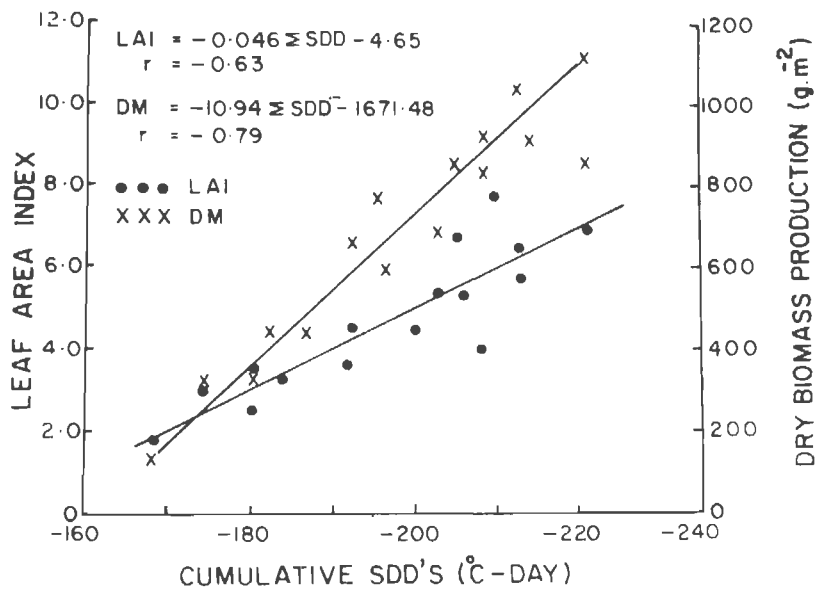


Fig. 7 Relationship of leaf area index and dry matter production of Brassica with cumulative stress-degree days (vegetative growth period)

and yield stability.

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REMOTE SENSORS FOR OBSERVING CROP CANOPIES

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ABSTRACT

With the launching of LANDSAT 1 in 1972 with a multispectral scanner (MSS) aboard, a new era of remote sensing in agriculture has begun. Numerous studies on crop and vegetation monitoring using spectral data and imagery of LANDSAT-MSS or other remote sensors have since been made. A brief description of the procedure adopted for crop studies by remote sensing and a review of some of these studies in the past is presented here. Since July 1982, the Thematic Mapper (TM), a second generation sensor, is also in the orbit. Results of various investigations evaluating the comparative performance of TM and MSS have also been collated.

It may be stated that LANDSAT-MSS data can be successfully employed for studying spectral characteristics and classification of crops and vegetation. Superior performance of TM is reflected in its capability of resolving twice the spectral classes that of MSS. With higher spatial and spectral resolution, TM should prove to be a promising new sensor for remote sensing of crop canopies.

IMPORTANCE OF REMOTE SENSING

Conservation and optimum use of land surface under vegetation is an important aspect of resource management. As the national population continues to grow apace, one of the most pressing problems facing agriculturists and environmental scientists is that of preserving land surface under forest, grass and agricultural crops, and utilising it for optimum production. With the evolution of Earth orbiting satellites, remote sensing has proved to be a promising tool to answer these intricate problems.

Observables of the Earth system can be classified as quasi-static or dynamic. Distribution of rock-types, topography of large land, and ice bodies may be termed as quasi-static while atmosphere, sea-surface, vegetation, surface energy balance quantities like precipitation, and soil moisture vary with time and hence are dynamic. Such dynamic quantities need systematic, consistent and frequent measurements with

continuity over long periods. Remote sensing offers the opportunity to view these processes on a larger and more comprehensive scale. In providing viewing and coverage on regional to global scales there is hardly any substitute for satellites as observational systems.

The early acreage determination of main crops, early yield prediction, information on pest and disease attacks, quantification of the effects of moisture deficiency or surplus and continuous updating of inventories are the requirements of modern agriculture. These requirements may be achieved on regional or national level through satellite remote sensing system only (NASA 1984 a, b, Everett and Simonett 1976).

REMOTE SENSING OF CROP CANOPIES

Aerial Surveys

Till 1960s remote sensing of earth surface was by aerial photography. By combination of field knowledge and careful examination of the images, photo-interpretation keys were developed for various crops in specific regions. It was also recognised that aerial photography was useful for the detection and mapping of crop diseases and pests infestation (Bell 1974, Bush and Collins 1974).

The development of visible colour and infrared colour and multispectral sensors had added further impetus to aerial survey of vegetative and other land surfaces. The observed spectral responses registered as spectral signatures could be interpolated by comparing with unique signatures known to be associated with particular objects or environmental phenomena.

Crop system is dynamic. Numerous factors affect spectral responses of crops including temporal variations like time of the day, season, biological structures like plant types, its vegetative growth and condition, stress due to shortage of water or attack of pests and diseases. Hence, corresponding spectral variations, representing these factors have to be identified and observed periodically. Moreover, processing and interpretation of data needs some back-up computing system. Remote sensors for crop monitoring should envelope these requirements (Barrett and Curtis 1982, Simonett 1976).

LANDSAT System

LANDSAT system was designed to make automatic observations using a payload consisting of return beam vidicon (RBV) and multispectral scanner (MSS). The MSS system is a line-scanning device using an oscillating mirror to scan at right angles to the spacecraft flight direction. Reflected optical energy is sensed simultaneously by an array of 24 detectors in four spectral bands (0.5-0.6, 0.6-0.7, 0.7-0.8, 0.8-1.1 μm) with

ground resolution of 80 m. The reflected energy is encoded in 64 grey levels per band. Digitization of analogue signal leads to an incoming data stream of 45 megabits (Barrett and Curtis 1982, Lintz and Simonett 1976).

Ground Truth for Crop Studies

The prime objective of ground data collection is to provide contemporaneous record of ground conditions, at the time of imaging. In practice, it is possible to obtain detailed synchronous data over only a small sample area. Data variables can be categorised as transient or non-transient. Data recording of transient features (e.g. crop stages, leaf cover, stress condition) must be synchronous. Such changes necessitate repetitive ground data collection. Retrieval of physical variables from remote sensing data is statistical in nature and cannot be made from first principles and hence comparative in situ observations or training data set are essential (Hajic and Simonett 1976).

Data Acquisition and Processing

The LANDSAT data is obtained in analog form as MSS electrical signals. This is then converted into images for bulk photographic processing. Also the analog data is treated so that precision images and colour images can be made. Treatment of data includes compression of data or enhancement of selected features and geometric and radiometric corrections. The system provides data in the form of computer compatible magnetic tapes (CCT) or analog magnetic tapes. CCT may be used for statistical analysis and interpretation of selected features.

There are broadly two approaches which are adopted in mapping crop canopies from spectral data. In supervised classification, training set of data obtained from matching known crop type/feature to sets of data from sensor system are entered into computer so that the computer classifies all similar data as the crop feature in question. In unsupervised classification approach, remote sensing data are grouped and mapped by clustering algorithms (Barrett and Curtis 1976).

REMOTE SENSING OF CROPS : STUDIES MADE OVER LAST DECADE

Multispectral sensing of crop by aerial as well as spacecraft-borne sensors has been most useful for vegetation and land use mapping. Various features like crop type, its condition, growth stage could be discriminated using one or more spectral bands in visible and near infrared regions. A linear combination of LANDSAT bands is capable of separating soil from vegetation and different plant types (Harlan 1983).

Crop Growth

During the growth period of vegetation IR reflectance plateau at 0.75-1.2 micrometers is the characteristic leaf reflectance of vegetation highly correlated to the red (0.63-0.69 μm) and near IR (0.76-0.90 μm). From spectral reflectance in the visible and near IR wavelengths leaf area index (LAI) may be evaluated. Spectral data in visible and IR bands may be used to map periods of critical growth stages of crop.

Crop Classification

LANDSAT-MSS has provided a continuous stream of multi-temporal images of agricultural fields, vegetation and land surfaces on repetitive basis. Number of investigations have been carried out for classification of crops and vegetation and soil surface employing various statistical classifiers. For example, spectral data may be analysed using clustering algorithm and merging sequence. Different vegetative and land surfaces may then be classified into various separable spectral classes. Richardson et al (1975) observed that each species has its spectral image which is dependent on plant morphology, growth stage and canopy geometry.

Crop Pests and Diseases

Plant diseases effect metabolic processes and reflectance of plants. Johannsen and Bauer (1972) classified diseased corn into three severity groups from LANDSAT-MSS data. High correlation is seen between wheat rust severity and ratio between MSS 4 and 6 spectral bands. Pisharoty and Hariharan (1973) detected wilt-root disease of coconut trees from aerial photographs and false colour image processing. Using spectral band, 0.82-0.88 micrometer, healthy and diseased citrus plants may be distinguished (Edwards et al 1975). Satellite multispectral data may be analysed by statistical techniques to estimate insect population and damage to crops. Spectral reflectance also change with incidence of pests and diseases.

Canopy Temperature and Yield Prediction

Thermal channel (10.8-12.5 μm) provides remote measurement of canopy temperature. Vegetation temperature rises when its water system is affected by water deficit, disease, insects etc. Plant temperatures were measured by radiometer with the thermal band and multiple view angle using inversion technique and therefrom density of vegetation and substrate temperature may be estimated (Kimes 1981). Using IR and thermal band, temperature of soil surface and crop canopies and also soil moisture may be determined. If environmental temperature is also known, crop yield may be predicted (Idso et al 1979). Spectral reflectance of wheat measured by a radiometer with four spectral bands of LANDSAT-MSS at stem extension and heading stages may be used to estimate grain yield (Aase and

siddoway 1981).

For crop studies, remote sensors operating in the range 0.4-2.5 micrometers distributed in multiple bands seem to be most suitable. The choice of bands will, however, depend on particular crop feature to be observed and the experience of remote sensing scientists. Interpretation and classification may be further improved by using narrow band width and supplementing MSS bands by thermal infrared band. This has been achieved in Thematic Mapper, an improved multispectral sensor on LANDSAT 4 and 5.

THE THEMATIC MAPPER

The Thematic Mapper (TM) is a second generation earth resources sensor placed in orbit aboard the LANDSAT 4 and 5 spacecrafts along with multispectral scanner.

The TM acquires data in seven spectral bands covering the visible (0.45 - 0.52, 0.52 - 0.60, and 0.63 - 0.69 micrometers), near infrared (0.76 - 0.90 micrometer), thermal IR (10.4 - 12.5 micrometers) and infrared (1.55 - 1.75 and 2.08 - 2.35 micrometers) regions of electromagnetic spectrum. The six spectral bands 1 through 5 and 7 provide 30 m ground resolution and band 6 gives resolution of 120 m.

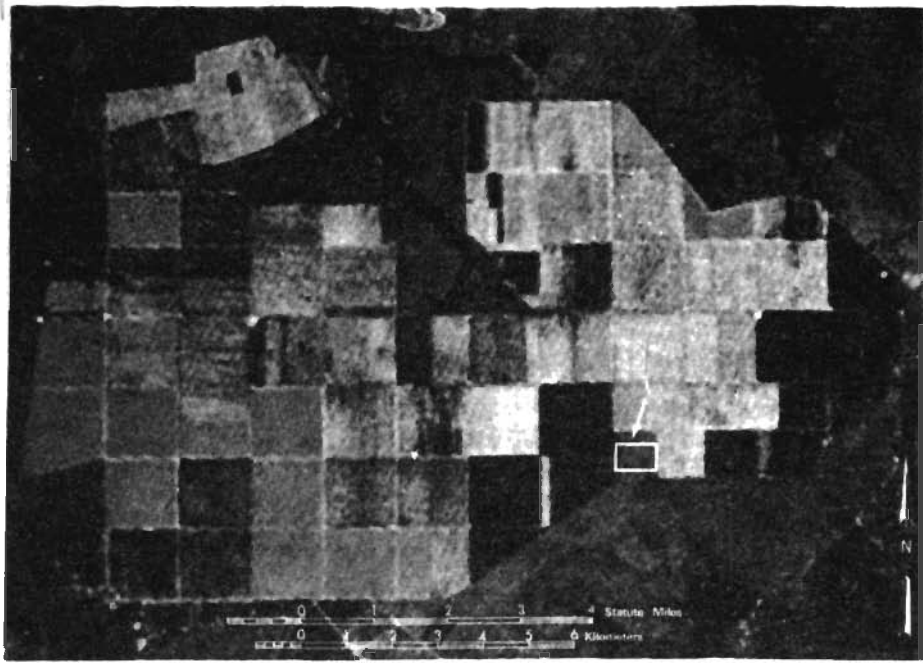
TM relies heavily on the technology of the MSS. TM is designed to achieve finer spatial resolution, sharper spectral separation, improved geometric fidelity and greater radiometric accuracy and resolution.

Comparative Performance of MSS and TM

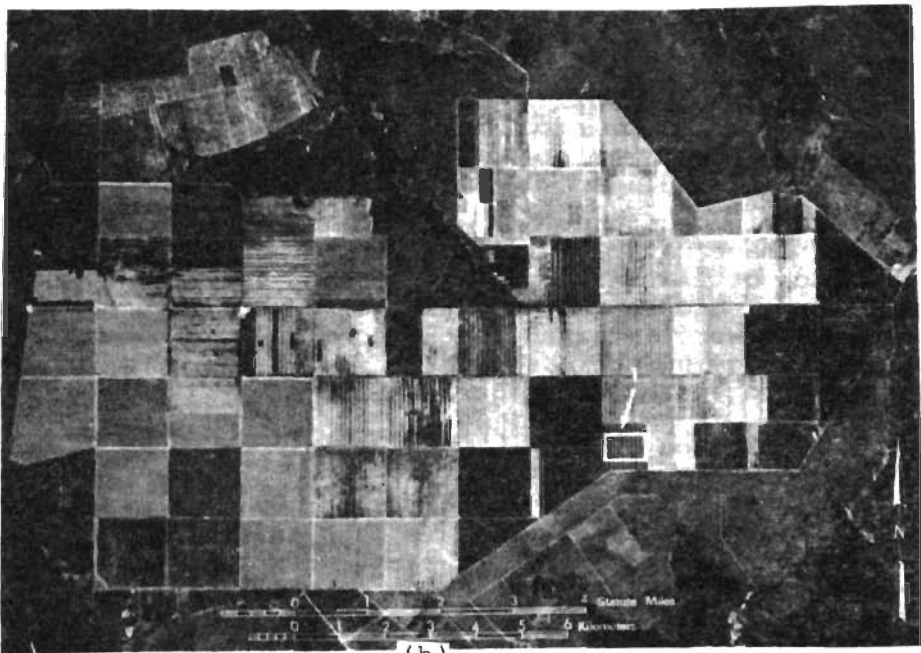
NASA, in conjunction with other scientific agencies organised Image Data Quality Analysis Programme (IDQA) to study performance of LANDSAT-4 sensors. Sites selected were mainly agricultural crops and vegetative cover. The optical and digital data were obtained in the form of CCTs. The data were analysed employing various statistical algorithms/classifiers and image processing techniques (Malia et al 1984) (Fig. 1).

Spatial Comparison

Spatial and spectral comparison as well as availability of the additional bands show that TM is significantly better than MSS in a statistical sense. However, from practical point of view corresponding increase in the technical information has to be assessed. Satellite data are required on a continuing basis and user must consider the cost of a data set and the frequency of observations.



(a)



(b)

Fig. 1 Comparison of MSS and TM images of agricultural scene
(a) MSS image (b) TM image

Crop Studies Using LANDSAT-4 TM Data

Image and digital data of LANDSAT-4 TM sensor was acquired for agricultural and forest study sites. Spectral characteristics of various features were evaluated through statistical analysis and interpretation of image products. Significant results include, (i) spectral variations in agricultural fields are due to variability in crop canopy structure, soil moisture and surface roughness, (ii) Discrimination of crop types is significantly improved by the addition of TM 5 band, and (iii) The thermal infrared data allows the discrimination of agricultural and forestry cover types based on differences in their radiant temperature responses (de Gloria 1984). Using the combined TM and TM simulator data the corn/soybeans separability was evaluated for individual bands and for combinations of bands as a function of time during the growing season. By Fisher information measure, the results indicate that the additional mid-IR bands of the TM allow corn and soybeans to be separated much earlier (Pitts 1984). It is noticed that the soil properties important to the plant can be detected using TM (Thompson and Henderson 1984).

LIMITATIONS OF MULTISPECTRAL SENSORS

With improved capabilities, multispectral sensors could be successfully exploited for crop monitoring. However, one of the major limitation of optical/thermal sensors is that in order to achieve high correct classification rates, it is necessary to have uninterrupted (cloud free) coverage of the area under investigation for successive passes. One way to rectify this problem is to use radar which is effectively immune to the presence of clouds in the atmosphere. Regions like Indian subcontinent where during monsoon most of the sky is covered with clouds, the only alternative is the microwave sensors for crop and soil mapping.

PERSPECTIVE FOR NEXT DECADE

In recent past, number of experiments on crop and soil mapping have been conducted by Indian scientists. To improve the potential and extension of such studies over large areas covering different agricultural and vegetative surfaces defined by various climatic conditions and soil types, satellite observations need to be recorded on repetitive and operational basis. Indian remote sensing satellite to be launched in 1987/88 would be a major technological development towards this end.

Science and mission requirements working group report (NASA 1984 a,b) describes Earth observing system of 1990s. It is proposed to be an information system to serve the needs of an integrated multidisciplinary study of the planet Earth. The

system envisages a substantial new observing capability in low earth orbit in such a way as to provide for sustained global as well as regional measurements over a decade or longer with flexibility to capitalize on new technologies. For many specialized problems in agriculture and other Earth science disciplines there is a need for a detailed localized coverage at higher resolution than is feasible today on global basis with frequent repetition. Proposed series of EOS of 1990's equipped with high spatial and spectral resolution multispectral scanners and multifrequency microwave radiometers promise to meet these requirements (NASA 1984 a,b).

CONCLUSION

Applications/performance of multispectral sensors for crop studies was reviewed. LANDSAT-MSS data with its four spectral bands could be successfully used for classifying various crops and vegetation. Double the spectral classes by TM compared to MSS is due both to the greater number of spectral bands and to greater spatial resolution of the TM and thereby its capability to discriminate various vegetative and land features is improved. With additional IR and thermal bands, TM may be used for determination of canopy temperature, soil moisture and yield. IRS-1 Programme is under way and opens up new avenues for remote sensing scientists in India.

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CROP STRESS MONITORING THROUGH REMOTE SENSING: A REVIEW

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ABSTRACT

An attempt has been made to review the work done in the field of crop stress monitoring by using remote sensing techniques. Crop stress conditions may be monitored by infrared thermometers without physical attachments to the leaf. Stress degree day concept may be used for scheduling irrigation and yield predictions.

INTRODUCTION

There indeed seems to be a consensus that we are living at a time when there is a very delicate balance between the supply and demand for essential foodstuffs, and that the vagaries of even a 'normal' climate could well upset the balance with catastrophic consequences. A good harvest depends mostly on favourable weather conditions in the growing season. Plant water stress due to drought conditions in the crop-growing season causes major reduction in the food grain production. Monitoring of abnormal weather such as drought is thus important for adopting suitable measure to reduce the loss of food production. New techniques for rapid and reliable assessment of crop stress condition are being developed to schedule irrigation in time. Remote sensing techniques play an important role in this endeavour, because of the large areas to be surveyed on a recurring basis.

The evaluation of water status with the help of remote sensing techniques has opened the way to improve yield prediction and scheduling of irrigation. The difference between the temperature of a plant canopy (T_c) and the temperature of the surrounding air (T_a) [$\Delta T = (T_c - T_a)$] is considered as an indicator of the water status of crop plants, since water stress causes partial stomatal closure, thus reducing transpiration and allowing sunlit leaves to warm up above ambient air temperature. Recently, the concept of 'stress degree day' which is a daily value of $(T_c - T_a)$ measured at the time of maximum surface temperature (generally 1 - 1.5 hours after solar noon) has been introduced to (i) predict the water

stress condition for scheduling irrigation, (ii) determine the water requirement and to develop a simplified evapotranspiration model for assessing water use, and (iii) predict yield.

BACKGROUND

The energy flux, R , from an object is related to its surface temperature by: $R = \epsilon \sigma T^4$

where ϵ is the emissivity, σ is the Stefan-Boltzmann constant and T is the temperature of the radiating surface in degrees K.

The total radiative flux (R_{LW}) also includes reflected radiation and is expressed as $R_{LW} = \epsilon \sigma T^4 + (1 - \epsilon) B^*$ where B^* is the flux of incoming longwave radiation.

The theory, techniques of measurements and difficulties associated with measurements of the canopy and soil temperature by infrared (IR) thermometers have been discussed by several workers (Tanner 1963, Fuchs and Tanner 1966, 1968, Fuchs et al 1967, and McGinnes and Aronson 1971). This IR thermometry constitutes an improvement over the use of contact sensors, such as thermocouples, thermistors, which must be attached to or inserted in a plant leaf and which can, thus, cause changes in the condition of the leaf as well as canopy environment.

During the past two decades, instruments that measure thermal radiation have been developed and refined to the point that canopy temperature measurements can be taken with various means. Hand-carried portable radiation thermometers are used conveniently to measure canopy temperature of the field crop. Thermal scanners carried on aircraft and space platforms allow for large area coverage with a resolution dependent upon the particular instrument and the altitude flown. Potentials for utilizing such devices in crop-water stress as well as crop yield predictions have been recognised recently.

In recent years, IR thermometers and thermal scanners have been operated from airborne platforms to measure surface temperatures over large areas.

Canopy temperature measurements from airborne platforms becomes difficult due to perturbations in the atmosphere between the earth's surface and airborne or space platforms from which measurements are made and from uncertainties in surface emissivity values.

Thus, the emissivity of the canopy, the flux density B^* , and the attenuation of longwave radiation caused by atmospheric absorption between the surface and aircraft are required to be known for incorporating correction in the canopy temperature measurements. Several authors have developed techniques for determination of B^* and ϵ (Fuchs and Tanner 1966, Conaway and Van

Bavel 1966, Davies et al 1971). Weiss (1971), Braun (1971), and Maul (1973) described methods to account for the atmospheric attenuation of IR radiation. Weiss (1970) and Richards and Irbe (1969) measured radiation over large bodies of water. Bartholic et al (1972) used a thermal scanner to measure soil and crop temperature in Texas and concluded that the thermal imagery obtained was adequate to discriminate crops showing moisture stress from unstressed ones to evaluate the uniformity of irrigation, and to evaluate the moisture status of the surface soils.

REVIEW OF THE WORK DONE

In late sixties scientists described how satellite information may be used in the future to manage large agriculture - forestry co-operatives. These scientific reports also pointed out the possibilities of predicting water requirements of crops using temperature information. Myers and Heilman (1969), Wiegand et al (1968), and Wiegand (1971) discussed potential uses of thermal infrared scanners for soil and crop temperature studies. The feasibility of using a thermal scanner for determining soil and crop canopy temperatures was studied by Bartholic et al (1972). Moore et al (1975) used data from the S-192 multispectral scanner aboard SKYLAB and outlined procedures for using emittance data for surveying areas of high soil moisture, scheduling irrigations, and providing inputs to water budgets of regions. Plant canopy temperature and the difference between the plant canopy temperature and the temperature of the surrounding environment have been used as an indicator of plant water stress ((Wiegand and Namken 1966, Ehrler and Van Bavel 1967, Aston and Van Bavel 1972, Ehrler 1973, Okuyama 1975, Nixon et al 1973, Idso and Ehrler 1976, and Blad and Rosenberg 1976).

During the last few years there has been a sustained research drive in this direction. Several workers (Horton et al 1970, Carlson et al 1970) have used temperature measurements of the plant canopy to detect crops under various degrees of water stress and therefore photosynthetic-stress.

Thermal infrared radiation in the waveband of 10.5 to 12.5 micrometer has recently been used to quantify crop stress and soil moisture depletion (Idso et al 1977, Jackson et al 1977). Those studies have shown that it is possible to quantify the amount of stress that a crop endures, allowing prediction of the yield. Under well-watered conditions, it was found that the leaves of a crop would be cooler than the air. As the crop water supply became limiting, the temperature differences would be reverse (Idso et al 1977, Wiegand and Namken 1966).

The temperature (ΔT) difference between plant canopy and air indicates the changes in plant water stress, which in turn are elicited by changes in soil moisture content in the root

zone.

Initially irrigation scheduling was designed based on 'stress day index' concept. Hiler and Clark (1971) and Hiler et al (1974) estimated 'stress day index' using measurements of leaf water potential, soil water potential, and evapotranspiration. They suggested, without further development, that the leaf-air temperature differential may be an indicator for stress day factor. Blad and Rosenberg (1976) working with corn, alfalfa and pasture observed that irrigated corn temperature was consistently higher than that of a nearby alfalfa field at later stages of the growing season. It was also warmer than the air except for short periods in the late afternoon. In late spring wheat and alfalfa were at approximately the same temperature and both were cooler than pasture. They concluded that wheat and alfalfa used water at about the same rate and that pasture used less water than either.

Jackson et al (1977) defined the stress degree day (SDD) as

$$SDD = \sum_{n=i}^N (T_c - T_a)_n$$

SDD-

Where SDD is the summation of $(T_c - T_a)$ over a period of N days beginning at day i. ith day is normally chosen in the peak floral initiation stage. When plant is under water stressed condition, $(T_c - T_a) > 0$. Thus the sum of the positive values of $(T_c - T_a)$ serves as an index of when to irrigate. Values of $(T_c - T_a) < 0$ is taken as zero. For Arizona (USA) winter climatic conditions, Jackson et al (1977) proposed an SDD of 10 as an index for the time to irrigate, recognizing that additional experiments would be required to quantify this factor adequately.

Idso et al (1977) tried to develop a link between the differential leaf temperature and air temperature $(T_c - T_a)$ and crop yield. Analogously to the centuries - old concept of the "growing degree day", they devised a "stress degree day" (SDD) concept, in which the final yield of a crop (Y) was hypothesized to be linearly related to the total SDD's accumulated over some critical period. Mathematically it is expressed as

$$Y = \alpha - \beta \left(\sum_{i=b}^e SDD_i \right)$$

where SDD_i is the mid afternoon value of $(T_c - T_a)$ on day i, and b and e represent, respectively, the days on which summation procedure is to begin and end.

Thus crop yield can be estimated from remotely acquired canopy temperatures and auxiliary air temperature measurements obtained during the period from head emergence to the cessation of head growth.

Now, the question arises as to how accurate is this remote measurement of canopy temperature? Does it represent the true

leaf temperature? Blad and Rosenberg (1976) compared leaf temperatures as assessed by attached leaf thermocouples, thermal infrared thermometers, and airborne infrared scanners. Agreement was close when the canopies completely covered the soil. With incomplete ground cover, however, there was some discrepancy between leaf temperature and remote indications (because the remote measurements were seeing some exposed soil). When the canopy is less than full, care has to be exercised to observe the canopy rather than a composite of soil and plants. Otherwise correction factor is to be worked out for each canopy.

CONCLUSION

The differences between canopy temperatures tended to be maximum near 1400 hours, thus making it feasible to use a measurement at this time to represent the whole day. Such ΔT measurements can be included as a part of routine monitoring by remote sensing techniques. However, the applicability of the method needs to be verified for different climatic regions of India. This information will also help to decide when to irrigate the crop and also to predict the crop yield in advance.

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MEASUREMENT AND SPECTRAL ASSESSMENT OF ALBEDO AND ITS RELATION TO WHEAT YIELD

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ABSTRACT

The albedo has been shown to bear good correlation with yield for wheat crop sown under different degrees of moisture stress. The present ground-based study explores the potential of albedo in estimation of yield for wheat crop sown on different dates. Methods of measurement and computation of albedo are given and its relationship to grain yield and biometric parameters discussed.

Since albedo cannot be monitored practically on a routine basis, attempt has been made to estimate it from spectral radiance/reflectance data. The linear combination of spectral radiance/reflectance appears to be the best estimator of albedo. The implication of these findings are discussed.

INTRODUCTION

Wheat is a major foodgrain crop of the world and pre-harvest estimates of its yield and production are crucial to the management of the food situation. Remote sensing techniques, based on the measurement of reflected solar radiation, have emerged as potential indicators of crop condition and grain yields. While most of these studies are directed towards the techniques involving multispectral directional measurements of radiance and reflectance (Tucker et al 1980, Singh et al 1982), the measurement of short-wave hemispherical reflectance i.e. short wave albedo (Janza 1975) has also emerged as a promising technique for estimating grain yields. Idso et al (1977 a,b) in their studies on albedo of wheat crop subjected to different degrees of water stress, have shown that albedo values just prior to ripening correlate highly with grain yield. Furthermore, they had verified the validity of albedo-yield relationships under different soil types, planting densities and geographical locations (Idso et al 1978). However, in a realistic situation, planting dates invariably differ with the implication of the crop being subjected to different environmental conditions. Also, for exploiting the albedo-yield relationships on actual application level, possibility of assessing albedo from multiband remote sensing data needs to be explored.

To look into these aspects, an albedo-yield experiment was initiated on wheat crop planned on different dates. The objectives were i) to validate and explore the correlation of albedo with yield and other crop condition indicators, and ii) to explore the possibility of assessing albedo from multiband radiance data.

MATERIAL AND METHODS

The experiment was conducted on Kalyan Sona variety of wheat (*Triticum aestivum*) during 1982-83 Rabi season at the Wheat Research Station of Gujarat Agricultural University, Vijapur (Mehsana District). Three plots measuring 4 x 6 meters were planted on three different dates (November 25, December 5 and December 15, 1982). The crop was sown at a seed rate of 100 kg/ha in north-south direction with row spacing of 23 cms. All the three plots were given recommended treatments of fertilizer and irrigation.

Albedo Measurement

To measure the reflected radiation an inverted pyranometer (Kipp & Zonen/Eppley) was installed in the centre of each plot at a height of about one metre from the ground level. The incoming solar radiation was measured using another pyranometer mounted in upright position. Two Kipp & Zonen double-channel printing integrators (Model CC-11) were used to obtain the hourly integrated data from all the four pyranometers. The integrators were installed near the plots inside a wooden box which was painted white and well-ventilated to avoid the undue heating of the integrators.

Radiometric Measurements

Spectral radiance over the plots was measured approximately twice a week, using a 7-band ISRO-GTR (Ground Truth Radiometer) operating in the spectral range of 0.4-1.09 μm (see Appendix-I). Also fortnightly measurements were taken with Exotech Radiometer (Model 100A) having four spectral bands similar to those of LANDSAT MSS. Irradiance was measured using a white reflectance standard with barium sulphate coating.

Biometric Measurements

Biometric parameters like leaf area index (LAI), green biomass (GBM) and dry biomass (DBM) were measured every ten days. LAI was determined by measuring green leaf area of six randomly picked plants using an electronic leaf area meter (LI-COR Model LI-3000). Grain yield was measured by harvesting the wheat from 4-9 sq. m area in the centre of each plot.

Data Analysis

The hourly and daily average of albedo values were computed as the ratio of the reflected and the incident solar radiation integrated for the corresponding period. Hourly albedo was plotted against hour of the day and the daily albedo against days-after-sowing (DAS) for each plot. Yield was regressed both against the minimum albedo just before maturity and against the slope of the albedo decline after heading. To compute the slope of the albedo decline, the curve of daily albedo vs DAS, for the period after heading, was smoothened using the method of moving averages. The albedo values thus obtained were regressed against DAS and the slope of the regression line was taken as the rate of albedo decline. Moreover, correlation of albedo with biometric parameters was studied using linear regression analysis. For estimation of albedo from radiometric data, linear combination of radiance and reflectance values, radiance ratios and normalised differences from both sets of data (i.e. ISRO-GTR and Exotech) were regressed against albedo.

RESULTS AND DISCUSSION

The diurnal variation of hourly albedo for a typical clear day is shown in Fig. 1, for all the three plots. The parabolic trough-shaped curve of diurnal variation, depicting higher albedo in the morning and evening and minimum at about solar noon conforms to the theoretical expectations and the experimental findings (Ling and Robertson 1982).

The plot of daily albedo vs DAS for each plot (Fig. 2,3,4) shows a series of maxima and minima. These variations correspond to the days of irrigation when the soil becomes wet and its albedo falls almost to half that of the dry soil. Since the crop canopy in all the plots never completely covered the underlying soil (max. LAI=2.5), these variations are observed throughout the measurement period. This fact also accounts for sharper peaks and troughs in the late-sown plot, which had the poorest crop cover and hence maximum soil exposure.

Apart from these short-term variations due to irrigation, the albedo shows decline after heading which is probably caused first by appearance of heads and later on due to leaf yellowing. This decline continues till the leaves and stalks begin to get dried up, and the albedo rises thereafter. This point occurs at 105, 95 and 85 DAS for the plots sown on progressively later dates, confirming the role of higher temperatures in hastening the development of wheat.

The minimum albedo prior to ripening does not correlate well with yield. This is contrary to the findings of Idso et al (1977 a,b, 1978). However, the rate of albedo decline after heading (till ripening), shows a very good correlation ($r^2 =$

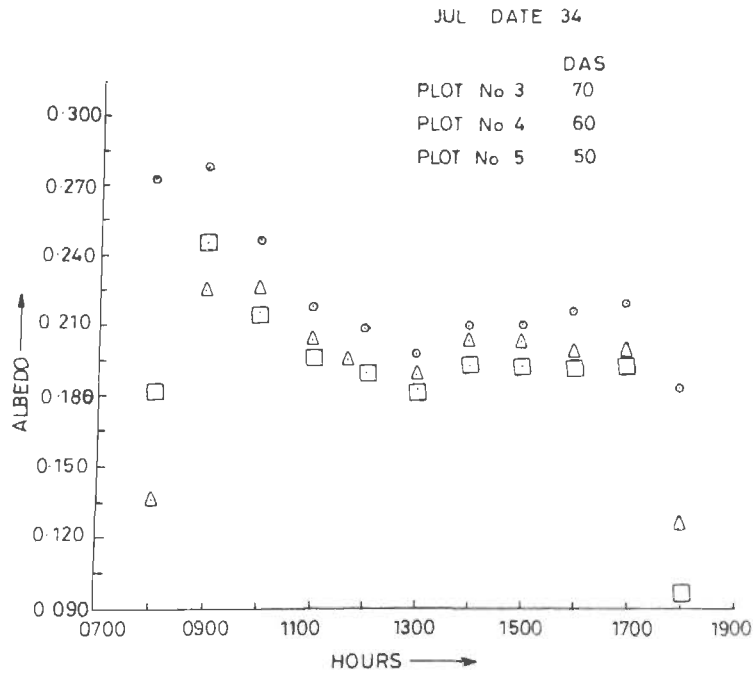


Fig. 1 Diurnal variation of albedo

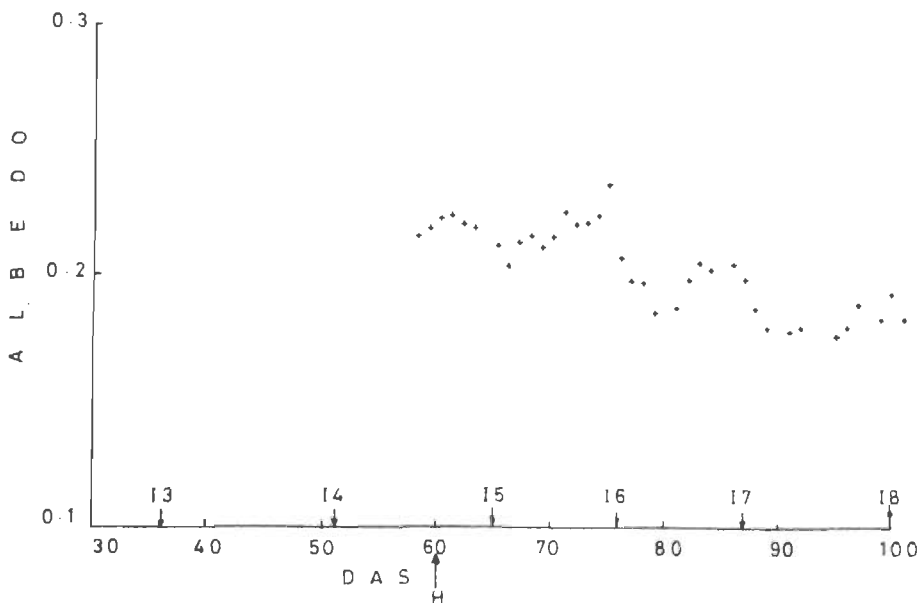


Fig. 2 Alebdo vs Days after sowing (DAS) for plot no. 3

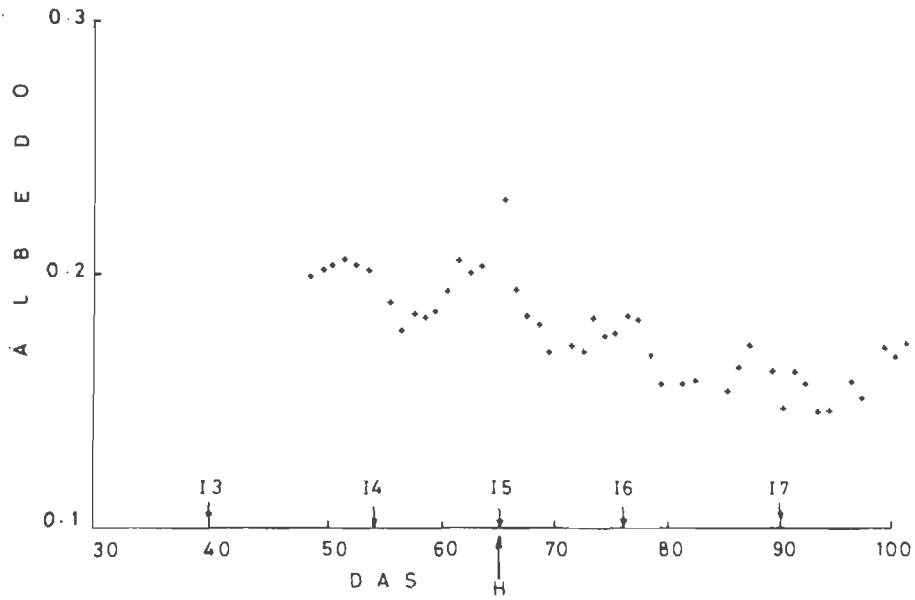


Fig. 3 Albedo vs Days after sowing (DAS) for plot no. 4

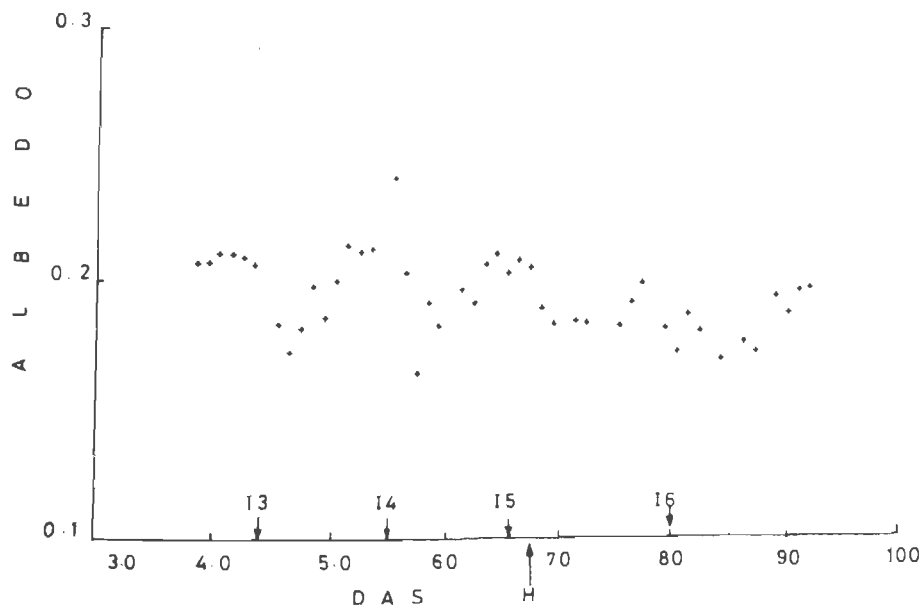


Fig. 4 Albedo vs Days after sowing (DAS) for plot no. 5
(I3, I4, I5, I6: Dates of irrigation, H: Heading)

0.94) with yield (Fig. 5). The reason for this correlation may be because of the fact that a good canopy cover, essential for good yields, would show a rapid decline in albedo after heading, whereas the albedo of a poor crop canopy with much of soil already exposed would not decline rapidly. These results may not be our final conclusion as only three data points were available for analysis.

Daily albedo values correlate linearly with LAI for corresponding days ($r^2 = 0.476$) (Fig. 6). Normally, solar radiation intercepted by a canopy is an exponential function of LAI (Idso et al 1977b). However, since range of LAI in this case was limited to a maximum of 2.5, we obtained a linear relationship. As far as other biometric parameters like GBM are concerned, albedo does not show any significant correlation which appears rather intriguing.

It has been pointed out that once albedo-yield correlations are validated, it should be possible to assess yields by monitoring albedo from satellite data (Idso et al 1977b). Since currently there are no satellites to measure radiation in 0.28-2.8 μm spectral region for direct computation of albedo, we explored the possibility of estimating albedo from spectral radiance data. Correlation of albedo with spectral radiances, radiance ratios, normalised differences and their combinations with albedo was attempted using linear and multiple linear regression of data sets from 4-band Exotech radiometer as well as 7-band ISRO-GTR. The results are summarised in Table 1. The maximum correlation was found with linear combination of 4-band radiance data from Exotech ($r^2 = 0.66$) followed by corresponding reflectance ($r^2 = 0.563$). The linear combination of 7-band GTR radiances gives moderate correlation coefficient ($r^2 = 0.50$).

CONCLUSION

Albedo appears to be promising in yield estimation of wheat planted on different dates. This finding forms an important link in the albedo yield relationship which are known to account for other variation in treatment viz., planting density, soil type, water stress etc. In this study, it is the rate of decline of albedo which correlates well with yield and not the minimum albedo as reported elsewhere. This, however, needs verification using a larger data set.

Another result which may be of considerable importance is the estimation of albedo from spectral radiance and reflectance. The results show that albedo bears good correlation to ground-based radiometric data. This could serve as a starting point for further investigation in estimation of albedo from satellite-based multispectral remote sensing data.

More research in terms of analysis of larger data sets is required for validation of these results. Efforts have already

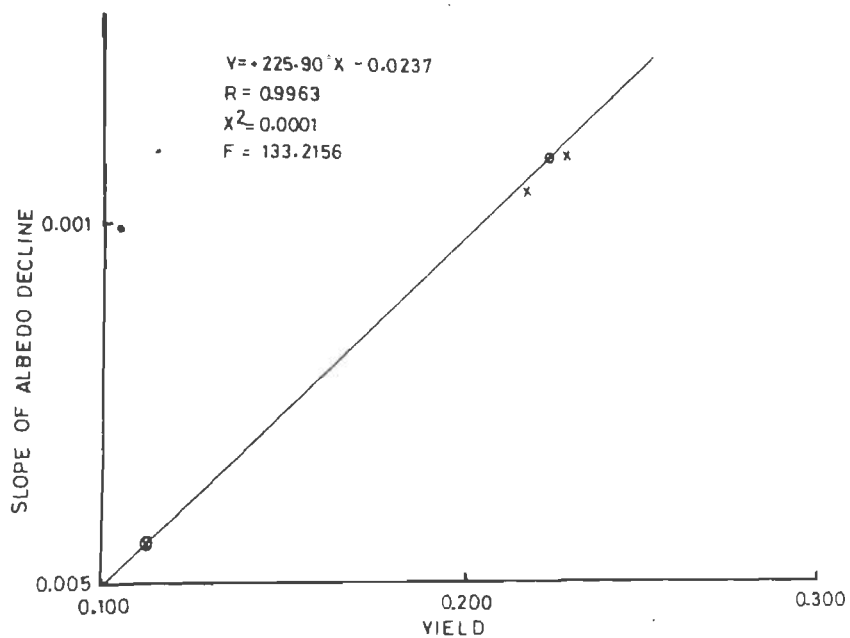


Fig. 5 Yield vs slope of albedo decline

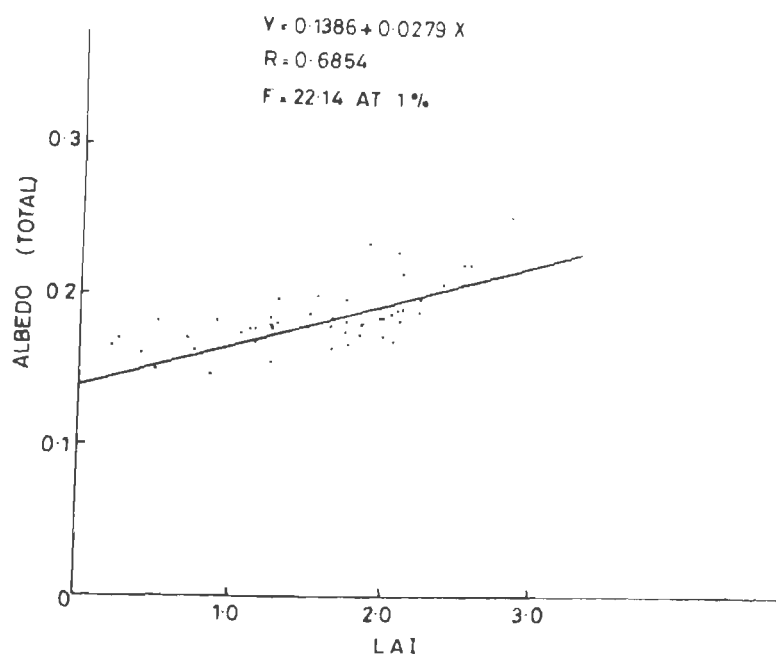


Fig. 6 Albedo vs Leaf Area Index

Table 1
Correlation of Albedo with Spectral Radiance/Reflectance

Independent parameter	Dependent parameter	Correlation coefficient	Coefficient of determination
	Daily albedo (linear fit)	Albedo (during 1000-1100 hrs) (linear fit)	Daily albedo (during 1000-1100) (2nd order polynomial fit)

Exotech			
MSS 4	0.1809(.0327)	0.2394(.0573)	0.6854(.46a) 0.5274(.2781)
MSS 5	0.3619(.1310)	0.4052(.1640)	0.4838(.2340) 0.5197(.2700)
MSS 6	0.3643(.1324)	0.3040(.0924)	0.3643(.1327) 0.3877(.1503)
MSS 7	0.0760(.0057)	0.0198(.0004)	0.5176(.267a) 0.5690(.3237)
7/5	0.2465(.0607)	0.5167(.2669)	0.2649(.070) 0.6356(.4039)
(7-5)/7+5	0.2952(.0871)	0.4061(.1648)	0.3433(.1178) 0.5819(.3386)
All bands (radiance)	0.810a(0.6561)	0.62(.3844)	-- --
All bands (reflectance)	0.750a(0.5625)	0.59(.3481)	-- --

GTR			
All 7 bands (radiance)	0.70a(0.49)	--	--
All 7 bands (reflectance)	0.709a(0.5026)	0.720a(.5184)	

a. Significant at 0.001 level.

been initiated in this direction.

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Appendix I
Spectral Bands of GTR and Exotech Radiometers

Bands	Bandwidth (nm)	
	GTR	Exotech
1	454-508	500-600
2	525-567	600-700
3	583-645	700-800
4	641-707	800-1100
5	710-770	
6	766-893	
7	832-1092	

LAND USE AND LAND DEGRADATION SURVEYS

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ABSTRACT

Land is a primary natural resource. Its proper and effective utilisation is extremely important to a country like India. The pressure on land in India is increasing tremendously not only because of the need to provide food, fibre and fuel for the ever-increasing population but also due to the competing demands from rapid industrialisation, urbanisation, communication and recreation. The scope for exploiting hitherto unused land for agriculture is rather limited. It is thus imperative that productivity of the land is maximized. Besides, it is necessary that this natural resource is conserved. Prime agricultural land is being lost to above-mentioned competing land uses. This is an irreversible process. Besides, there is degradation of prime agricultural land due to preventable causes like waterlogging, salinity, erosion and desertification. The country thus needs scientific land use planning to conserve this important natural resource, to maximise its productivity and to see that its use is environmentally sensitive.

The information requirements for land use planning comprise reliable, up-to-date and comprehensive data on physical, ecological and socio-economic resources. Remote Sensing techniques are particularly suited to provide spatial information on natural resources and have made significant contributions in mapping, inventorying and monitoring of land resources. During the last decade the data from airborne and spaceborne sensors have been extensively used in the country to carry out land use surveys, monitoring of land use changes and to carry out land degradation studies. The techniques for the same can be considered to be quasi-operational. Indian Remote Sensing Satellite Utilisation Programme (IRS-UP) has taken up these activities as a part of its application programme. It is envisaged that pilot-scale projects which have been taken up in collaboration with user agencies, will lead to operationalisation during the next couple of years for land use/land cover and land degradation surveys and monitoring. The present state of the art, problems faced and effort under IRS-UP towards operationalising the technology for these activities are reviewed in this paper.

INTRODUCTION

Land, water and air are our natural endowments. Survival of the human race depends on its living in harmony with the nature and not misusing these natural endowments. Many a civilization has perished in the past when the people misused and overexploited the land, and interfered with their environment. For example, the Mayan, the Mesopotamian and the Harappan civilisations vanished from the surface of the Earth because they recklessly cut trees and forests and impoverished the productivity of the land.

In India, we have enormous pressure on the land. The population has been increasing at an alarming rate. During the 1951-81 period the population increased by 90 per cent. To meet the requirements of food, fibre and fuel for this population, we need more production from the land. However, what is happening is that being a developing country we have competing demands on the land from industrialisation, urbanisation and newer human settlements, setting up of hydroelectric and irrigation projects, communication (railways, roads etc), mining activities and recreation.

More often than not, it is the prime agricultural land which is used for these purposes. This is an irreversible process and an unmistakable drain on agricultural resources. Besides, there is loss of agricultural and forest lands due to reversible or preventable causes like erosion, waterlogging, salinity/alkalinity, desertification, toxic effects of chemicals, industrial and agricultural effluents etc. These processes turn good agricultural land into wasteland. Out of the 329 Mha area of the country, the estimates of wastelands varying from 30 to 150 Mha are being put forward. Even area under forests is fast getting depleted in spite of our declared national goal of having 33 per cent area under forests. The depletion in the forest area is primarily due to overexploitation by reckless cutting of forests, encroachments for agricultural purposes, shifting cultivation etc., beside the natural causes.

Public is now becoming increasingly sensitive to the degradation of our environment. There are also demands for having a better standard of living by the masses. It is therefore, imperative that we should adopt scientific land use planning so as

- i) to prevent losses of agricultural land as well as forests due to reversible as well as irreversible processes,
- ii) to institute reclamation/development measures to convert wastelands into productive lands,
- iii) to determine priorities where demands from competing land uses have to be met,
- iv) to enforce environmentally sensitive land uses,

- v) to maximize productivity of the land to meet the growing demands for food, fodder, fibre and fuel, and
- vi) to regulate development activities through land use models which predict the consequences of the suggested land uses under these development activities.

It is only through such planning that disasters can be prevented, otherwise in the words of George Marsh, a great American conservationist of 19th century, man would soon reduce the world to "a condition of impoverished productiveness, of shattered surface, of climate excess, as to threaten the depravation, barbarism and perhaps even extinction of the species." The fate of the Mayans, the Mesopotamians and the Harappans mentioned above is relevant in this context.

ILRI (1977) has emphasized the land use planning in the following words: "The land-use planning may be concerned with putting environmental resources to new kinds of productive use. The need for land use planning is frequently brought about, however, by changing needs and pressures; involving competing uses for the same land. The function of land-use planning is to guide decisions on land use in such a way that the resources of the environment are put to the most beneficial use for man, whilst at the same time conserving those resources for the future".

In India, we have a serious problem of land degradation. About 175 Mha (53 per cent) of the geographical area is subject to problem of soil erosion and degradation through various processes, both natural as well as those initiated by human activities. The degraded lands found in India are of the following types:

1. Waterlogged and marshy areas
2. Saline soils including coastal and deltaic saline soils
3. Alkaline or sodic soils
4. Sandy soils
5. Gullied and/or ravinous land
6. Riverine land subject to torrents or 'Chos'
7. Laterite soils
8. Gravelly and stony soils
9. Shifting cultivation area
10. Degraded lands due to industrial and mining activities.

Table 1 gives vital statistics on soil erosion and land degradation.

The possibility of finding hitherto unknown land which can be brought under cultivation seems rather remote. The human ingenuity has led to cultivation of even steep slopes

Table 1
Soil Erosion and Land Degradation

Degraded land	Area (Mha)
Total geographical area	329
Total problem area (soil erosion and land degradation)	175
Area subject to water and wind erosio	150
Waterlogged area	6.0
Alkali soils	2.5
Saline soils including coastal sandy soils	5.5
Ravines and gullies	4.0
Area subject to shifting cultivation	4.33
Riverine land and torrents	2.73

(Source: Dept. of Agriculuture, Govt. of India)

in hilly areas or cultivation of river beds in off-season. What is, however, not realized are the consequences of such activities in terms of land or environmental degradation. Even as it is, the agriclutural productivity of land is rather low in India. For example, the people's Republic of China with 20 per cent less area under cultivation has more than twice the food production as compared to that of India. What is, therefore, needed is proper land use planning, emphasizing the maximisation of productivity in the country.

The information requirements for land use planning comprise reliable, up-to-date and comprehensive data on physical, ecological and socio-economic resources. Remote sensing techniques are particularly suited to provide spatial information, the hallmark of physical data requirements. it is generally agreed by remote sensing specialists that remote sensing has the potential to make the most significant contributions in the area of land use data collection and more so in the agriclutural land use (Nunnally 1974). The latter is apparently the most important area of interest to practically all countries of the world, especially to the developing countries like India where agricluture forms the backbone of the national economy.

An international symposium on "Study of Land Transformation Processes from Space and Ground Observations" held at Ottawa in 1982 has shown the state of the art for such studies (Regan and Wolman 1983) using remote sensing techniques.

In this review we shall examine the role of remote sensing techniques in land use/land cover mapping and land degradaton studies in India, with particular reference to the studies carried out in which Space Applications Centre has been involved. We shall also briefly discuss the planned

efforts under IRS Utilisation Programme for land degradation studies.

LAND USE CLASSIFICATION

Current Land Use Classification

The land use classification, currently used in the country, was adopted in 1950-51. It gives the land utilisation details under nine classes. Sometimes this classification is referred to as 9-fold classification. The classes are:

1. Forests
2. Area under non-agricultural uses
3. Barren and unculturable land
4. Permanent pastures and other grazing lands
5. Miscellaneous tree-crops and groves not included in the net area sown
6. Culturable waste
7. Fallow land other than current fallows
8. Current fallows
9. Net area sown

The definitions are given in Appendix I. This classification scheme is incompatible with remotely sensed data. For example, in forest areas, the remotely sensed data would record the actual vegetation cover. The cropped area within a forest or forest blanks will be identified as such but comparison with conventional data would not be possible because legally such areas are termed forests. It is, therefore, important that we should arrive at a suitable land use classification system which is compatible with both the conventional data collection techniques as well as the remote sensing techniques.

LAND USE VS LAND COVER

Before we discuss suitable land use classification scheme based on remotely sensed data, it is necessary to make a distinction between land use and land cover. Land use refers to "man's activities on land, which are directly related to the land" (Clawson 1965). Land cover denotes "the vegetational and artificial constructions covering the land surface" (Burley 1961).

A remote sensor records response which is based on many characteristics of the land surface, including natural and artificial cover. An interpreter uses tone, texture, pattern, shape, size, shadow, site, association etc. to derive information about land use activities from what is basically information about land cover (Anderson 1971). Supplementary information is quite often needed for

inferring land use activities. The title 'land use mapping' is quite often applied to remote sensing image classification procedures as a whole, which tends to amalgamate the distinct concepts of mapping land use and land cover (Sung 1977)

It may be mentioned here that digital image processing can provide only land cover information whereas visual or manual interpretation can provide both land cover and land use information.

LAND USE/LAND COVER CLASSIFICATION FOR RS DATA

The generation of remotely sensed data/images by various types of sensors flown aboard different platforms at varying heights above the terrain, and at different times of the day and the year, does not lead to a simple classification system. In fact, many researchers believe that no single classification could be used with all types of imagery and all scales (Nunnally 1974). To date comparatively the most successful attempt in developing a general purpose classification scheme compatible with remote sensing data has been attempted by Anderson et al. (1971, 1976). Many of the other classification schemes used with remotely sensed data are basically modifications of Anderson's classification scheme. This classification system is commonly referred to as USGS or Anderson classification system (Appendix II).

Four levels of classification are suggested. Table 2 lists the levels of classification and corresponding typical data characteristics.

Level I information can be used at inter-state and statewide level of planning. Level II at statewide to regional scale of planning. Level III at regional to local scales of planning, whereas level IV information can be used at local or microlevel planning.

The USGS classification system is "resource oriented". It is capable of further refinement and improvement to keep pace with advances in remote sensing technology and the varied uses. It is flexible enough to allow subclasses to be added at level III and IV. Even level V can be added. It may be mentioned here that information at level I and II has never been collected directly in the past. It was collected indirectly by aggregating level III (or further levels) information and consequently suffers from many errors which creep in in the process of aggregation. Remote Sensing provides such information directly.

REMOTELY SENSED DATA FOR LAND USE/LAND COVER MAPPING

There are three basic functions for which the data

acquired by remotely sensed systems are used, namely inventorying, monitoring and/or modelling of land use/land

Table 2
Data Characteristics of Different Levels
of lassification+

Classification level	Typical data characteristics
I	Landsat type of data
II	High altitude (12 km or above) aircraft imagery; scale less than 1:80,000
III	Medium altitude (3-12 km) imagery
IV	Low altitude imagery (upto 3 km), scale more than 1:20,000

+ Adapted from Anderson (1976).

cover. These are defined as (Merchant 1981):

Inventory:	Mapping of spatial distributions, assessment of condition, acreage estimation (by district, region, watershed, state).
Monitoring:	Evaluation of land use/land cover change (areal statistics, location, rate and nature of change).
Modelling:	Integration of land use/land cover data with ancillary data (geographic information system development, land suitability modelling, assessment of vulnerability, projections).

LAND USE MODELS

It is realized by most land use investigators "that meaningful decisions in land management and/or land use planning cannot be made until data on the actual use of land can be integrated with other data, such as data on environmental factors, economic factors, and ownership" (Joyce 1973). Land use models must, therefore make use of such data.

Joyce (1973) has enumerated the following components of a land use model:

1. Acquisition: Data acquired and manipulated into a useful information format to be supplied as a base for the model.

2. **Simulation:** The information is then used to simulate a real ongoing process.
3. **Projection:** A certain policy, decision, or course of action is then provided to the model.
4. **Prediction:** The model then accepts the course of action, operates with the information, and then attempts to predict a future or past state.
5. **Output:** The information is displayed or presented in a form that is meaningful to a decision-maker.

Many approaches are being tried. In general a geographic base has been advocated. The existing topographical maps can be subdivided into grid-cells, the size depending upon the level of details needed. The image resolution and the scale of presentation maps are very important factors in this choice. The suggestions by Earth Satellite Corporation (1974) are given in Table 3.

Table 3
Information Characteristics for Modelling

Level	Presentation map scale	Information cell size (m)	Imagery resolution (m)
1	1:500,000	600x600	60 x 60
2	1:250,000 or 1:125,000	120x120	3 x 3
3	1:24,000	8 x 8	0.6x0.6

Such cells can be used for storing and organization of all available physical, socio-economic and census data. Existing geologic maps, soil maps, vegetation maps, transportation network maps etc., serve as further inputs. Such ancillary data are then superposed over the remotely sensed data base. It is then possible to test various models for any desired land use and compare it with the current land use. Predictions about land-use change can also be attempted.

STATE OF THE ART

Both visual interpretation and digital processing techniques have demonstrated the capability to distinguish land use categories of USGS classification level I and level II (See Appendix II) in Landsat MSS data. In certain cases, it has been possible to achieve level III of USGS

classification (Sahai et al 1980).

For operationalization of remote sensing techniques for land use/land cover mapping and monitoring of changes, a fairly high degree of identification and mapping accuracy is required. Various studies on land use/land cover mapping using Landsat MSS data, show that (Earth Satellite Corporation 1974):

- i) Level I categories can be identified generally at 90 per cent accuracy or better.
- ii) Level II categories can be identified at an accuracy of 80 to 85 per cent with the exception of the categories comprising urban or built-up area.
- iii) For generalized land use mapping, involving comprehensive land cover/use categories, the threshold of detection is typically 10 acres (4 ha), however, in the mapping of high contrast areas, like scarred earth surface e.g. strip mining or water/land contrast, surface areas of 1-2 ha can also be identified.
- iv) Linear features such as canals, highways, railwaylines etc. as narrow as 15 meters can be identified.

For the bulk-processed Landsat MSS data, positional accuracy of ± 5 pixels, and in the case of precision products, positional accuracy of ± 1 pixel is achievable. Availability of 30-m spatial resolution data from Landsat-Thematic mapper has changed this picture.

Although the potential for change detection and identification of certain types of land use changes has been demonstrated, the capability of detecting changes consistently in land use/land cover patterns with acceptable accuracies (greater than 85 per cent) in a variety of geographic environments has not been fully demonstrated (Estes 1982).

INDIAN EXPERIENCE

Land use/land cover and land degradation surveys, using remote sensing techniques, have been primarily conducted in the country by the National Remote Sensing Agency (NRSA), Hyderabad, Indian Institute of Remote Sensing (IIRS), Dehradun, Centre of Studies in Resources Engineering (CSRE), Indian Institute of Technology, Bombay, Central Arid Zone Research Institute, Jodhpur, Uttar Pradesh Remote Sensing Applications Centre, Lucknow and the Space Applications Centre (SAC), Ahmedabad. National Atlas and Thematic Mapping Organisation and the Survey of India have also carried out some studies using satellite imagery. Survey of India has been routinely using aerial photography to include latest

information on broad land use categories in the topographical maps on 1:250,000 and 1:50,000 scale.

NRSA has conducted land use surveys in parts of Andhra Pradesh, Haryana, West Coast region, Nagaland, Orissa, Mizoram, Tripura, Arunachal Pradesh and Uttar Pradesh covering in all about 45 Mha area (NRSA 1983). Most of these studies have been conducted using Landsat MSS data. The image interpretation and computer-aided analysis involved the use of M-DAS system and visual interpretation of the imagery or of the enhanced data products. In some cases, available aerial photographs were utilised for the studies supplemented by ground truth data. The final land use maps are on 1:250,000 scale or 1:1 million scale.

Land use/land cover change detection studies were carried out by NRSA in the States of Tripura and Nagaland using Landsat data. Increase in the areas under shifting cultivation and deforestation was detected and delineated. Such studies are also being extended to the other states of northeastern region of India (NRSA 1983).

IIRS, All India Soil and Land Use Survey, and National Bureau of Soil Survey and Land Use Planning, have been primarily conducting soil surveys using aerial photographs available from Survey of India (SOI). Land cover information is collected during ground truth data collection in connection with the soil surveys. CSRE has conducted land use surveys in Chandrapur district (Maharashtra) and Goa-Hubli area. Studies using SOI aerial photographs supplemented the above-mentioned studies.

Extensive land use/land cover and land degradation studies have been carried out at SAC. These studies have been primarily dependent on the visual interpretation of aerial as well as satellite imagery. Main data source of aerial imagery is the colour infrared (CIR) photography conducted by SAC using 70-mm format Hasselblad cameras. In some cases black-and-white aerial photographs from SOI or NRSA have also been used. The satellite imagery used comprises Bhaskara, Landsat MSS and Landsat RBV imagery. Digital analysis of Landsat data using both supervised and unsupervised classifications have been attempted.

The first land use survey in the country using remote sensing techniques (other than panchromatic aerial photographs) was carried out in 1974. ARISE - Agricultural Resources Inventory and Survey Experiment - jointly conducted by the Indian Council of Agricultural Research (ICAR) and SAC during 1974-75 in Anantapur district of Andhra Pradesh and Patiala district of Punjab enabled 30 land use/land cover categories to be delineated under seven major classes: agriculture, orchards, trees, forests, miscellaneous lands, water bodies and public use in Anantapur district (Sahai 1977). Main data source was the

CIR photographs on 1:30,000 scale.

A major land use survey based on multiband aerial photography was conducted in Panch Mahals district (Sahai et al 1983a) during 1976. Detailed land use maps on 1:12,500 scale were prepared for six talukas and on 1:7,500 scale for the Godhra taluka. A detailed map of Ratanmal reserved forest on 1:10,000 scale has been prepared which shows details like plant communities present and their sub-categorization based on crown density. Forest classification showed plantations (4 sub-classes) and natural forest cover (8 sub-classes). A set of 166 land use maps were presented to the Government of Gujarat in May 1979.

Another important project (Sahai et al 1980, 1985a) conducted jointly by SAC and Kerala State Land Use Board (KSLUB), based on multiband aerial photography was in the Idukki district of Kerala. Classification scheme used for mapping is shown in Table 5.

Table 4
Classification Scheme for Land Use/Land Cover Mapping

A Agricultural area - A1 Paddy fields - A2 Sugarcane - A3 Rubber - A3.1 Freshly planted - A3.2 Well grown - A4 Tea - A5 Coconut - A6 Tapioca - A7 Mixed crops - A8 Miscellaneous crops	C Wasteland - C1 Waste and barren - C2 Rock outcrops - C3 Eroded land (rills and gullies) - C4 Marshy area D Waterbodies - D1 Lakes - D2 Streams - D3 Rivers - D4 Canals - D5 Tanks, ponds, wells
B Forest - B1 Eucalyptus plantations - B2 Teak plantations - B3 Mixed forests/ miscellaneous - B4 Reeds - B4.1 Pure reeds - B4.2 Mixed reeds - B5 Forest blanks - B6 Forest fire-affected areas	E Public Use - E1 Roads - E2 Railroad F Unsurveyed/Unclassified

The project resulted in the preparation of 90 land use maps for the entire district on 1:15,000 scale each covering 5° x 5° or about 9 x 9 km area. Geomorphological maps and structural geological maps on the same scale have also been

prepared. This has enabled KSLUB (1984) to prepare a comprehensive "Land Use Plan for Idukki District".

Other land use/land cover studies using aerial photography have been conducted in Ukai Command area (Sahai et al 1985b) and Chittoor (Sharma et al 1983) district of AP. A land use map covering a part of Ukai Command area is shown in Fig. 1. Sharma et al (1980) demonstrated the utility of aerial photographs by carrying out reconnaissance survey of ravines in the Sabarmati basin.

Land use/land cover studies based on visual interpretation of Landsat imagery have been conducted by SAC for many parts of the country. These studies cover the entire Kerala State, districts of Panch Mahals, Kutch, Ahmedabad, Sabarkantha and Mehsana in Gujarat, Saurashtra peninsula, and the entire Ukai catchment (62,000 sq. km area) and the command area. All these maps have been prepared on 1:250,000 scale. In all cases atleast level I of USGS classification was delineated. In the case of Panch Mahals district (Sahai et al 1983a) thirteen level-II classes could be delineated. In Idukki district (Sahai et al 1980, 1985a) even level-III classes like tea, rubber, paddy, mixed crops could be delineated. These studies were extended to the whole state of Kerala. Figure 2 shows the land use map of southern part of the State. In the Ukai-Kakrapar command area (Sahai et al 1985b), it was possible to delineate (Fig. 3) agricultural land as irrigated (2 sub-classes), unirrigated, and degraded (3 subclasses). An important aspect of this study was the delineation of waterlogged areas and their correlation with hydro-isobaths of 0.0-1.5 and 1.5-3.0 m (Sahai et al 1982). Salt-encrusted areas whose extent was more than 12-14 ha were also delineated.

In the Sami-Harij area of Gujarat, a desert area with severe salinity ingress problem (Sahai et al 1983c), land use/land cover classification led to the delineation of dried river and stream courses, very high salinity zone (three sub-classes), high salinity zone (3 sub-classes), moderate salinity zone with sandy clayey soil, and low salinity zone with good vegetation cover.

Other land degradation studies conducted at SAC are

- i) Land degradation /hazards: Idukki, Mehsana, Kudremukh and Sikkim.
- ii) Waterlogging and salinity: Mahi and Fatehwadi command areas.
- iii) Coastal erosion : Gulf of Khambhat (Mahi estuary), East Coast (AP), and Saurashtra.

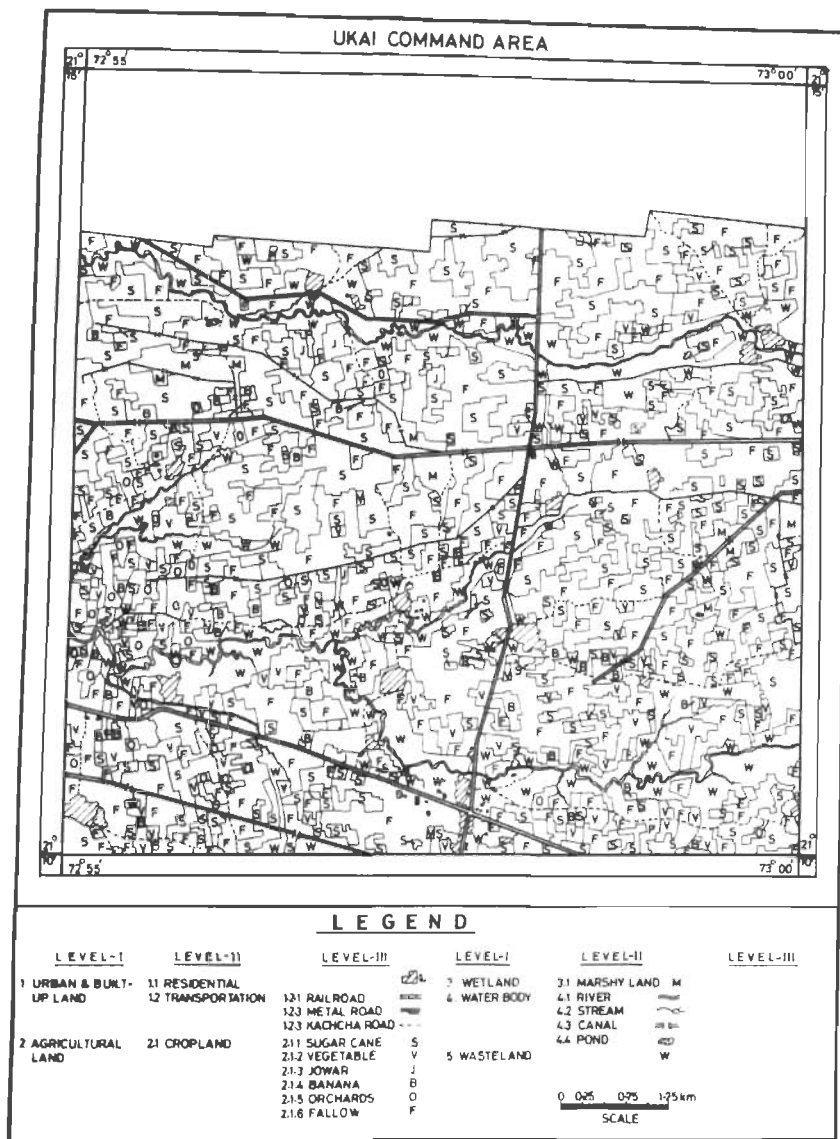


Fig. 1 A typical of a part of the command area showing cropping pattern and land use, interpreted from CIR aerial imagery

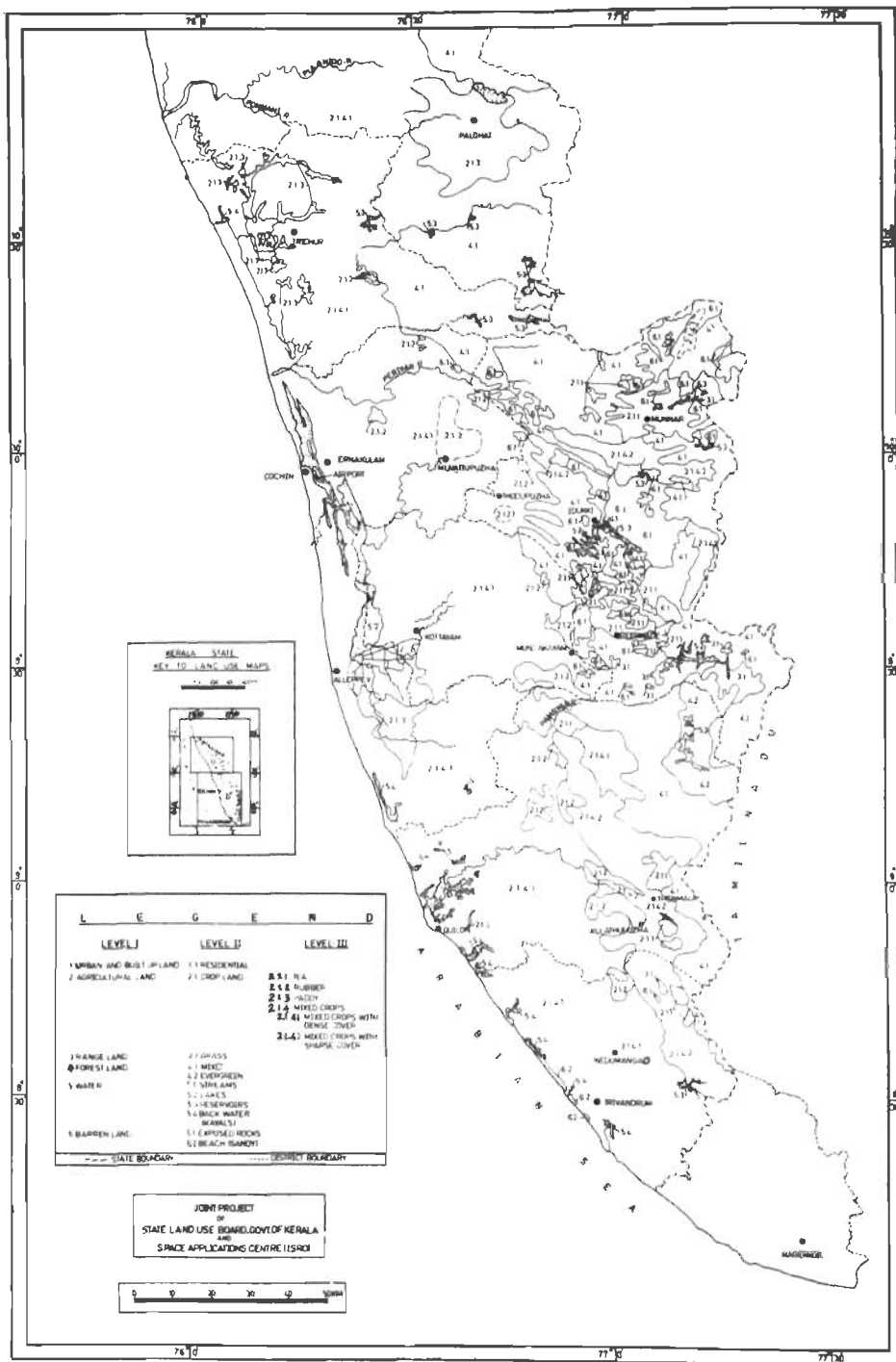


Fig. 2 Land use map of southern part of Kerala state prepared using LANDSAT imagery

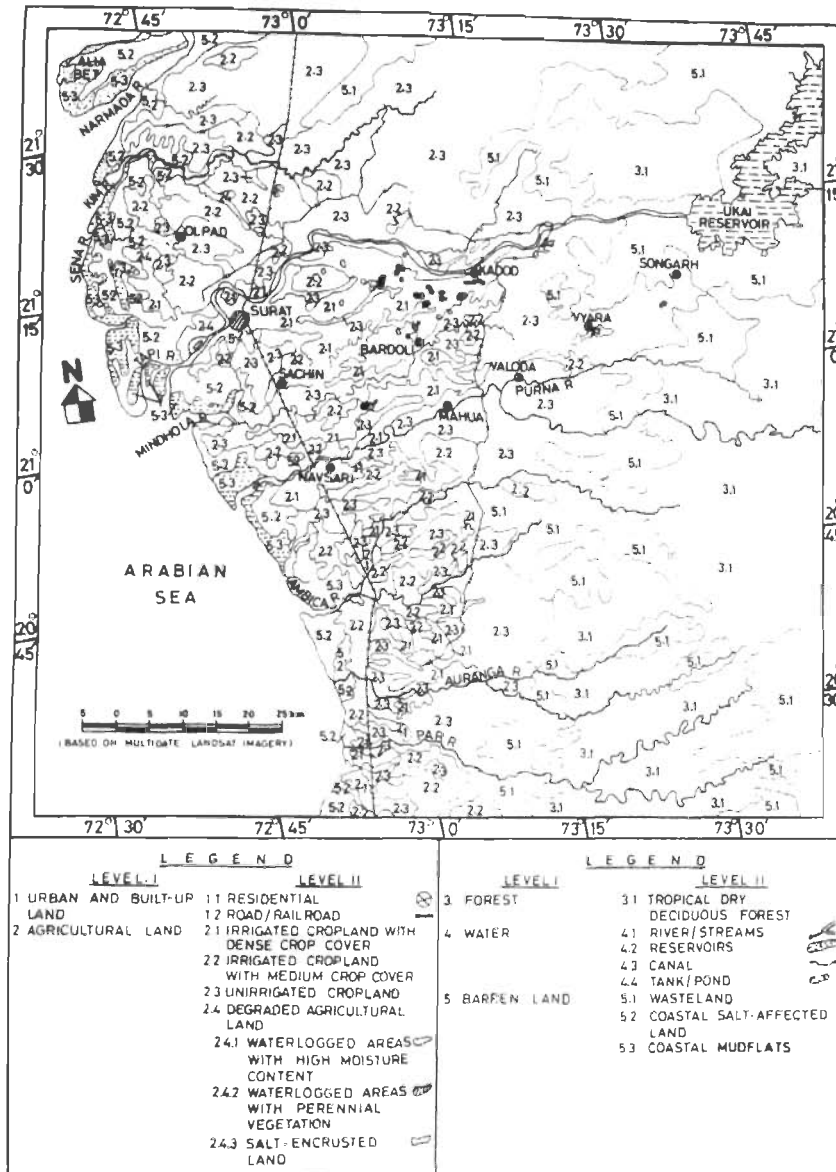


Fig. 3 Land use map of the Ukai-Kakrapar command area (Gujarat)

IRS- UTILISATION PROGRAMME

Under the Indian Remote Sensing Satellite Utilisation Programme, two projects have been identified in the category of quasi-operational application projects. This categorisation implies that feasibility of these applications has been well established in the country as is also evident from the examples of work cited above. What remains to be done for operationalisation of the technology is to carry out pilot scale projects in collaboration with user agencies. Both these projects have been taken up by the National Remote Sensing Agency, Hyderabad in collaboration with the following organisations.

Land use/land cover Survey and Monitoring

- i) Department of Science and Technology, Rajasthan
- ii) Department of Agriculture, Tripura
- iii) Department of Planning, Maharashtra

Land Degradation

- i) Department of Agriculture, Rajasthan
- ii) Central Soil Salinity Research Institute, Karnal
- iii) Central Arid Zone Research Institute, Jodhpur
- iv) All India Soil and Land Use Survey, New Delhi
- v) Soil Conservation Directorate, Manipur
- vi) Soil Conservation Directorate, Tripura

Test sites have been identified and the work has been initiated.

It is hoped that by the time IRS-1A is launched, these projects would become operational in the country.

CONCLUSION

Land use/land cover mapping of aerial CIR photographs, black-and-white aerial photographs, aerial MSS data, and Landsat MSS/RBV data and imagery has been carried out extensively in the country. Based on the use of different type of imagery, following observation can be made.

- i) For detailed land use mapping CIR aerial photography provides the best data.
- ii) Satellite imagery has the capability of providing directly small-scale maps without going through the process of aggregation as in the conventional method of preparing land use maps.
- iii) For regional planning the satellite imagery is quite adequate. The synoptic view provided by the satellite imagery is not obtainable even from a mosaic of aerial

- photographs. The latter lacks uniform illumination.
- iv) For achieving the best results in detailed land use mapping, a three-tier approach satellite-aircraft-ground is the most desirable one.
 - v) For regional land use mapping even visual interpretation of satellite imagery is adequate and is the most cost-effective method for preparing land use maps.
 - vi) Change detection or monitoring of land use changes is best handled through digital processing. However, this requires a lot of R&D work to establish procedures for achieving better than 90 per cent accuracy.

To sum up, we can say that land use mapping has already acquired a quasi-operational status in the country and will definitely achieve an operational status by the time Indian Remote Sensing Satellite IRS-1A is launched.

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Appendix I

Definitions of Land Use Classifications

Classification	Definitions
1. Forests	Area under forests includes all lands classed as forests under any legal enactment dealing with forests or administrated as forests, whether State-owned or private, and whether wooded or maintained as potential forest land. The area where crops are raised in the forest and grazing lands or areas open for grazing within the forests are included under the forest area.
2. Area under non-agricultural uses	All lands occupied by buildings, roads and railways or under water e.g., rivers and canals and other lands put to uses other than agricultural.
3. Barren and unculturable land	This covers all barren and unculturable land like mountains, deserts, etc., land which cannot be brought under cultivation unless at a high cost shall be classed as unculturable, whether such land is in isolated blocks or within cultivated holdings.
4. Permanent pastures and otehr grazing lands	These cover all grazing lands, whether they are permanent pastures and meadows or not; village common grazing lands included under this head.
5. Miscellaneous tree-crops & groves not included in the net area sown	Under this class is included all cultivable land which is not included under net area sown, but is put to some agricultural use; lands under casuarina trees, thatching grass, bamboo bushes and other groves for fuel etc., which are not included under orchards are classed under this category.
6. Culturable waste	These include all lands available for cultivation whether not taken up for cultivation or taken for cultivation once, but not cultivated during the current year

and last five years or more in succession; such lands may be either fallow or covered with shrubs and jungles which are not put to any use (they may be assessed or unassessed and may be isolated blocks or within cultivated holdings); land once cultivated but not cultivated for five years in succession is also included in this category at the end of the five years.

7. Fallow land other than current fallows	This refers to all lands which were taken up for cultivation but are temporarily out of cultivation for period of not less than one year and not more than five years; the reasons for keeping lands fallow may be either poverty of cultivators or inadequate supply of water or malarial climate or silting of canal and rivers or unremunerative nature of farming.
8. Current fallows	This class comprises cropped areas which are kept fallow during the current year; for example, if any seeding area is not cropped again in the same year it is treated as current fallow.
9. Net area sown	This represents the area sown with crops and orchards, counting areas sown more than once in the same year only once.

Adapted from Report of the National Commission on Agriculture, 1976, Part XIV, pp. 149-150.

Appendix II

Land Use and Land Cover Classification System for
use with Remote Sensor Data

Level I		Level II	
1.	Urban or built-up land	11	Residential
		12	Commercial and services
		13	Industrial
		14	Transportation, communications and utilities
		15	Industrial & commercial complexes
		16	Mixed urban or built-up land
		17	Other urban or built-up land
2.	Agricultural land	21	Cropland & pasture
		22	Orchards, groves, vineyards, nurseries, & ornamental horticultural areas
		23	Confined feeding operations
		24	Other agricultural land
3.	Rangeland	31	Herbaceous rangeland
		32	Shrub and brush rangeland
		33	Mixed rangeland
4.	Forest land	41	Deciduous forest land
		42	Evergreen forest land
		43	Mixed forest land
5.	Water	51	Streams and canals
		52	Lakes
		53	Reservoirs
		54	Bays and estuaries
6.	Wetland	61	Forested wetland
		62	Nonforested wetland
7.	Barren land	71	Dry-salt flats
		72	Beaches
		73	Sandy areas other than beaches
		74	Bare exposed rock
		75	Strip mines, quarries & gravel pits
		76	Transitional areas
		77	Mixed barren land

8.	Tundra	81	Shrub and brush tundra
		82	Herbaceous tundra
		83	Bare ground tundra
		84	Wet tundra
		85	Mixed tundra
9.	Perennial snow or ice	91	Perennial snow fields
		92	Glaciers

Reproduced from Anderson et al (1976)

**AN INVENTORY OF THE LAND USE OF THE PARSON
VALLEY RESERVOIR WATERSHED IN NILGIRIS DISTRICT, TAMIL NADU**

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ABSTRACT

The hilly tracts of Nilgiris district have a number of hydroelectric power reservoirs in the two main basins of the Moyar and the Bhavani rivers which are now experiencing silting problems. The watersheds of these reservoirs have been studied with a view to locate the problem areas causing soil erosion and to carry out suitable soil conservation measures.

Parson Valley reservoir is one of the chain of reservoirs in the Nilgiris. The reservoir, at the head reach of all the reservoirs, does not at present undergo perceptible silting. However, the land cover in the watershed is changing over the years, exposing soil cover as analysed from photo-interpretation. The multistage forest plantation adopted in the watershed appears to add to soil cover disturbance during and after the felling of trees periodically for commercial purposes. The local and regional analysis were carried out visually using large scale aerial photographs and LANDSAT imagery, and the results are discussed in the paper.

INTRODUCTION

Watershed is the most acceptable unit for the purpose of planning for optimum use and conservation of soil, water and natural resources. The watershed of the river valleys need immediate attention in watershed planning as they are subjected to bad management practices resulting in soil erosion and alarming rates of siltation in reservoirs. The Kattery reservoir in the Ketty valley of Nilgiris District of Tamilnadu has been silted up completely for which dredging work is now in progress. This can be cited as an example of mismanagement of watershed in this area.

The Nilgiris is located at an elevation ranging from 1000 m to 2636 m above mean sea level. It covers an area of 130 km² (from 10°30'N to 11°49'N) x 185 km (from 75°44'E to 77°87'E).

The topography is rolling and steep. It forms part of the Bhavani river basin. The river Moyar in the north and the

Bhavani in the south, originate and flow in this basin and later drain into lower Bhavani dam to join the Cauvery river basin.

The Moyar river follows a shear zone while the Bhavani river in the upper reaches above Mettupalayam, follows a lithological boundary and in the lower reaches, flows through mixed gneiss upto the Bhavani town.

The oldest reservoir is the Kattery reservoir constructed at the end of nineteenth century in the Bhavani basin. In the middle of the twentieth century a large number of reservoirs have been added for hydel power, irrigation and water supply. The important ones are Pykara, Mukurti, Parson Valley, Portimund, Glenmorgan across the Moyar river and its tributaries and the Emerald - Avalanchi, Kundah, Upper Bhavani, Pillur in the Kundah-Bhavani river basins.

The Bhavani basin accounts for 50 per cent of the hydel power produced by the entire state of Tamilnadu. The installed capacity of the power stations are given below.

Power station	Year of operation	Installed capacity in MW
1. Pykara	1932-33	70
2. Moyar	1951-52	36
3. Kundah I	1959-60	60
4. Kundah II	1959-60	175
5. Kundah III	1964-65 & 1978-79	180
6. Kundah IV	1965-67 to 1977-78	100
7. Kundah V	1963-64 to 1981-82	20 20

The future programme of power generation in the Bhavani basin would be as follows:

i. Parson valley	30 MW
ii. Kundah ultimate stage	160 MW
iii. Nellithorai	50 MW
iv. Pykara ultimate stage	150 MW
v. Lower Bhavani	8 MW
vi. Pykara	2 MW

It is observed that the well-managed forest watersheds of Pykara and Mukurti have not silted up the reservoirs even to 0.1 per cent over a period of 48 years, whereas the ill-managed agricultural watersheds of Kattery has caused complete silting of its storage dam in 10 years. The ill-managed plantation watershed (tea estates) of Kundah generated soil erosion to an amount of 45 per cent of its reservoir capacity in 8 years.

This clearly indicates the need for proper land use management for the prolonged life of reservoirs and sustained production of power.

STUDY AREA

Parson valley reservoir located about 20 km west of Ootacamund has a total geographical area of 14.79 sq.km. It is located at 11°25'N latitude and 76°36'40"E longitude. This reservoir is constructed across the Parson V alley Nalla in the Wenlock downs reserve forest in 1930. Total extent of the watershed is 14.79 sq.km. and the Full Reservoir Level (FRL) is 2209.8 and Bed Level (BL) is 2186.33 m.

This watershed is located at 2200 m above mean sea level. It is one of the reservoirs located in the uppermost reaches. As the location of this watershed is above 2000 m, the entire area was covered with natural grasslands till 1969. The grasses like *Chrysopogon zeylanicus*, *Themeda triandra*, *Andropogon lividus*, *Ischaemum indicum*, *Cymbopogon polyneuros* are predominant in these areas. These grasslands were subjected to biotic interference like continuous overgrazing, and introduction of forest plantations and thereby disturbing the ecology of this area. The composite land use now existing in this watershed includes the natural grasslands, Shola forests, Wattle and Blugum plantations apart from very few pockets of agricultural lands with contour stone-wall and bench terrace constructions.

The Parson valley nallah drains into the Mukurti reservoir which is the major dam in the Moyar river basin. This watershed is adjacent to Emerald watershed of the Kundah river system. Hence the water from this reservoir is diverted into Emerald reservoir by means of a tunnel and, therefore, it is included in the Kundah hydro-electric system though it originally belongs to the Moyar river basin. The next important factor is that this reservoir is also used for supplying drinking water to the Ooty town which is located near by.

METHODOLOGY

The conventional land use mapping consumes considerable time to acquire and compile data to produce a map of current land use of an area. By the time such a map reaches public or planners, it becomes out of date due to subsequent changes. Further, the topography of the area is highly undulating and hence manual survey is very expensive and time-consuming. The detailed topographic survey of the area was done by Survey of India in 1908 and later corrected upto 1970. The latest topographic sheet available is based on the surveys conducted in 1970.

Hence the following remotely sensed available data were used to extract current and relatively meaningful information about topography as well as land use of the watersheds.

1. False colour composite imagery taken by LANDSAT-1 in 1972.
2. Aerial photographs, 1:25,000 scale, taken in 1974-75.
3. Aerial photographs, 1:50,000 scale, taken in 1980-81.
4. Aerial photographs, 1:10,000 scale, taken in 1981-82.

Of the three groups of aerial photographs available, visual interpretation was done using the 1:25,000 scale aerial photographs of the 1973-74 and 1:10,000 scale aerial photographs of 1981-82. The aerial photographs of 1:50,000 scale of 1981-82 were not used for detailed visual interpretation as the large scale aerial photos of 1:10,000 scale of the same time were available.

However, the diapositives of 1:50,000 aerial photographs were used to prepare 1:25,000 scale contour map at 10 m contour interval using the stereo-plotter. With these multidade photographs and the information available from the topographic sheets of the earlier years, following temporal analysis was done.

RESULTS AND RECOMMENDATION

From the temporal study it has been found that the land use has dramatically changed in the past 16 years (from 1969 to 1984). Prior to 1969 the entire area was classified as a Reserve forest consisting of natural grasses and sholas. The District Gazetteer also claims 14.79 sq.km. as forest land. But the aerial photographs of 1972-73 indicated about 25 per cent land under forest cover. The 1981-82 aerial photos indicate about 45per cent land under forest plantation. The man-made forest plantation are reducing the natural grasslands in this watershed (Fig. 1).

Area in sq. km.			

	1954 Toposheet	1972-73 aerial photo- graphs	1981-82 aerial photo- graphs

Forest	0.13	3.98	6.27
Grassland	14.27	8.55	6.09
Water spread area	--	1.46	1.46
Others	--	0.43	0.58

The eastern and southern catchment areas having minute gullies and rills, are prone to landslip.

The topography is steep to very steep. The slope is above 20 to 30 per cent in most of the areas excepting the alluvial flood plains which have a slope of above 5 to 10 per cent.

Contour mapping was done using diapositives of 1:50,000 aerial photographs taken in 1981-82. The map is on 1:25,000 scale and has contours at an interval of 10 m. The section of watersheds have been compared and it is noticed that the watershed generates soil erosion (Fig. 2).

The soils in the northern slopes are lateritic soils. The southern slopes consists of lateritic soils with top humic layers. The swampy plains formed in these areas contain alluvial and colluvial soils.

One aspect which induces landslips in these southern slopes is the presence of white alumina clay alongwith laterite soils. While water infiltrates into these soils having the different density, porosity and infiltration capacity, it causes landslips.

The visual interpretation of the 1:1,000,000 scale false colour composite from LANDSAT of Feb 1973 covers whole of the Bhavani basin and areas in Kerala and Karnataka states. The Parson valley reservoir appears as a small blue dot and the area around is in light pink colour i.e. mixed vegetation with grass. This is confirmed by the visual interpretation of the 1:25,000 aerial photograph taken in 1972-73. However the satellite imagery does not give more information as the study area is about 14 sq. km. only.

The terrain is very steep with more than 30 per cent slope. This can be classified as a class VIII land for soil conservation purposes. This watershed is located above 2200 m where natural grasses grow in a dense manner and protect the soils from runoff thereby reducing or preventing soil sedimentation in the reservoirs. This is evident in the undisturbed slopes of Pykaras and Mukurti lakes.

The interesting factor noticed in the forest plantation is that they are not as effective as the grasses to prevent soil erosion. The presence of multistage forest plantation in the small area of 14 sq. km. causes frequent disturbance in ground cover.

The forest plantation are sholas, very dense forest plantation, new grown forest plantation, newly contoured planted area, the areas where trees have been felled and coppice shoots of eucalyptus are allowed to remain. A forest

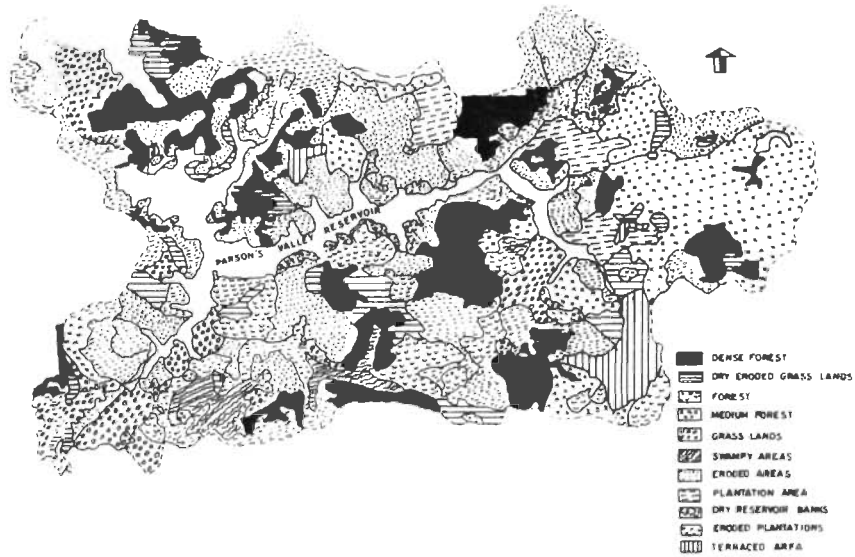


Fig. 1 Land use map of Parson valley sub-watershed during 1981-82

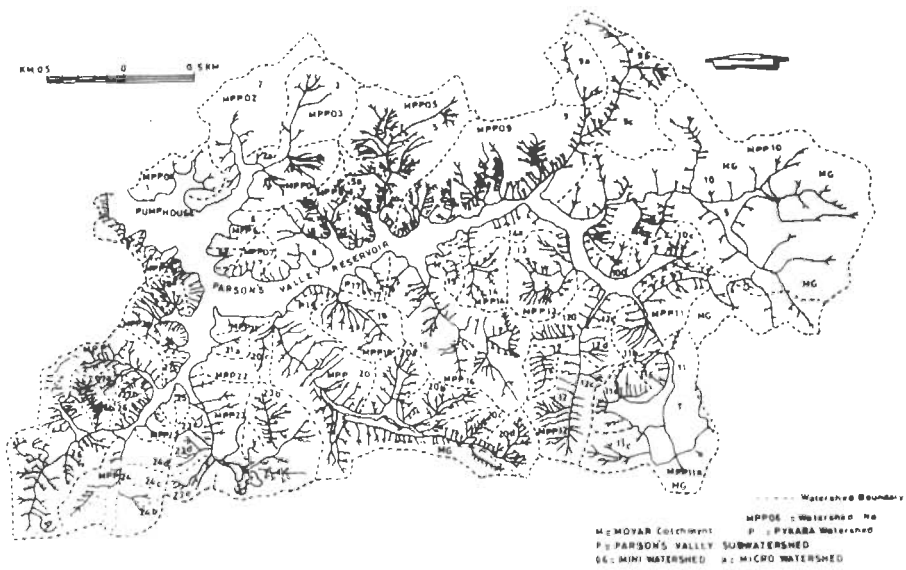


Fig. 2 Watershed map of Parson valley sub-watershed

plantation will be effective in protecting the watershed only when it is allowed to remain permanently to ensure effective soil conservation during rainfall.

The just planted areas with barren soils are clearly visible in 1:10,000 scale aerial photograph. If the present condition of multistage forest plantation is allowed to continue there is likelihood for the reservoir to have slow and steady sedimentation in future.

The minor gullies and rills are visible in the newly planted areas. It is suggested that if soil conservation measures such as contour trenching are taken up alongwith plantation this will reduce formation of gullies and thereby arrest erosion of soil.

The major gullies which are in the process of forming into big ravines were noticed in the downstream side of the stream leaving the Parson valley dam, in the 1:10,000 aerial photograph. However, while ground truth verification was done it was noticed that the entire gullied area was under forest plantation. The silver oak trees of 1 to 1.5 m height are covering the gullied area. This will protect this zone to a great extent. If check dams with river training works are introduced this will help in completely reclaiming the gullies.

The southern watershed, though under grasses and not under intensive afforestation, because of the swampy plains and the grasslands protects the reservoir from silting up. Whereas the northern slopes, though having forest plantation programme, are feared to add more sediments as the soils are exposed in the slopy track. The soil mulch is absent. The trees also do not give good canopy or they are not serving as a permanent forest.

CONCLUSION

The remote sensing techniques were useful to study the watershed characteristics in a very short period.

The Parson valley reservoir, though at present has lower silting level compared to the other reservoirs, will be reaching its perceptible siltation stage very soon unless the proper land use management practices are correctly followed. Some of the measures recommended are:

- a) The lands which are taken up for afforestation should be put under permanent forest. The commercial forest plantation where tree felling is done every 7 or 8 years leaving the soil exposed to erosion also requires suitable soil conservation measures.
- b) Forest plantation should be accompanied by contour trenching, check dams and other soil conservation structures so that the sediment flow can be arrested till

- the forest grows.
- c) The removal of natural grasslands available in the high southern slopes and few pockets of shola forests should be avoided.
 - d) The agricultural lands on the southeastern side should be maintained properly to avoid soil erosion.

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**AERIAL REMOTE SENSING APPLICATION TO AN EVALUATION OF
HYDROLOGICAL AND WATERLOGGED CONDITIONS IN A PART OF
GANGETIC ALLUVIAL PLAIN OF UTTAR PRADESH**

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ABSTRACT

Hydrological field data and the hydrogeological information obtained through aerial photographs have been combined to delineate the waterlogged and salt-affected areas and various fluvial hydrogeomorphic features in Sumerpur block of district Unnao, U.P., forming a part of Gangetic alluvial plain and covering an area of about 274 km². The study area is facing the acute problem of waterlogging, which, at certain places, has resulted in the development of Usar i.e. saline-soil. These features have been easily noticed on airphotos of 1:60,000 scale. Besides, various geomorphic features of fluvial origin have been also identified in the study area, through aerial photos, these include point-bars, flood-plain, abandoned meandering channels, meander cut-offs, oxbows, and back-swamps. The hydropotentiality of some of these features is extremely good, chiefly for the future ground-water management practices in the area. Considering the prevailing hydrological conditions, minor-irrigation as well as various agricultural programmes are needed to be implemented here, in order to solve the waterlogging and allied problems of the area, chiefly for the judicious and integrated development of irrigational/agricultural sector.

INTRODUCTION

During the past several decades, conventional techniques are being followed for assessing the water resources, particularly the ground water regime of an area. These methodologies are not only difficult, but also time-consuming, costly and can provide only one - time data, and need more accuracy through newer techniques, chiefly to arrive at some realistic picture. With the advent of remote-sensing era, it is now possible to provide an accurate information system for any hydrogeological domain. The aerial/satellite remote sensing techniques are now being extensively applied not only in the delineation of different fluvial geomorphological features of ground water significance, but also in monitoring the waterlogged, high soil-moisture and salt-affected areas,

particularly in an alluvial plain. If the hydrological information as obtained from aerospace data analysis is coupled with reasonable ground truth data, the result would be a relatively comprehensive evaluation of hydrogeological regime of an area. An endeavour has been made to decipher the hydrogeomorphology, waterlogging, soil-salinisation etc. in a part of Gangetic alluvial plain of Uttar Pradesh, primarily to determine the ways for maintaining the natural hydrological balance.

DESCRIPTION OF STUDY AREA

Location

Block & district	Area	Geographic co-ordinates	Topographic map
Block Sumerpur (Dist. Unnao)	274 sq.km	N Lat 26° 35' 24" to 26° 50' 09" E Long 80° 36' 24" to 80° 53' 42"	63 B/11, 12 15, 16.

Climate

The area experiences subtropical type of climate with average normal annual rainfall for the district Unnao being 840 mm. (as per IMD).

Topography, Drainage and Relief

Topographically, the area is flat with gentle undulations, belonging to Gangetic alluvial plain, although having low surface along the course of the river Ganga. The general elevation in the area varies from 112 m to 117 m above msl.

The area is mainly drained by the river Ganga and its tributaries viz. the Loni nadi, the Pipri nala, the Kharhi nala, the Samrai nala etc. Besides, there are some ponds and lakes in the study area, which might be a contributing factor in the hydrological regimetal changes occurring in the area.

Soils

The main soils of the area are Unnao clayey loam, Unnao sandy loam, sandy clay, Unnao loam, and Unnao clay loam (as per University of Agriculture and Technology, Kanpur). Few patches of Usar (salt-affected soil) are also found in the area.

Geology and Hydrogeology

Geologically, the area is having Quaternary alluvium of Indo-Gangetic plain. Ground water in the area occurs under water table to semi-confined conditions. The presence of palaeochannels in the area indicated good aquifers with high potentiality. The position of ground water budget in the study area, as calculated on April 1, 1981 is as follows:

Area	Recoverable recharge (MCM)	Net draft (MCM)	Ground water balance (MCM)
Block Sumerpur	126.50	32.59	93.91

Qualitatively the ground water in the area has no adverse effect on the crops. As per the chemical analysis results, the ground water is of good to moderate quality, being suitable for irrigational purposes.

Agriculture

Regular Rabi and Kharif crops are usually sown in the area.

Irrigation

In the area of investigation, canal system and private irrigation structures are being used for irrigational purposes.

ANALYSIS OF AERIAL PHOTOS

In order to gather realistic information on the hydrogeological conditions prevailing in the study area, panchromatic aerial photographs on 1:60,000 scale were analysed, and in the process various fluvial hydrogeomorphologic features were identified, as shown in the enclosed photohydrogeological map (Fig. 1).

The area of investigation, falling broadly in Ganga-Loni sub-doab, has been classified primarily into two main hydrogeomorphic zones having different depositional morphologic features: (a) Recent alluvial-plain deposits, which include river-channel, flood-plain deposit, point-bar, and channel bar, occupying the major T_0 terrace, (b) Older alluvial-plain deposits, which include abandoned meandering channels, meander cut-offs, back-swamps, minor river channel of the Loni river and few nallas, falling in T_1 and T_2 terraces.

Characteristic hydrogeomorphic units of fluvial origin are being discussed as below:

River Channel

The main river of the area is the Ganga, extending for about 11 km in the present region. It is a perennial channel serving as ground water drain. The channel material seems to be sand, being fine to coarse grained. The channel bed

infiltration is possibly through sand. Besides, a small river, the Loni and few nallas also drain the area to some extent. The drainage system is not uniform having low density.

Flood-Plain Deposit

On the air-photos, active flood plain on T₀ terrace of river Ganga is a smooth land bordering the main channel, being agriculturally a productive land. It consists of unconsolidated sediments mainly coarse sand, and is considered to be hydrogeologically good, exhibiting mottled texture on air photos due to varying amount of moisture content. Besides, due to braiding of river Ganga, few prominent channel bars have been also developed in the area.

Point-Bar Deposit

It is a highly permeable and unconsolidated fluvial deposit usually coarse sand with occasional clay and silt, serving as a good recharge zone with exceedingly low run-off, having streaky multiple channel appearance and displaying ridge and swale topography (as observed on air-photos). Ground water potentiality of such feature is very high. It covers an area of about 3.5 sq. km.

Channel-Fill Deposits (Palaeo-Channels)

These are permeable deposits and include abandoned meandering channels, meander cut-offs and oxbows, which are filled with seasonal water or with fluvial material like silt to clay or sand, although having coarser sand at depth. They can be distinguished on the air-photos by light to medium grey tone and from their uniform surface pattern like present day channels. These features are the potential sources for ground water development, chiefly through tubewells, serving as zone of good recharge and low run-off, and where ground water usually occurs at shallow to moderate depth, under water-table and confined conditions.

These palaeo-channels illustrate various developmental stages of the river system of Ganga, and are considered to be fossil meandering courses possibly of the river Ganga.

The prominent abandoned meandering channels have been mapped near villages Narikhera, Bhagwant nagar, Gohrenda, Jahanganj (Baraila Jhil), Kandra and Pokhri. These abandoned channel courses are covering a total area of about 14.5 sq.km and having different length variations given as follows:

Table 1
Channel Details

Geomorphic unit	Length variation (km)	Symbol (as per plate no. 1)	Shape
1. Abandoned meandering channels	0.60-9.9	I	Meandering straight to semi-circular.
2. Meander cut-offs including oxbow lakes.	0.90-2.7	II	Loop/crescentric/oxbow-shaped.

Back-Swamps

These are moderate to dark-toned slightly depressed relief areas as identified on aerial photos, being filled with finer sediments-mainly silt, deposited in stock water. Water table is possibly free, i.e., near the surface, hence ground water occurs at shallow to moderate depth with poor potentiality. These swampy bodies have been mapped near villages Langrakhera, Bajeora, Behta, Ganjiri, Kundanpur and mainly in between river Loni and Purwa branch of Sarda canal, indicating high soil moisture area. These cover an area of about 9.2 sq.km.

In the process of present investigations through air-photointerpretation, high soil moisture/waterlogged and salt-affected (Usar) areas have been also located in the area, as illustrated below:

Waterlogged Areas

The presence of high soil moisture, indicated by dark tone on air-photos as compared to its surroundings, is suggestive of high watertable and such areas are susceptible to waterlogging, as depicted in Fig. 1. This phenomenon of waterlogging and its causes and remedies, ably supported by field observations, is being discussed separately.

Salt-Affected Areas (USAR)

The rising water level in relation to waterlogging usually causes the precipitation of sub-surface salts on the ground, which subsequently result in the development of salt-affected/saline soil. These salt-encrusted patches have been easily mapped in detail on aerial photographs, by their characteristic light tone, white grey colour, which is indicative of total or nearly total absence of vegetation, with high reflectance of bare and hard surface. These salt-affected barren lands (Usar areas) have been delineated near villages Panaikalan, Mohkampur, Kisakhera, Ganjiri, and Devpur (Fig. 1), having an areal extent of about 12.5 sq.km.

HYDROGEOLOGICAL OBSERVATIONS

Historical premonsoon and post-monsoon water-table data of the present area for eight hydrograph stations, between the years 1978 and 1982, has been analysed with a view to observe the changes occurring in the ground water regime (Fig. 2 & 3). It has been noted that a part of study area, covering villages Mudiankhera, Bhagwantnagar, Ajabkhera, Akwara, Ganjiri, Gahrenda etc., falls within a contour showing depth to water table as 2 m or less, thus having a tendency to get waterlogged (Fig. 2). Graphs showing pre-monsoon and post-monsoon water-levels for some of the hydrographs stations have been plotted supporting the waterlogged conditions in part of the area (Fig. 3).

During the year 1982, when the present investigation was taken up, waterlevel ranged from 3.58 m to 10.50 m bgl. in post-monsoon period. Water table data for the year 1978 indicates that the fluctuation in the area range from 1.37 m to 3.82 m while during 1982, it ranged from 0.50 m to 2.67 m. Further, it has been also observed that there is a decrease in average water table fluctuation by 0.80 m between 1978 and 1982.

Random well-inventories carried out in about 15 villages of block Sumerpur during postmonsoon period, 1982, indicate that the water level ranged from 0.74 m to 4.55 m bgl., while the total depth varies from 2.70 m to 13.48 m bgl. Some of these observations show that depth to water level is within 2.00 m range, which is suggestive of waterlogged conditions coinciding with the historical hydrographic data, as shown in Fig. 2.

WATERLOGGING AND ITS POSSIBILITIES

Waterlogging is a phenomenonal problem caused by excess inflow vis-a-vis out-flow, both surface and ground water, in a particular hydrographic basin. An area is said to be waterlogged when the depth to water lies within the root zone of crops, i.e. the area with water levels within 2 m bgl. are considered to be waterlogged and with water levels between 2 and 3 m bgl. as near waterlogged.

In the study area, water table, at places, has reached very close to ground level, possibly due to seepage from existing network of unlined canals, inadequate drainage, stagnation of water due to field-to-field irrigation, besides, also due to seepage from abundant natural lakes and ponds. Seepage due to these factors has resulted in the rise of waterlevel within 2 m bgl. (as clearly observed in post-monsoon periods), indicating waterlogged conditions (Fig. 2).

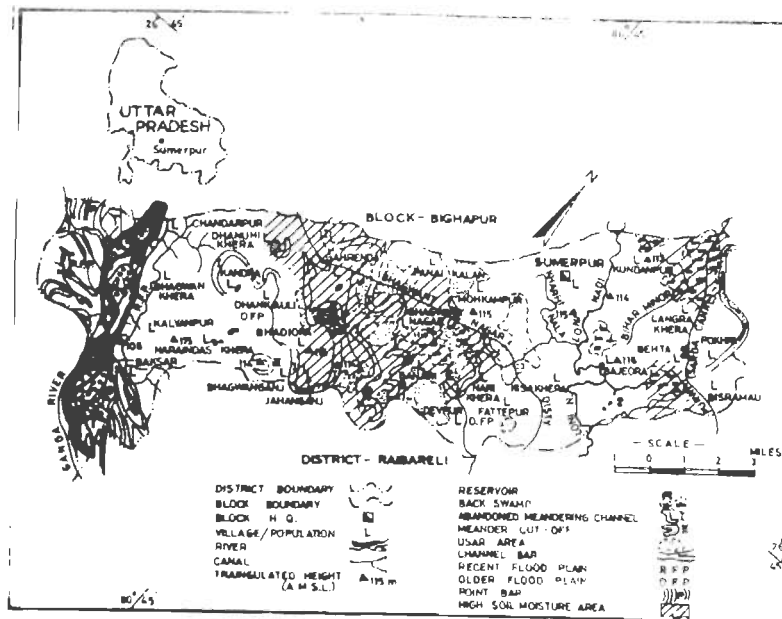


Fig. 1 Photohydrogeological map of block-Sumerpur, district Unnao

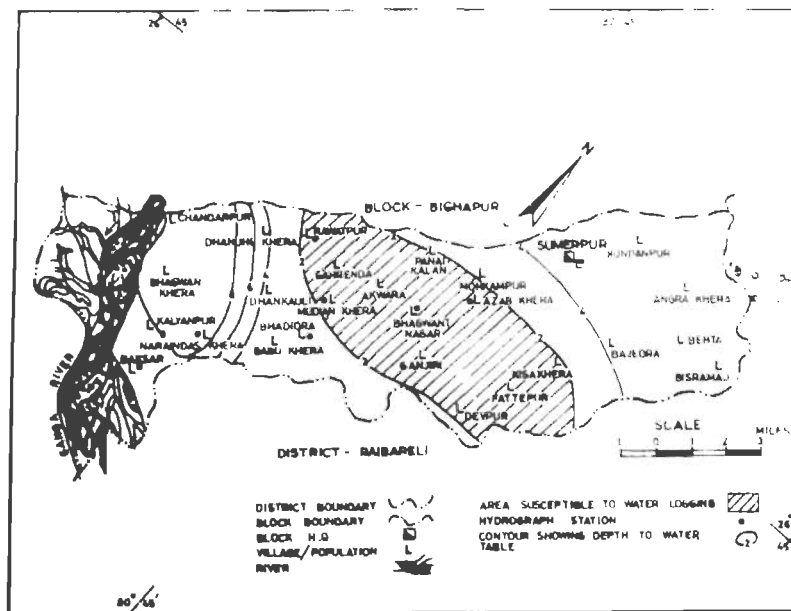


Fig. 2 Map showing water table contour (post-monsoon, 1982) in block-Sumerpur, district - Unnao

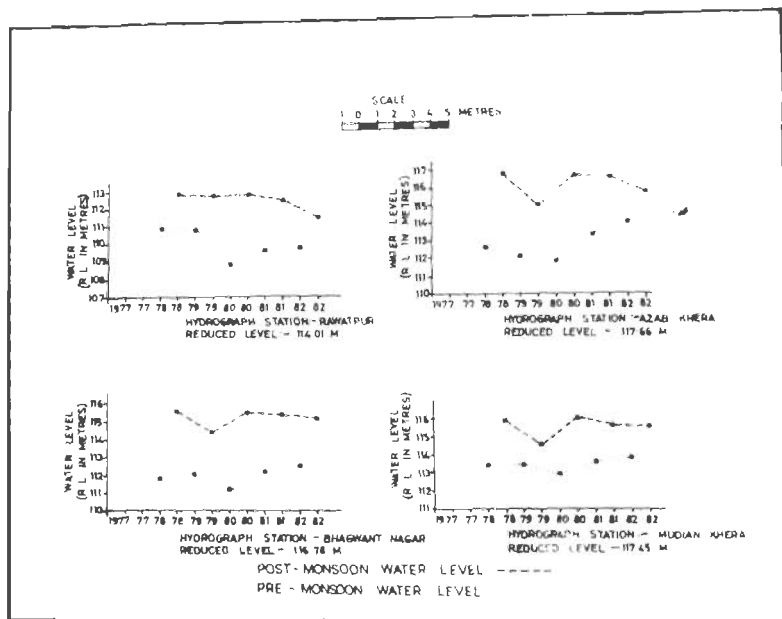


Fig. 3 Graph showing water level for pre-monsoon and post-monsoon period from year 1978-1982 (with respect to R.L.)

The area, having high soil moisture being susceptible to waterlogging, have been marked on the air-photos by dark tone (as shown in Fig. 1), truly matching with the available ground truth data (as given in Fig. 2).

Effects

The rise in water level with respect to waterlogging may lead to following adverse conditions which may ultimately effect the regional ecological balance:

- i) Precipitation of subsurface salts on the ground, subsequently forming salt-affected lands, which are unfit for agricultural purposes.
- ii) Decrease in productivity and fertilizer absorption-capacity of soil.
- iii) Increase of recharge and flooding of agricultural areas.
- iv) Decrease in agricultural produce.
- v) Damage to floors and mudwalls of village hutments.

In the present area, the raised water level/waterlogging at certain places has resulted in the development of user/salt-affected areas (Fig. 1).

CONCLUSIONS AND RECOMMENDATIONS

Aerial photo-interpretation, combined with ground truth information, helped enormously in evaluating the hydrogeological regional characteristics of block Sumerpur, dist. Unnao of Uttar Pradesh. The present investigations have led to the following specific conclusions.

1. The area is covered with Gangetic alluvium of quaternary age, having almost plain topography.
2. Photo-analysis of the study area has revealed the presence of various hydrogeomorphologic features, these include point bar, flood-plain, river channel, channel bar falling in recent flood-plain deposits, while the other significant features are abandoned meandering channels, meander cut-offs, oxbows, back-swamps being preserved in older alluvial plain.
3. Abandoned channel courses of streams offer potential sites for obtaining large supplies of ground water, mainly through tubewells.

4. Waterlogged conditions and salt-affected lands have been also mapped successfully on the aerial photos.
5. Hydrographic data has helped in demarcating high water table area (i.e. within 2 m range bgl), indicating waterlogged conditions in a part of the present area, which coincides with the results of air-photo analysis. Such high water-level/waterlogged conditions have developed the barren and salt-encrusted patches (Usar areas).

On the basis of aforementioned investigations, following recommendations are being made-

1. Adequate irrigation water-management, well-planned and controlled development of surface and ground water resources for their conjunctive use must be followed.
2. Abandoned channel and related features, being hydropotentially very good, may be selected to intensify the minor irrigation programmes by constructing discharge tubewells, which will ultimately solve the waterlogging and allied problems of the area.
3. Besides, in order to prevent the hazards of waterlogging, other remedial measures, such as lining of canals and other water courses mainly to check seepage, construction of surface drains cutting across the ground water-table contours, tree-plantation, change in cropping pattern, reducing canal discharge during the non-irrigated periods, must be taken up in the area, primarily for the integrated development of agricultural and irrigational practices.
4. Usar/salt-affected areas should be suitably reclaimed for future agricultural practices.
5. Periodic assessment of waterlogging and related hydrological regimen should be carried out regularly through remote-sensing techniques, for the future developmental plans.

ACKNOWLEDGEMENT

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**MONITORING LAND COVER CHANGES USING
INDICES DERIVED FROM REMOTELY SENSED DATA
(A CASE STUDY)**

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ABSTRACT

The usefulness of remotely sensed data for monitoring changes in land cover is widely recognised. This paper suggests methods for generating two indices namely, the index of patchiness of the pattern of clusters and the index of crowding of pixels within a cluster from LANDSAT data. These indices are used for monitoring the changes in land cover in a location in India where mining of iron ore is in progress.

INTRODUCTION

The use of remotely sensed data in the planning and management of natural resources is increasing. In most of the cases its utility has been limited to the description of land cover in the form of maps. The usefulness of land cover maps generated from remotely sensed data has increased by its use in combination with other collateral and field data. Recent studies (Anderson et al 1976, Kleckner 1981, Merchant 1981, Kamat et al 1983) reveal that remotely sensed data can be used effectively for monitoring changes in land covers. The changes in the land cover patterns effect the ecological system directly. The degradation in the quality of ecosystem is a problem faced by ecologists, planners, administrators, social scientists and many others, who often look for a measure of change in order to assess the impact of development. The objective of this paper is to use multivariate LANDSAT data and evolve suitable methods for generating indices pertaining to land cover in order to monitor the changes.

The various indices that can be derived are measure of aggregation, mean crowding, index of crowding of the samples within clusters (Pielou 1977) and interspersion and juxtaposition (Mead et al 1981). Out of these only two indices, viz. the index of patchiness of the pattern of clusters and the index of crowding of individuals within the clusters are used to estimate the changes in land cover for the Kudremukh region in south-west India, where land cover is getting disturbed because of mining activities. LANDSAT MSS data for December 1976 and Nov 1978 are used to derive these indices. The sample referred to here is equivalent to the spatial resolution of a

LANDSAT pixel and the cluster is a group of pixels.

METHODOLOGY

A spatial analysis of the land cover was carried out for the units, where each unit contains a number of clusters, using the following measures (Pielou 1977).

Index of Crowding of Pixels within Clusters

If the pixels occur in clusters, then the number of pixels per unit has a mean $M = m_1 m_2$ and Variance $V = m_1 V_2 + m_2 V_1$ where m_1 and V_1 are the mean and variance for the number of clusters per unit and m_2 and V_2 are the mean and variance for the number of pixels per cluster. This can be written as (Lloyd 1967)

$$M = \frac{V}{M} + M - 1$$

where M is the index of mean crowding of pixels, M is the mean of the number of pixels per unit, and V is the variance of the number of pixels per unit.

Index of Patchiness

It is defined as the ratio of mean crowding to mean density. It can be expressed as (Lloyd 1967)

$$P = \frac{M^*}{M}$$

where P is the index of patchiness, M^* is the mean crowding, and M is the mean density

From the observations, if it is found that M^* is a linear function of M , the value of M^* at $M=0$ is an estimator of the index of crowding of pixels within the clusters and the slope of the line is an estimator of the index of patchiness of the pattern of clusters.

CASE STUDY

Results

In a recent study (Kamat et al 1983) it was found that grasslands and forest covers in the Kudremukh region, Karnataka, India is getting disturbed because of the mining of the iron ore deposits. The study area is enclosed between the latitudes $13^{\circ}8'N$ to $13^{\circ}20'N$ and longitudes $75^{\circ}8'E$ to $75^{\circ}18'E$. The study used multitemporal LANDSAT MSS data, aerial photographs and field data and produced 1:250,000 scale land cover maps for delineating changes. The land cover maps derived from December

1976 and November 1978 LANDSAT data are used for computing the indices for crowding of pixels and patchiness of the pattern of clusters. Table 1 gives the percentages of area under various land covers. The mapping unit in the above scale map is 6.5 km

For each of the above mentioned cover types, the number of pixels per unit and index of mean crowding of pixels in a unit are calculated. These values for a number of units of forest covers and grasslands are chosen from locations where actual disturbances are taking place, and plotted as shown in Fig.1 & 2. From the figures, it can be observed that the number of pixels per unit and the index of mean crowding of pixels for the above mentioned covers are correlated linearly. The intercepts of the lines from the ordinates give the indices of crowding of pixels within clusters and slopes of the lines are the estimates of patchiness of the pattern of clusters. Table 2 presents the values of indices for the above-mentioned covers.

Discussion

Landcover map generated from December 1976 data gave four types of covers viz. dense forest, moderately dense forest, grassland with scattered shola forest and open jungle. Six types of land cover have been identified in the land cover map of November 1978, namely, dense forest, moderately dense forest, mining and reservoir. Thus after 1976 two new and additional land cover have come up in this region namely mining and reservoir. It can also be seen that after 1976 the region was subjected to developmental activities and as a result of which older land cover patterns are affected.

The index of crowding of pixels within the clusters in the disturbed locations shows a decreasing trend for the two land covers and their values vary from 7.30 to 3.18 for forests and from 7.45 to 5.81 for grasslands (Table 2). Crowding refers to the density of pixels for the same cover. Therefore, this leads to the conclusion that there was an increase of non-forested patches within forested areas and therefore the density of forest pixels is showing a decreasing trend. Similarly, in the case of grasslands due to the increase in mining related activities the density of pixels for grassland is decreasing. In contrast to index of crowding, the index of patchiness of the pattern of clusters shows an increasing trend for both the land covers and their values have changed from 0.92 to 0.98 for forests and from 0.93 to 1.09 for grasslands. The land cover map of November 1978 also shows that the disturbance due to open jungle, grassland with scattered shola forest, mining activities is mainly in the grasslands.

The differences in percentages of areas give quantitative information about the changes for the whole study area and the land cover maps present the same spatially, whereas the index of patchiness shows the increase of non-forested patches within the covers in a unit and the index of crowding indicates a reduction of densities of the covers for both the forests and grasslands in the disturbed area. However, it may be noted from

Table 1 that actually area under forests is marginally increasing and that under grassland is decreasing in that region. The reason seems to be that the Kudremukh Mining Authority was simultaneously implementing an afforestation scheme while mining operations were proceeding.

CONCLUSION

LANDSAT MSS data can be used for generating indices viz. the index of patchiness of the pattern of clusters, and the index of crowding of pixels within a cluster. With the help of these indices it is possible to monitor the changes in land covers. Though the present results are encouraging, it is desirable to carry out similar studies at other test sites to support and confirm this approach.

Table 1
Distribution of Land Covers

Name of class	Percentage of area	
	December 1976	November 1978
Dense forest	26	27
Moderately dense forest	14	16
Open jungle	13	14
Grassland with scattered		
Shola forest	43	38
Mining area	-	4
Unclassified	4	1

Table 2
Indices Derived from Land Cover

Year	Land cover	Index of crowding of pixels within the clusters (M2)	Index of patchi- ness of the pattern of clusters (P)
1976	Forest	7.30	0.92
	Grassland	7.45	0.93
1978	Forest	3.18	0.98
	Grassland	5.81	1.09

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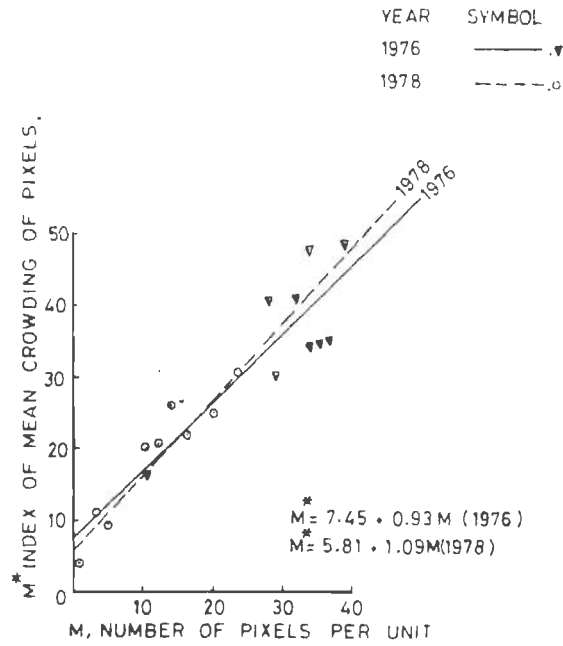


Fig. 1 Correlation of number of pixels per unit and index of mean crowding for grasslands

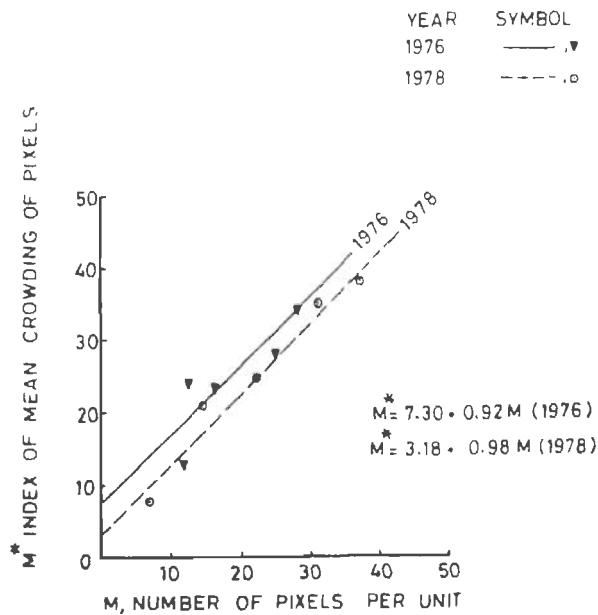


Fig. 2 Correlation of number of pixels per unit and index of mean crowding for forests

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VISUAL INTERPRETATION OF LANDSAT IMAGERY FOR MONITORING LAND USE PATTERN

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ABSTRACT

Land is required for various purposes like agriculture, plantation and vegetation, shelter and many other developmental activities. Remote sensing technique, particularly from a satellite platform, provides a comparatively faster and cheaper way of collecting the information about land use and related land features for monitoring the changes in agricultural pattern of a given region. In this paper LANDSAT-MSS imagery of scene 157-039 has been analysed using visual interpretation method for mapping the land use features and monitoring the changes occurring therein, if any, over a period of 3 years (1974-1977).

INTRODUCTION

The conflicting demands of human activities and the pressure of increasing population have made it essential to plan the use of land in an optimal manner, so as to reap maximum benefits for the millions of human beings. In order to achieve this aim, it is necessary to have up-to-date information concerning present land use pattern and monitoring changes in the areal extent of different features at a regular interval of time. Since most of the land features are somewhat interrelated to each other, one has to take an integrated view of the project area, so that development of one land use feature does not have adverse effect on the other related features.

The rapidly developing technology of remote sensing offers an efficient and timely approach for mapping and collection of land-use change data. The synoptic view of a very large area and its temporal coverage are the major assets of any satellite-based remote sensing system. The analysis of LANDSAT MSS imagery in most of the developing countries, has generally been carried out by visual interpretation methods, based on the basic elements of photo-interpretation like tone, texture, pattern etc. These elements are usually recognised by the analyst and used to establish the image entities.

AREA UNDER INVESTIGATION

The area under investigation includes parts of the states of Uttar Pradesh, Haryana and Himachal Pradesh in northern India as shown in Fig. 1. It is situated approximately between latitudes $29^{\circ}45'$ to $31^{\circ}00'N$ and longitudes $77^{\circ}00'$ to $78^{\circ}45'E$, with an areal extent of about 1.8×10^6 hectares. The area is highly undulated, rising in elevation from 250 m to 6500 m above m.s.l. Snow cover is the most peculiar feature above 3000 m elevation, while below it most of the hills and mountains are covered with different types of forests. In the lower reaches, below 500 m, the study area is almost flat with highly fertile agricultural land which is well irrigated by a net work of canals taking off from the Ganga and the Yamuna rivers. About 22 per cent of the total area is under cultivation, having wheat and rice as the main Rabi and the Kharif crops and sugarcane as a round-the-year crop.

VISUAL INTERPRETATION OF LANDSAT IMAGERY

Band 5, LANDSAT imagery, acquired on May 8, 1974 and April 13, 1977 of scene 157-039, had been selected for carrying out the land use mapping in the study area. These images, blown-up to 1:250,000 scale, were analysed monocularly using well-established visual interpretation method and various land use features delineated. In the study area the following land use and land cover classes could be easily identified and deciphered on the LANDSAT enlargements: (i) thick forest, (ii) thin forest, (iii) agricultural and grassy, (iv) sandy, (v) barren area, (vi) snow, (vii) major urban area, and (viii) water features.

The above land use and land cover delineations were transferred to the base map, already drawn on transparent mylar sheet for further analysis, a sample area of which for April 13, 1977 is shown in Fig. 3.

RESULTS AND DISCUSSIONS

The distribution of areal extent of each land use and land cover class as obtained from land use maps of May 8, 1974 and April 13, 1977, has been shown in Table 1 and graphically presented in Fig. 2. A comparison of percentage coverage of the same classes in the years 1974 and 1977, has been shown in Table 1. The comparison of the above results shows that:

- a. the area under thick forest has increased by 2.93 per cent, may be due to some new plantation or maturing of trees after nearly 3 years,

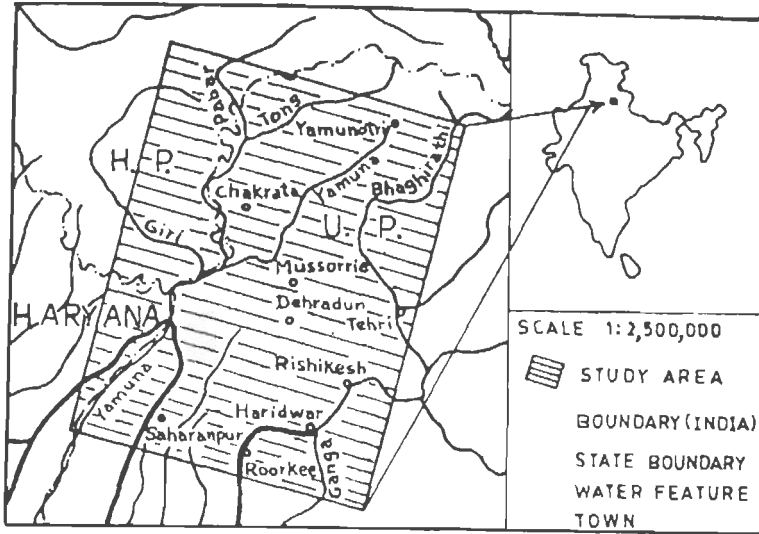


Fig. 1 Location map of area

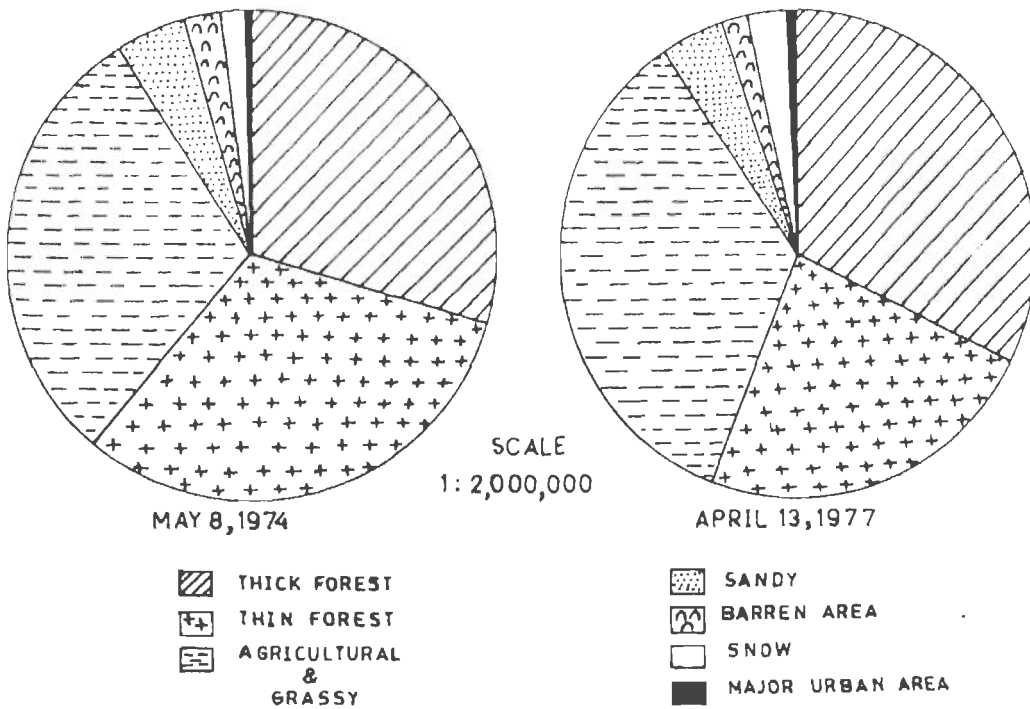


Fig. 2 Distribution of areal extent

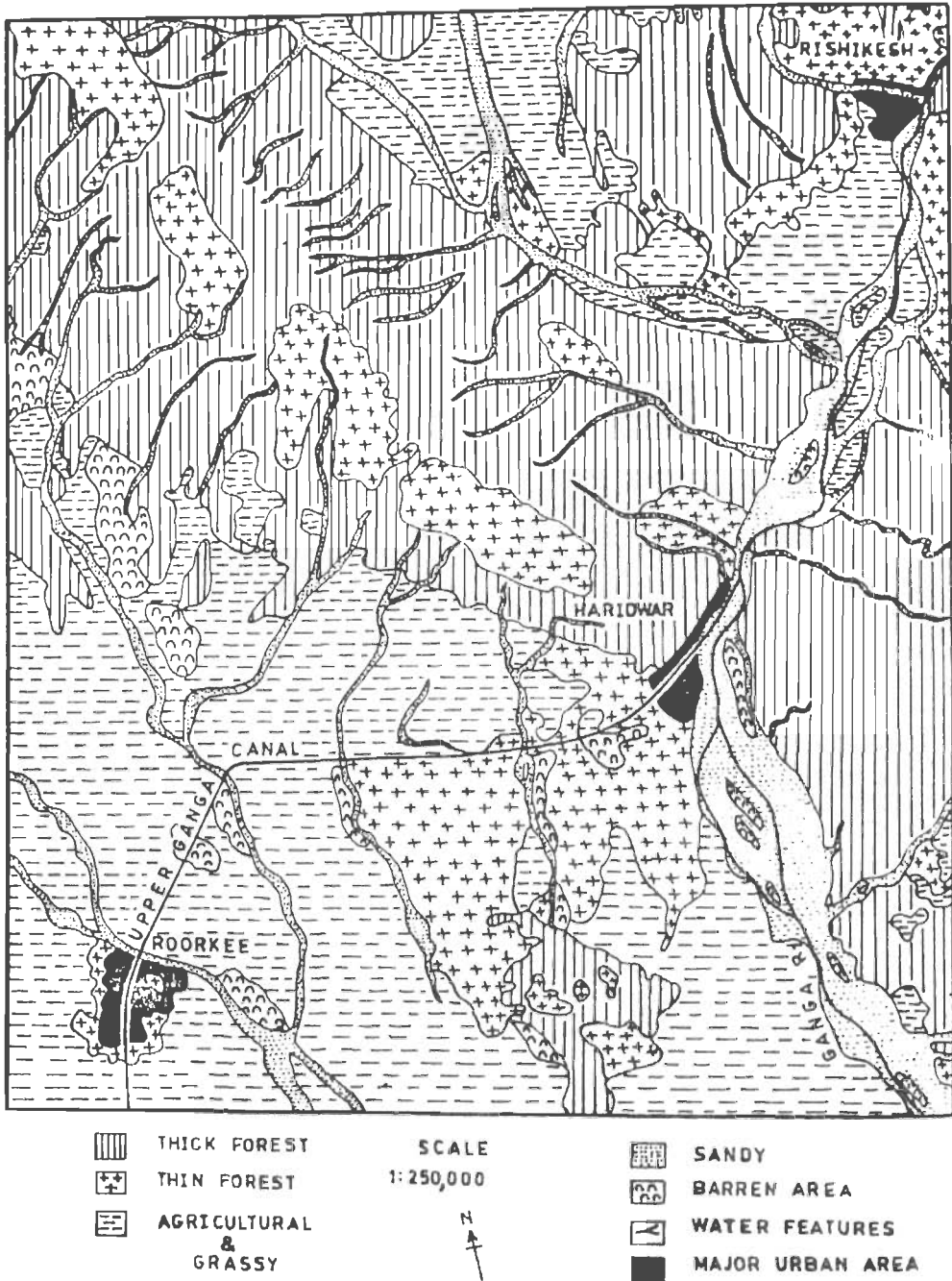


Fig. 3 Land use and land cover map of sample area

- b. the area under thin forest has decreased by 8.07 per cent which may be partly due to (i) conversion of the thin forest into thick forest, and (ii) clearance of some area for agricultural purposes. Both these arguments are supported by increase of 2.93 per cent in (a) above and about 4.91 per cent in the agricultural and grassy area, and
- c. Snow cover is more in the month of April 1977, by 0.77 per cent as compared to May 1974. The change in season, climatic condition and exposure to the sun results in increase in snow-melt and consequent barring of snow-covered rocky areas. This is again verified by larger extent of barren area in May 1974 as compared to April 1977 (by 0.60 per cent).

Table 1
Areal Distribution of Various Land Use and
Land Cover Classes from Land Use Maps

Land use classes	May 8, 1974		April 13, 1977		Change in % area 1974-77
	Area (ha)	% area	Area (ha)	% area	
Thick forest	529571.25	29.35	582590.64	32.28	+2.93
Thin forest	571033.13	31.66	425807.52	23.59	-8.07
Agricultural and grassy	543903.75	30.14	633003.77	35.06	+4.91
Sandy	77146.88	4.28	77650.63	4.30	+0.02
Barren area	41315.62	2.29	30606.25	1.69	-0.60
Snow	32833.12	1.82	46845.07	2.59	+0.77
Major urban area	8336.25	0.46	8860.12	0.49	+0.04
Total...	1804140.00	100.00	1804140.00	100.00	--

A time and cost analysis of the visual interpretation method has shown that the cost of land use analysis comes out to be about 10 paisa per sq.km.

The above results show that visual interpretation method, using 1:250,000 scale black-and-white LANDSAT enlargements, is quite suitable for developing countries like India, due to its simplicity and operationally cost-effective nature.

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FLOOD-PRONE AREA MAPPING IN THE GANGA SUB-BASIN WITH THE HELP OF SATELLITE IMAGERY

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ABSTRACT

Of late, vast potential of the use of satellite imagery in all-round development and exploitation of natural resources has come to be greatly realised. The Ganga Flood Control Commission, in collaboration with the Space Applications Centre and the Survey of India, has taken up a pilot project for mapping of flood-prone area in one of the worst-affected part i.e. the Ghaghra sub-basin with the help of satellite imagery. This paper gives a brief account of this pilot project and the methodology adopted. The functions of the different participating agencies have been briefly described and the work done so far has also been detailed. Though the work is still not complete, scope of its utility as an important tool to the scientists and engineers for speedy and economic analysis of water resources problems is clearly established.

INTRODUCTION

The utility of remote sensing techniques in providing maps for land use/land cover is unique and enormous. Land use may be identified with any of the following activities either singly or in combination:

- (i) Agriculture,
- (ii) Irrigation,
- (iii) Drainage,
- (iv) Flood Control Planning including anti-erosion works, river training measures, flood plain zoning and flood proofing,
- (v) Control of salinity,
- (vi) Watershed management including soil conservation measures,
- (vii) Control of water pollution,
- (viii) Control of ground water,
- (ix) Pisciculture etc.

However, for the present, discussion is restricted to land use/land cover from the point of view of floods and flood control only.

Floods in India are a regular feature and they take a high toll of lives and properties every year. The Ganga sub-basin

alone accounts for 52 per cent of total flood damage in the country, though it has only 26.3 per cent of the area. A good part of the Ganga Basin has low flat surface and due to high runoff suffers from recurrent floods almost every year. The soil of the sub-basin is alluvial and is extremely fertile with dense population. The high velocity of water in the upper reaches of the river, where the gradient is steep, creates problem of soil erosion thus carrying high concentration of silt. In the flat region, however, the velocity gets reduced and the silt gets deposited resulting in frequent shifting of the river course, leaving oxbow lakes, dead channels etc. Some areas get waterlogged and some face problem of salinity. Thus, a closely controlled and judicious application of flood control measures is required, so that maximum area is protected from floods at the least cost. The land use pattern also has to be such that it is put to the most beneficial use during whatever little time is available for agricultural activities before and after the flood. Towards this goal it is imperative that extent of flooded area, extent of soil erosion, change in the river course, state of inter-basin boundaries, abandoned and new channels, damage to crops, areas under active attack of the rivers etc. be known at the end of each flood.

For the existing method of ground survey which may be done once in decades, the above task is too expensive, time consuming and more often than not, impossible. Aerial photography provides a partially quicker solution to this problem but its range in yielding information is limited besides also being time-consuming and expensive. The Indian Air Force and the Air Survey Company of India have been using this technique which is still being used for its higher spatial resolution and stereo information. Besides, the technology involved is simple. With the advent of multispectral scanner, initially mounted in aircrafts and later in satellites the era of what is called "remote sensing" has set in. In essence, the MSS consists of scanners in the form of bands each receiving energy within specified wavelength limits of the visible as well as infrared region rather than covering only visible spectrum as in the aerial photography. The image of the same area taken with different bands emphasises different characteristics of the area. For example, one may emphasise the structural features only while the other may depict vegetation etc. in greater detail. The correlation is established from comparing specified areas of the imagery with the ground truths of these areas and extending them to the whole area covered later on logically. Images from all the bands may be studied collectively as well as with "the false colour composite" method explained with respect to the LANDSAT imagery later in the paper. Comparison of imagery of different bands and those taken at different times of an area yield invaluable information which is not possible by any other means. In short, it is called multirate and multispectral technique. The cost involved is much less once the infrastructure is developed. Other advantage is that it gives a synoptic view of an area from the vantage point of a satellite orbiting in space and

covers a large area in each image within extremely small interval of time. For LANDSAT, this time interval is about 30 seconds approximately.

STATE OF ART

LANDSAT data have been interpreted to achieve the desired objectives. (The multispectral scanner system of LANDSAT band 7 (0.8 to 1.1 micrometer) is generally used for identifying water bodies and related features). The standard imagery which is available at 1:1 million scale can be enlarged to 1:1/4 million scale.

The imagery of the area in question is interpreted to identify the different physical features. In the course of interpretation of different colours, texture, tone etc. in the imagery, the ground truth verification is done and a legend is established which is extended to the whole area.

In this connection, it may also be mentioned that topographical maps on a scale of 1:250,000 prepared by the Survey of India are also available which also contain useful information. These maps can also be integrated into the flood plain maps obtained with the help of satellite imagery. This integration may help in finding out the changes in river works and allied features from time to time.

FLOOD PLAIN MAPPING OF THE GANGA BASIN FROM LANDSAT IMAGERY

With floods in India creating havoc every year the need for detailed survey of areas affected cannot be postponed any longer. Up-to-date maps with details of geomorphic and hydrological features of such basins are urgently desired for exhaustive study of floods and in contemplation of measures for controlling them. With possibility of identification of many flood zones in such basins, Central Water Commission (CWC) has already approached Survey of India (SOI) to prepare maps of such areas on the large scale of 1:15,000 with 50 cm. or 1 meter contour intervals. With the advent of the remote sensing technique, a pilot project for the flood plain mapping of the Ganga Basin with the help of LANDSAT data has been initiated to delineate the flood-prone areas, so that appropriate preventive measures could be taken. Besides this, further application of this technique to other areas could be considered after successful completion of this project.

Purpose/Aim

The main purpose of the project is to prepare detailed maps of the flood plains of the Ganga Basin on a scale of 1:1 M and for selected areas in the scale of 1:250,000 using LANDSAT

imagery and the supporting ground truths.

The proposed maps will be of immediate use to the Ganga Flood Control Commission (GFCC), Patna for flood plain management, projection, planning and to take up various flood control measures in the flood prone areas of the Ganga Basin.

The features to be delineated are as under:

- i) River course and meander pattern
- (ii) Drainage pattern
- (iii) Sub-basin boundaries
- (iv) Limnological features
- (v) River levees
- (vi) Inundated areas
- (vii) Back swamps
- (viii) Marshy areas
- (ix) Remnants of river channels
- (x) Oxbow lakes
- (xi) Dead arms of streams
- (xii) Flood plain deposits
- (xiii) Flood plain boundaries
- (xiv) Features of river action
- (xv) Sandy features
- (xvi) Any other hydrological or cultural features that can be discerned from the imagery
- (xvii) Large habitational centres

The part of Ganga Basin to be covered in this project lies between 78° to 90° E longitude and 24° to 28° N latitude which covers the whole affected area of the Ganga Basin. The area in question can be seen in Fig. 1.

Participating Agencies

The project with the above objectives was taken up jointly by Ganga Flood Control Commission (GFCC), Patna, Space Applications Centre (SAC), Ahmedabad and the Survey of India (SOI), Dehradun. Dr. M.S. Dhanju of the Space Applications Centre, Ahmedabad was the Principal Investigator of the Project. The tasks entrusted to the three agencies were as follows:

The Ganga Flood Control Commission had undertaken the following tasks:

- (i) In co-ordination with SAC to carry out ground truth collection and providing necessary logistical and support.
- (ii) Provide the required budget.
- (iii) Instruct its various State agencies to provide the necessary data and also logistics help to the project and institute the required coordination machinery.
- (iv) Evaluate the project.
- (v) Provide necessary manpower.

The Survey of India had undertaken the following tasks:

- (i) Provide the use of rectifier equipment and allied

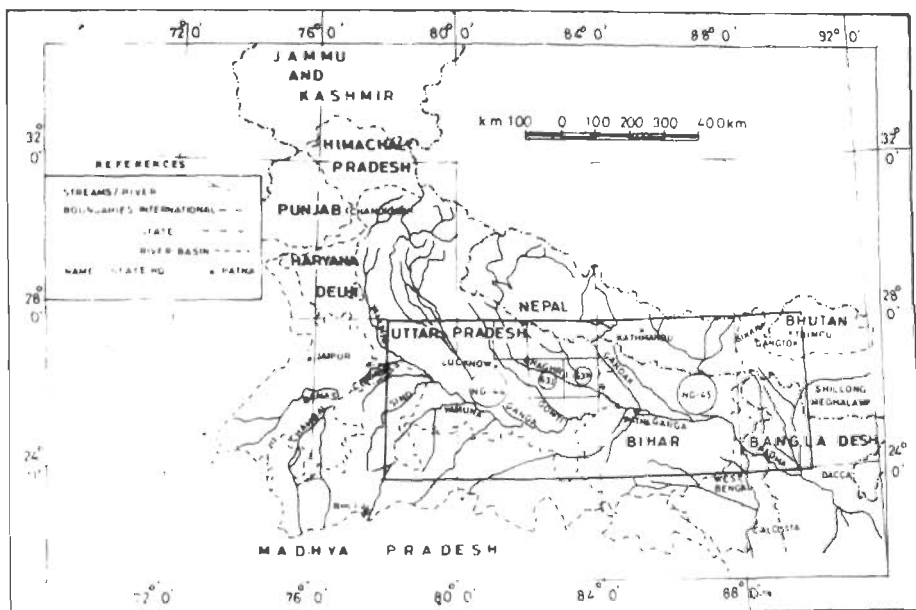


Fig. 1 Map of Ganga basin

- photographic facilities.
- (ii) Provide cartographic help in standardisation in preparing maps from the interpreted satellite imagery i.e. one sheet on 1:1 million scale and one sheet on 1:250,000 scale, and production of the final maps.
- (iii) Evaluate the project.
- (iv) Provide necessary manpower.
- (v) Provide assistance in interpretation and verification of topographical/cultural details that appear on Survey of India topographical maps.

The Space Applications Centre had undertaken the following tasks:

- (i) Provide access to the available LANDSAT imagery.
- (ii) Provide photographic facilities.
- (iii) General administrative and technical support to the project at Ahmedabad.
- (iv) Carry out the interpretation of the LANDSAT imagery.
- (v) Co-ordinate ground truth collection.
- (vi) Carry out the project coordination and evaluation.

Period of Imagery

The imagery for this study were taken in the post-flood period, pertaining to the year 1972-77 after the monsoon was over. Using realtime data during the monsoon was considered not possible due to likely presence of clouds masking the area at the time of actual flooding. Hence for this pilot study past data which could be readily obtained was used by Dr. Dhanju though in future, use of most recent data or even concurrent monsoon period imagery could be considered. Even by this method, delineation of inundated areas has been possible as the rivers of the basin carry large silt load which gets deposited in the plains almost during each flooding thus making the flood prone/affected area different from the adjoining areas. It may be remarked that as long as the river course does not change significantly, the flood plains also do not change significantly. In fact, by a judicious interpretation, it has been possible to even differentiate between flood waters occurring due to direct spill of the bank and those carried down from the upper catchments etc. as well as accumulated out of rainfall in low pockets.

METHODOLOGY

Three test areas corresponding to 63 E, 63 J and 63N toposheets of SOI maps had been chosen on experimental basis. The area is flat in nature, visited by recurrent floods and a typical representative in respect of physiographic properties. Aerial photographs and map in the scale of 1:15,000, with 1m contour interval, of the test area of 63 E (part of Ghaghra-Rapti basin) made available a large number of details for cross-checking. Existing maps of the area on the scale of

1:1M, 1:250,000, 1:50,000 and 1:15,000 were frequently referred.

For the identification of flood features, the observed ground features had been correlated with the imagery of the area by comparing the photo-interpretation elements (i) tone, (ii) texture, (iii) shape, (iv) size, and (v) continuity in the imagery corresponding to that area. For example, from the imagery in the spectral band of 0.8 to 1.1 micrometer which has been used for this project, a shade in the imagery having black tone, smooth texture, regular shape, longish size and stretching continuity had been identified with main course of river. Once legends for the test area are confirmed, they are extended to all other areas of the basin logically as the physiographic condition of the flood plains is more or less same everywhere.

Imagery from a single band, i.e. band 7 (0.8-1.1 micrometer) had been used as this has proved extremely useful in identifying flood plain features being essentially water-land interface features, for which the imagery is aptly suitable.

For improved interpretation, multirate scenes of good quality were used. In some cases imagery in other bands was also used which gives a better identification of forest areas.

The images from LANDSAT were 9" (23 cm) dia-positives on 1:1M scale. Colour additive viewing of 70 mm dia-positives on 1:1M scale were resorted to for feature enhancement.

Ground truths were verified by the concerned investigator by actually visiting the areas. Finally the legends prepared were scrutinised and standardised and transferred to the map in presentable form. In preparing the final map, colour scheme corresponding to the standard topographical map has been used:

- Black colour: for area of inundation and related flood plain features as interpreted from the appropriate LANDSAT imagery together with railway lines, towns etc.
- Blue : for water features like river course, streams and drainage pattern.
- Red : for cultural features, roads etc.
- Green: for forest areas and vegetation and
- Brown: for heights and contours.

It may be remarked that the feature to be shown in black and blue colour are interpreted directly from the LANDSAT imagery while other details are simply integrated from the existing maps.

To test the reliability of the legends, interpretation of the imagery was carried out by different investigators independently. This was tested by comparing the imagery of the different years of that area.

PROCEDURE

All the three organisations, the GFCC, the SOI and SAC worked in close coordination. A series of discussions took place among them from time to time. Roughly the procedure adopted has been as follows:

The SAC has provided the LANDSAT imagery which is in 9" format on 1:1M scale to the SOI, or more specifically, to the Northern Circle and O.C. No. 20 (photo) Party (N.C.) of the SOI. Here they were rectified and enlarged to 1:250,000 scale by the rectifying machine SEG VI. The Zoom Transferscope was used to remove the scale error of the LANDSAT imagery and to transfer the information from the imagery to the required scale maps of 1:250,000. The enlarged maps were returned to SAC to carry out manual interpretation of the flood plain features in accordance with the agreed legend which was established by SAC. Shri V.K. Verma, Deputy Director of GFCC provided the required hydrological assistance. Shri T.S. Negi, Surveyor from No. 20 (P) party assisted Dr. Dhanju in interpretation and preparation of the project map. These informations were also transferred to 1:1M scale by SAC for preparing the final map. SAC was also required to identify the area which required further studies with aerial photography, existing maps in various scales like 1:1M, 1:250,000, 1:50,000 and 1:15,000 and ground visits etc. The features identified on the screen of the zoom transferscope were marked on tracing sheet and put over existing toposheets to compare with the details shown on the map etc. SAC returned the final imagery to SOI. This was then transferred on the base map. The method of transfer of hydrological features on the map was decided by the SOI. This way, extensive study with respect to 63 E area of the toposheet of the SOI were carried out.

Legends

Legends for the following features were established, each being identified with typical parameters of photo-interpretation like tone, shade etc.

- (i) Main river course
- (ii) Tributaries and minor streams (which are identifiable on the LANDSAT imagery)
- (iii) Inundated areas between floodway and main river
- (iv) Inundated area getting flooded from streams spilling in upper reaches
- (v) Poorly drained depressions
- (vi) Well drained depressions
- (vii) Alluvial fan depressions
- (viii) Permanently water-congested areas
- (ix) River levees
- (x) Oxbow lakes
- (xi) Flood plain boundary
- (xii) Water bodies

- (xiii) Canals
- (xiv) Forests

With a view to classify the flood plain, the GFCC provided assistance of a hydrologist. He classified the flood-affected areas into four broad zones. The different areas were classified in the following manner and legends were established:

Legend (I): Area subjected to local flooding "Khadir area" which lies in between the flood way of the main river. Such areas are always flooded during the monsoon period. These areas have black tone, smooth to coarse texture and regular shape, which run along the river course.

Legend (II): Area subjected to sheet flooding due to bank spill of the main river/tributaries. Such areas have gentle slope and are free from regular drainage problems. The area remains submerged only when there is high water stage in the main river. Such area also receive runoff from the adjoining high grounds and this runoff may cause temporary drainage problem during high stage (floods) in the main drainage (channel). These areas have patchy black tone, coarse texture, regular to discontinuous shape which stretch along the banks of the main river.

Legend (III): Area having local depressions without proper drainage facility. Such areas generally face waterlogging problems. The area remains submerged during whole monsoon season. Such areas are saucer-shaped and are traversed by old courses of the rivers. The drainage problem is generally caused by the runoff coming from the high grounds. Some portion of the flood water from the area II may sometimes find its way to the local depressions causing waterlogging problem. These areas have light black to grey and dark in middle tone, smooth to patchy texture and roundish to long shape which are enclosed in between high grounds and are scattered in continuous patches.

Legend (IV): Areas which are free from waterlogging/drainage problem. These areas are well drained and have comparatively steep ground slope. There is no serious flood problem in such areas. These areas have grey to whitish tone, smooth texture and found to be irregular in shape and stretching in patches.

The areas classified above were marked on a tracing paper and compared with the existing SOI maps for that area. The maps on scale 1:250,000 and 1:50,000 were used to compare the flood plains classified on the satellite imagery. It was found that in general the interpretation done on the satellite imagery were comparing well with SOI maps. In order to get better picture of the terrain some longitudinal sections of the areas were also marked with the help of available contours on 1:50,000 maps. The L-section were marked on the toposheet No. 63E/7,11 & 15 and then the topography of the terrain was compared with the classification already done for the portion of the area on the

satellite imagery. It was found that the four zones marked on the areas were matching in both the cases.

Job Completed

Map for the whole project area, i.e. area lying between 78-90° E long. and 24-28°N lat. in 1:1M scale is complete with all the details pertaining to features to be shown in 5 different standard colours. Similarly, maps in 1:250,000 scale corresponding to 63 E, J and N of the SOI toposheets is complete in all respects. For areas corresponding to 72 G&J maps in scale of 1:250,000 with details pertaining to only black and blue standard colour scheme is complete. Incorporation of legends extracted in the exercise of this projects have been tried. Contour lines from existing toposheets have also been transferred to these maps. It is interesting to see the flood plain features in the light of these contours. The final maps are in standard form incorporating newly identified features.

Limitations

A number of limitations in the mapping of flood plain with LANDSAT data are clearly noticeable. Mapping during the actual flood period would have straightway given the extent of flood-affected areas, but this was not considered possible because of likely cloud cover or the satellite not scanning the area at the moment of floods. However, extensive study of the imagery could give some flooded areas covered even during monsoon period. Secondly, low spatial resolution (80 m) of the imagery makes it difficult for identification of smaller dimension objects like small water bodies, canals, road, railway lines etc. which ought not to be neglected for the study of floods. As such a locational error of 200 m. could have occurred. Small scale map from imagery is another problem. It may not be out of place to mention that new maps on the scale of 1:15,000 with 1/2 to 1 m. contour interval are required for the flood prone areas which are flat in nature, especially for flood plain zoning and for the correct prediction of areas likely to be flooded by the river. Such topographical maps would also enable identification of places where embankments have to be constructed with a view to providing protection from floods to certain specified area, towns, installations or industries. The LANDSAT imagery does not prove useful for this purpose. The imagery at best, can go down upto the scale of 1:250,000 without significant loss of details.

The other most severe limitation of the LANDSAT imagery is that it provides no information about contours or the altitude whose need has just been stated. Future sensors, however, may provide stereo information as well. Aerial photographs, however, do not suffer from this limitation.

Legends, though established scientifically, are not always universal and sometimes give misleading conclusions. They

failed with respect to the doab area where physiographic condition was not very much different from other parts of the basin.

CONCLUSION

This pilot project shows a promising role of remote sensing technique in the field of mapping for flood plain management. A number of flood plain features have been identified which were hitherto not covered in detail in existing maps. Some progress has been achieved in establishing legends which may enable a quicker interpretation of any other area mapped with similar physiographic condition as of the Ganga Basin. Certain limitations too, have been observed but can be removed once high sophistication in the remote sensing technique is achieved and then this technique would not be playing just a supplementary role.

ACKNOWLEDGEMENTS

The authors are very thankful to Sri J. Bahadur, Chairman and Sri S.J. Thomas, Member for inspiration and guidance in preparing this paper. Thanks are also due to Dr. M.S. Dhanju of the Space Applications Centre, Ahmedabad, but for whose initiative and efforts this pilot project would not have been completed.

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APPLICATION OF REMOTE SENSING IN MONITORING DESERTIFICATION IN RAJASTHAN AND ADJOINING REGIONS

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ABSTRACT

Visual and digital analysis of LANDSAT imagery in conjunction with ground truth revealed that the natural desertification processes such as wind erosion/deposition, water erosion and salinity have desertified different landforms in Rajasthan and adjoining regions by creating natural hazards like sand dunes, rills, gullies, ravines and saline depressions. Due to increasing human activities, the biotic desertification process became dominant and created the accelerated erosional, depositional and salinity hazards resulting in the deterioration of the productivity of the agricultural lands.

The detailed evaluation of one LANDSAT scene covering the middle Luni basin enabled to quantify the areas degraded by different desertification processes. In the basin 30 per cent, 4 per cent, 10 per cent and 11 per cent areas have been desertified by wind deposition/deflation, water erosion, natural and man-induced salinity respectively. This study has also helped to detect the temporal changes in saline areas.

Digital analysis of LANDSAT MSS band 5 image has enabled to detect the least, moderate and high vulnerability of areas to desertification in the western parts of the middle Luni basin.

INTRODUCTION

Desertification is one of the serious environmental problems which has attracted the global attention of the environmental scientists. It is also a significant problem in India (and a great concern has been voiced even on the floor of the Parliament) regarding encroachment of desert towards northeast. Remote sensing has been found to be an important tool for the study of the problems related to desertification by several workers (Worester and Dalsted 1978, Reining 1979, Myers 1979, Singh et al 1977).

Realising the seriousness of the problem, the investigation on the desertification problems by employing

remote sensing technique in conjunction with ground truth was done in Rajasthan and the adjoining regions and its salient findings are discussed in this paper.

MATERIAL AND METHODS

False colour LANDSAT mosaic on 1:1000,000 scale, LANDSAT black-and-white enlarged paper prints on 1:500,000 and 1:125,000 scale, 70 mm and 23 x 23 cm positive₂ black-and-white transparencies, additive colour viewer (I²S), reflection projector, zoom transferscope and Survey of India topographical sheets were used as basic material for this study. LANDSAT imagery was visually interpreted and the preliminary boundaries of the desertified areas were delineated and mapped. Field traverses right from the Rann of Kachchh to Delhi were carried out and the data on the erosional, depositional and salinity hazards leading to desertification were recorded along the selected query points. Laboratory and field data were finally analysed and integrated into maps.

Visual analysis of the computer printouts of the LANDSAT MSS bands 5 and 7 was done and the areas vulnerable to desertification were identified, delineated and mapped.

RESULTS AND DISCUSSION

Rajasthan and Adjoining Regions

Systematic analysis of the remotely sensed and field data has revealed that large areas of Rajasthan and the adjoining regions have been desertified by the natural and biotic desertification processes. It has been observed that the sand dunes of 10 to 80 m height created by the natural desertification processes like wind deposition/deflation are largely concentrated in discontinuous patches in the western, southwestern and northwestern parts of the Rajasthan, Punjab and Haryana. These colossal sandy deposits have caused enormous damage to the fertile alluvial plains. These sand dunes are now stabilised and such new dunes are not being formed by the natural desertification processes. The water erosion by creating the rills and gullies of different dimensions has degraded the landforms like hills, piedmont plains, pediments, and older and younger alluvial plains. The natural saline depressions, viz Pachpadra, Thob Ka Rann, Mitha Rann, Khara Rann, Sanwarla Ka Rann, Jamsar, Nal, Kaparda, Didwana and Sambhar lake etc., have salinised large tracts of the vast alluvial plains.

In the recent period, due to increasing human activities, the biotic desertification processes became dominant and disturbed the ecological balance of the fragile landforms

(ecosystems). The cultivation and grazing on the stabilised sand dunes by unscientific methods have reactivated their slopes. The reactivated sand in the form of sand sheets and low dunes has piled up on the adjoining lands which, in turn, has depleted their agricultural productivity. The accelerated water erosion has washed away the sediments from the alluvial plains and flat buried pediments. The rills and gullies have also been created on the hills, piedmont plains, pediments and alluvial plains. These hazards have depleted the biological productivity of these landforms.

Due to the human interference with the natural drainage system, the fertile agricultural lands have become saline. The construction of Jaswant Sagar dam and the Summair Samand canal along the Luni river have created salinity hazards in the downstream resulting into the desertification of the potential agricultural lands. In Ganganagar - Suratgarh sector, due to the diversion of the Ghaggar drainage channel into the interdune plains, the waterlogged conditions have developed and 18 saline depressions have been created. The seepage water from these saline depressions has desertified 1798 acres in adjoining fertile land. After the construction of the Gang canal, the salinity has also developed and it has affected the productivity of the land in Ganganagar area.

Middle Luni Basin

It has been observed from the evaluation of one LANDSAT scene of the middle Luni basin that the largest area (about 30%) has been affected by wind deposition in the form of sand dunes, hummocks, and sand sheets. In this context, it is significant to note that no lateral movement of sand has been observed. The bare sand occurring on the flanks and crests of the dunes and the agricultural lands in the form of sand sheet and low dunes appear in white tone on the LANDSAT image which indicates the recent accumulation of sand due to intense biotic activities. The areas affected by wind deflation are mostly concentrated between the sand dunes and constitute only 4 per cent of the total area of the scene. The area affected by water erosion are confined to the rocky/gravelly and buried pediments. About 10 per cent of the scene has been desertified by this hazard.

Areas affected by natural salinity are observed in the vicinity of Thob, Pachpadra, Sanwarla, Samuja, Harji and Manador villages covering about 3 per cent of the area of the scene.

Salinity hazards, observable in the medium to heavy textured alluvial plains in the eastern and southeastern parts of the scene, appear to have developed due to man's interaction with fragile arid environment. Excessive irrigation by saline water, and the construction of tanks and canals across the beds of prior drainage channels are the prime factors that have contributed to the development of salinity. Thus the causes can

clearly be termed as man-induced. In quantitative terms, about eight per cent of the area of the scene has been affected by this process.

A comparative study of the Survey of India topographical sheet of 1960 and LANDSAT imagery of January 1977 in conjunction with ground truth has indicated spectacular changes in the acreage of saline areas with the passage of time. The large agricultural areas near Sanwarla, Harji, Manadar, Nosra and Khutani were non-saline in the year 1960 but they have been salinised between 1960 and 1977. In quantitative terms, it has been computed that in 1960 an area of only 38.12 sq. km was affected by salinity but in 1977 the area affected increased to 103 sq. km., an increase of about 171 per cent. This soil degradation is indeed alarming from the viewpoint of the decrease in productivity of the land.

In the event these processes are allowed to continue unchecked, more land could be affected in the future. Thus, it has been estimated that about 8 per cent of the area in the light to medium textured alluvial plains and the flat interdunal plains will be affected by wind deposition and deflation in the future.

In contrast to the above, there are certain areas near Saila, Thanwar, Agolai, Keru and Beru villages where, because of the development and use of ground water resources for irrigation and crop production, the phenomenon of desert reclamation has been ushered in.

The multidate LANDSAT scene of the Middle Luni basin provides an excellent opportunity to assess the intensity of desertification processes in dry/cool and dry/hot seasons. It is observed that in the imagery of the dry/hot season, the western part of the scene was blurred and hazy implying the presence of a sand-storm resulting from high wind velocity. Thus, it can be concluded that wind erosion is at its peak in this season. On the other hand, examination of the same area in dry/cool season over several years reveals that the earth's surface features are distinct and clear over the entire scene, implying a calm season with little wind action. Therefore, the problem of desertification by aeolian activity in this season could be assumed to be minimal. However, the problem of salinity (particularly man-induced) appears prominent in the dry/cool season due to the use of saline water for irrigation. Thus, the multidate scenes prove very beneficial for detection of location and extent of different types of desertification processes occurring in different seasons.

Vulnerability of Lands to Desertification - An Assessment

LANDSAT band five computer printout map depicts the vulnerability to desertification processes of aeolian landforms in a small subscene in the Middle Luni Basin. This feature is reflected in light dark tone pixels. Analysis of the pixels

reveals that the areas of dark pixels due to the presence of vegetation and moisture (brightness value 0-65) which occupy an area of 3.36 km² in the subscene, are least vulnerable to desertification (Table 1). The light to dark gray pixels due to moderately sparse to sparse vegetation (brightness value 66-69) indicate areas moderately vulnerable involving an area of 6.07 km² in the subscene. The bright pixels, due to accumulation of fresh sands and no vegetation (brightness value 70-83) constitute the areas highly vulnerable to desertification and seem to occupy the largest area (11.72 km²) in the subscene.

Table 1
Assessment of the Vulnerability of the
Areas to the Desertification in the
Western Part of the Middle Luni Basin

Vulnerability	Gray level	Value	No. of pixels	Area (sq.km)	Per cent
Less	1	0-65	745	3.36	15.9
Moderate	2-3	66-69	1346	6.07	28.8
High	4-6	70-83	2599	11.72	55.3
			4690	21.15	100.00

CONCLUSION

Remote sensing in conjunction with ground truth has proved an important tool in monitoring desertification processes such as wind deposition/deflation, water erosion and salinity in the Rajasthan and the adjoining regions. The accumulation of the sand in discontinuous patches in these regions indicates that the desert is not spreading towards north-east upto Delhi. LANDSAT imagery has enabled detection of the temporal changes in the landforms (ecosystems) caused by different desertification processes in various seasons. Digital analysis of the computer compatible tapes (CCTs) enables quantification of the extent of the desertified areas which could help in combating desertification processes.

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**REMOTE SENSING AS AN AID FOR IDENTIFICATION AND MAPPING
OF PRESENT DAY PROCESSES AND NATURAL HAZARDS IN THE
INDIAN DESERT**

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ABSTRACT

Studies conducted by the Central Arid Zone Research Institute (CAZRI) have indicated that the interpretation of remotely sensed data can be of immense help in identification and mapping of the present-day morphological processes and associated natural hazards, because of the ability of the sensors to have a synoptic view of the terrain. It is humanly impossible to match this factor of synoptic viewing by field investigations. The field data can, however, corroborate or substantiate the findings from the interpretation of remote sensing data. The dynamic nature of the morphological processes could also be better understood and assessed through remote sensing because of new possibilities of repetitive coverage at low cost. Recognisable types of morphological processes and hazards in the Indian desert have been mentioned in the article and their usability in the broader perspective of economic development have been discussed with examples from upper Luni basin.

INTRODUCTION

Situated to the west of the Aravalli mountain ranges, the desert terrain in India is fascinating yet challenging so far as its main economic activity, agriculture, is concerned. Apart from aridity one of the major stumbling blocks for agricultural operations here is the land deterioration due to the complex interplay of present-day geomorphic processes and inherited terrain types. We may call the manifestations of those processes as natural (or more appropriately geomorphic) hazards. However, to call an area hazard-affected one has to assess, first of all, whether the manifestations of the process/processes operating in the area are inhibitive to the economic activities. This requires thorough investigation of the terrain, preferably with a bird's eye view and this is where remote sensing techniques become more important. Although data obtained from field investigations is absolutely necessary to check the validity of the data gathered from interpretation of remotely sensed images, personal experience of the author indicates that maximum valuable and mappable information for

this type of study is obtained from remote sensing and the field information can only supplement and complement the remotely sensed data. Much, however, depends on the investigator's ability to identify the hazards and their intensity in broader perspective of the desert.

Interwoven with this problem is the assessment of the processes for predicting future vulnerability. Although detailed analysis for a long period on a group of sites can provide enough information on the type of changes that may occur, such studies generally take too long a time to be useful to the planners. Instead, semi-detailed or rapid reconnaissance studies with the help of remote sensing techniques may help the investigator in having a synoptic view of the terrain and in identification of the probable vulnerable areas with a fair degree of accuracy, especially through an understanding of the surface features and tonal differences in the images. New vistas opened by satellite remote sensing in terms of repetitive coverage of an area at a low cost can be an added bonanza in this regard, although the height at which many of them operate may be a limitation in identification and mapping terrain details. It is hoped that the new generation of high resolution scanners will help in removing this drawback.

THE CLASSIFICATION

Realising these facts the CAZRI has evolved a classification system for mapping the processes presently active in the desert, their intensity and associated hazards. The dominant processes within the desert and its fringes here are the fluvial and the aeolian ones, and generally they create problems of erosion, deposition and salinity/alkalinity. From the studies so far undertaken in the desert, it has been possible to identify seven main types of hazards, namely, sheet, rill, gully and stream bank erosional, wind erosional and depositional, and salinity/alkalinity hazards. The types of hazards can be suitably graded according to their degree of severity into slight, moderate, severe and very severe. Combining both the factors (i.e. type and degree) we can have a number of mappable erosional, depositional and salinity/alkalinity hazard classes. Some probable combinations are as follows:

- A.
 - (1) Slight to moderate sheet to rill
 - (2) Slight to moderate rill to gully
 - (3) Moderate to severe sheet to rill
 - (4) Moderate to severe rill to gully
 - (5) Severe to very severe sheet to rill
 - (6) Severe to very severe rill to gully
 - (7) Slight to moderate stream bank erosion
 - (8) Moderate to severe stream bank erosion
 - (9) Severe to very severe stream bank erosion
- B. Wind erosional and depositional hazards

- (10) Slight to moderate wind erosion
- (11) Moderate to severe wind erosion
- (12) Slight to moderate wind deposition
- (13) Moderate to severe wind deposition
- (14) Severe to very severe wind deposition
- C. Salinity/alkalinity hazards
 - (15) Slight to moderate salinity/alkalinity
 - (16) Moderate to severe salinity/alkalinity
 - (17) Severe to very severe salinity/alkalinity

Several other combinations can be worked out from the classes listed above to suit the actual conditions in the field.

UTILITY - SOME EXAMPLES

Information on these different hazards, their genesis, types, degree and extent help much in isolating the problematic areas for conservation and management purposes. For example, in the upper Luni basin, where the basin axis is roughly oriented east-west and comprises a variety of lithology and topography from the Aravalli mountain ranges to the rocky/colluvial/alluvial plains and the sand dunes, and where the climatic gradation from east to west provides similar changes in processes from east to west, the mapping of the hazards and interpreting them in association with other physical parameters have helped in understanding the causes of the peculiar distribution of the hazards, in predicting the future vulnerability of the land and also in suggesting areas for immediate ameliorative measures.

In quantitative terms, the fluvial erosional hazards cover a maximum of about 55 per cent of the total basin area of 13440 sq. km. Its intensity decreases from the mountainous terrain in the east to the alluvial plains in the west. The next major hazard, the salinity/alkalinity of land covers only about 9.3 per cent of the basin area but its impact on agricultural and related activities are felt more than the other hazards. The aeolian hazards have affected only about 1.3 per cent area at the basin outflow region and in pockets in the east. Apart from these hazards, different combinations of them have affected about 4 per cent area. Thus about 70 per cent of the total basin area is affected by different hazards and 30 per cent of it, especially in the deep older alluvial plains, is free from them.

When the details of hazards, areas affected by them and their maps are compared with other relevant physical information, it is realised that the most damaging problem facing the basin is the hazard of salinity/alkalinity which has either rendered useless or has depleted the productivity of a considerably large area in the central and western parts of the Luni and the Jojri catchments (Shankarnarayan and Kar 1983). Although weathering of Jalore granite at shallow depth is the

major factor for release of salts, construction of tanks and canals at wrong sites and mismanagement of water have also added to the problem (Kar and Shankarnarayan 1984). It is alarming to note that the areal extent of the hazard is increasing gradually and unless some remedial measures of soil and water management are taken immediately, large areas around the peripheries of the already salinized lands will be seriously threatened in the near future, leading to desertification (Fig.1).

While the western desert plains of the basin is facing salinity problem, the eastern part of it, especially within the Aravallis and along its foothills, has dominant water erosional problem because of wetter climate and greater slope. Soil conservation measures are needed most in this part, especially in the areas where pre-Aravalli granite-gneisses have produced low undulating erosional surfaces and along the Aravalli foothills.

Compared to the above problems the problem of aeolian hazard is insignificant. Notable areas of sand deposition and dune formation are around Pushkar and Budha Pushkar in the east where high biotic stress on the fossil dunes and sandy plains plus a sort of wind gap created by the alignment of the hill ranges are conducive to the sand accretion process. Another major area of aeolian hazard is at the basin outflow point where reactivation of riverine sand at the confluence of the Luni, the Bandi and the Guhiya have created low sandy ridges and hummocks. Both the areas are in need of immediate sand control measures, including the lessening of biotic pressure on vulnerable sand dunes, especially those in the east (Shankarnarayan and Kar 1983).

To illustrate our points a map on the type and degree of natural hazards in a representative catchment of the basin, the Guhiya catchment (Fig. 2), and a map showing the distribution of major problematic areas, including areas of future vulnerability in the same catchment (Fig. 3), are also appended, which are self-explanatory.

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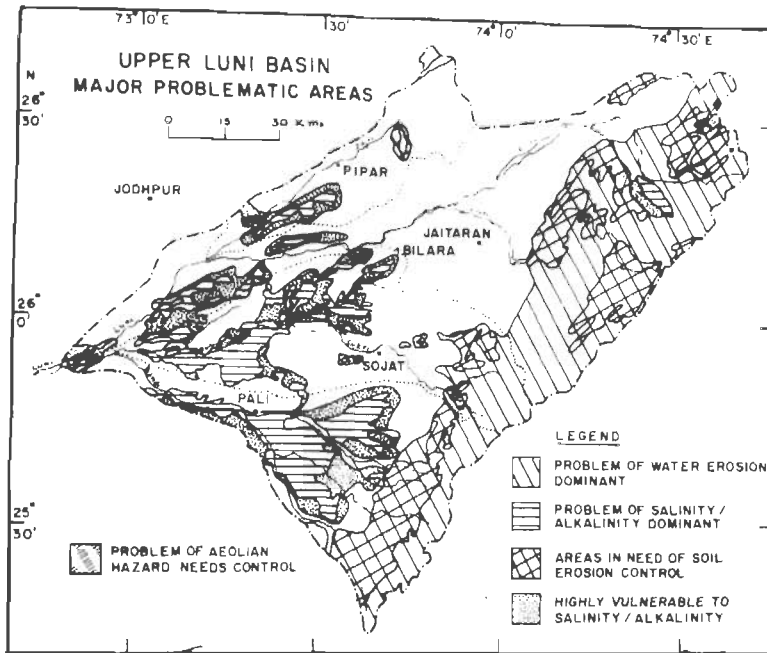


Fig. 1 Major problematic areas of Upper Luni Basin

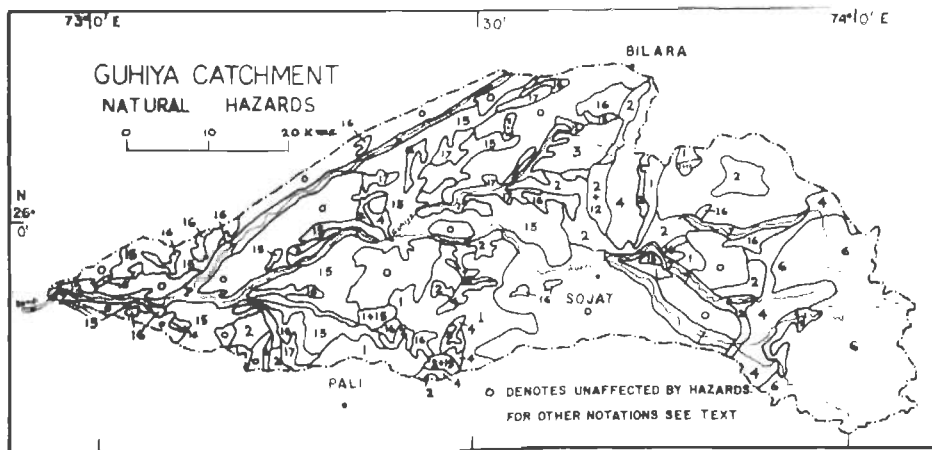


Fig. 2 Map showing the natural hazards of Guhiya Catchment

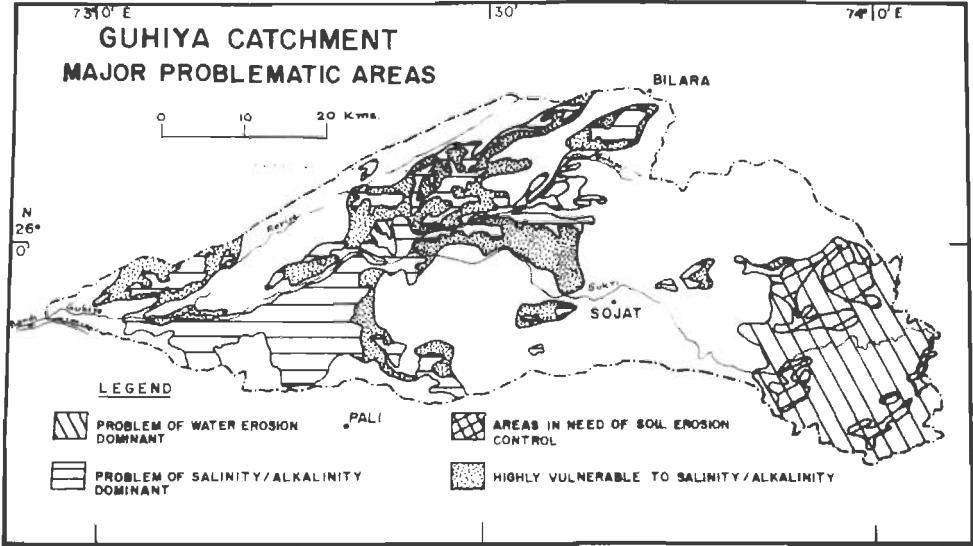


Fig. 3 Major problematic areas of Guhiya Catchment

FEASIBILITY OF THE APPLICATION OF REMOTE SENSING TECHNIQUES FOR LAND USE MAPPING IN ROCKY DESERT

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ABSTRACT

In the present investigation an attempt has been made to study a rocky desert region in western Rajasthan using remote sensing data. Making use of black-and-white transparencies/paper prints of LANDSAT MSS, additive colour viewer and collateral data, study area has been classified into many land use classes. A key was prepared for visual interpretation of LANDSAT MSS data based upon which a broad land use map showing various units was prepared for Siwana tehsil. The various classes depicted are cultivated land, double-cropped and mono-cropped areas, sandy waste, sandy waste with stony waste, stony and gravelly waste, stony and gravelly waste with shrubs and trees near settlements, reserved forests and protected land. Acreage has also been estimated which shows cultivated area to be the maximum (71 per cent), followed by wastelands (14 per cent) and miscellaneous land use (15 per cent). Conjunctive use of multirate LANDSAT data, aerial photographs, topographical maps, field survey and other collateral data is suggested for optimal results.

INTRODUCTION

The area chosen for the study is the Siwana area, situated within $25^{\circ} 23'03''$ N to $25^{\circ} 57'34''$ N latitudes and $72^{\circ} 07'30''$ E to $72^{\circ} 50'53''$ E longitudes, in the arid zone of the Western Rajasthan. Siwana area is essentially an agricultural tract. Agriculture is, however, limited by sand dunes on the south and west, on the precipitous hill slopes and the high degree of wind and water erosion in the undulating plains. Although cultivation is practiced even on sand dunes, such a practice is periodical and the dunes are generally left fallow for a period of two years.

About 45 per cent of the total geographic area of Siwana is cultivated. In the plains, about 7 per cent of the area is covered by thick deposits of sands, as for example in the riverine tract of Piplun and Kundal hills. Cultivation can be intensified by adopting suitable soil conservation measures and management practices. The evolution of the landscape has been

affected both by wind and water erosion. Sheet, gully and rill erosion are still active in the region, while aeolian depositions are in progress in the west. The effect of wind erosion in polishing and eroding the rocks is marked.

The geomorphology of the Siwana area has been dealt in detail (Sen 1962) earlier by tracing the progress of an arid cycle in the evolution of relief. The area represents an intermont basin landscape. Over much of the area, fractures gave an initial topography of tilted fault blocks separated by intermontane plains. The present topography is marked by steep-sided residual mountains and hills on an extensive and very nearly level plain. The residual hills are too high to be mere monadnocks on a peneplane surface. The steep sides and abrupt transitions were due to the process of weathering. The nearly-level extensive plain had been formed by the backwearing of the mountains. The backwearing caused 'slope retreat' of hills which resulted in the replacement of the hills by gently-sloping piedmont formed progressively at the base of the backworn slopes, which has resulted in diversified residual hills. The landscape has thus a characteristic resemblance with "inselberg" type.

The geological formation on which the Siwana area stands are rhyolite, typical reddish coloured rocks with porphyritic feldspar and granites. The rhyolites are of volcanic origin. Granites are not ore bearing. Drainage lines are ill defined (Heron 1928). The interesting feature is the inland basins which are enclosed between ridges. Each drainage line has its own local base level. All the rivers are 'misfit' and get lost either in the sandy deposits or in the detritus brought down by them during the period of short "cloud bursts".

A comparison of the present land use map and geomorphic-units map indicate that cultivation is restricted only to favourable locations. Based on data collected in field traverses, it was observed that agriculture is mainly affected by three fundamental geomorphic factors, viz., slope, erosion and effective soil depth. Other factors were, therefore, not taken into consideration (Sen 1965).

In earlier communications, the methodology and advantages of using aerial photographs for land use mapping are described in detail (Sen 1978). In this paper some of the advantages and limitations of using LANDSAT imagery for land use mapping are only described.

The remote sensing techniques have given a new dimension in mapping the natural resources. The CAZRI is actively engaged in mapping the present land use for arid and semi-arid zones of India, based on remote sensing techniques followed by sample ground truth investigation. The study is confined to Siwana region, an arid rocky tract of western Rajasthan desert.

SIGNIFICANCE OF LANDSAT IMAGERY

The LANDSAT satellite takes four images of any place - green, red and two infrared images (band 4,5,6 & 7). These are combined to form a colour image when interpreted through Adcol viewer and the image provides an accurate picture of the whole area. By superimposing one band on the other (through Adcol viewer) a number of land use units can be obtained by permutation - combination method. One of the advantages is that LANDSAT is markedly superior to aerial photograph in that the whole area is imaged at the same time and under identical lighting conditions.

The present study demonstrates how to bring out a generalised land use map based on interpretation of 4-band LANDSAT imagery obtained through adcol viewer together with as much integration of activities as possible at every stage. The study is emphasised from following view points:

- a) Obtaining land use from the imagery - interpretation of 4 bands by permutation - combination techniques - preparation of photo mosaic and photo map.
- b) Undertaking ground truth data collection survey and correlating them with the multispectral signatures depicted on the photo map.
- c) Establishing ground control points with a view to correlate the relationship between the units obtained in the photo-map and its corresponding ground features so that the actual land use units can be established and standardised.
- d) Sample survey to arrive at a suitable classifications based on object and theme.
- e) Correction of the photo-map in view of ground truth established by sample survey and their correlation with photo maps.

Three sets of interpretation are carried out prior to sample survey for ground truth investigation - study on regional aspects, pattern elements, and photo elements. The latter is done in a detailed way by permutation and combination method of all the four bands of the imagery through Adcol viewer to classify the images. The complete edge gradient study (Sen 1978) is undertaken by means of studying the total variation, structure and texture of the images of the object. These studies enabled us to prepare photo maps with similar image and 'key' of interpretation for field checking - ground truth investigation on sample basis. In case of detailed reconnaissance survey, sampling is done on stratified sampling basis (taking the regional pattern identified as unit), in case of reconnaissance and detailed survey, it is based on random and 25 per cent systematic sampling on grid basis (grid is proportionate to the scale of the map to be cartographed), respectively. Once the photographic images are correlated with the corresponding type of land use in the ground, the sequence of events which form a particular land use unit can often be

delineated and many aspects of land use can be inferred. The findings are also correlated with the available information and data collected (Sen 1978). After the field checking and study of convergence of evidence, the previous interpretation is corrected and final cartographic work is undertaken involving transferring of details, compilation and editing of data etc.

RESULTS - SIWANA AREA

Present Land Use

The survey and mapping results reveal (Table 1a) that out of the total area of the region, cultivated lands (including short and long fallow) constitute 70.79 per cent, wastelands 13.95 per cent and miscellaneous land uses 15.26 per cent, respectively. Amongst the cultivated lands, double-cropped area constitutes 5.38 per cent of the total area and 7.6 per cent of the total cultivated land. Monocropping is done in rotation. Areas under different intensities of cultivation are: 80-100% : 8.55%; 60-80% : 34.74%; 30-60% : 19.89%; 20-30% : 2.02%; 10-20% : 0.03% and below 10% : 10.18%, respectively. Main crops produced in double-cropped land and lands with good intensity of cultivation are Bajra, Moong, Moth, Sesamum, wheat, Raida, Taramira, Jeera, chillies, isabgol, vegetables and fodder crops. Wheat, Raida, Taramira, barley and gram are also produced under rainfed condition by conserving moisture in depressional areas. Bajra, Moth, Guar, and Sesamum are common crops of the lands with moderate intensity of cultivation and marginal lands. Details of wastelands and miscellaneous land uses are given in Table 1a.

Land Use Changes

Over the last three decades considerable changes in land use have taken place (Table 2). Net area sown increased by 5.72 per cent during 1961-1971 and consequently fallow lands decreased. From 1971 to 1981, no substantial change has occurred in net area sown but irrigated area increased four times. Double cropped area also increased by 5.66 per cent during 1971-81. About 185 ha land has been taken up by the Forest Department for pasture development and fodder and fuel production near Kusip, Indrana, Thumbli, and Bhim Khera villages. The Luni flood of 1979 has turned good irrigated land into marginal land along its course mainly comprising the Kotri, Karmawas, Mongra, Bamsin, and Jethantri villages. Saline waste also increased by the expansion of Sanwarla rann during flood. On the other hand more area has been brought under irrigation by exploitation of groundwater in Padru, Indrana, Kusip, Thapan, Kundal, Siwana, Mokalsar, Ramaniya, Meli, Dewandi and Samdri villages.

Table 1
Land Use Interpretation Key for Visual Interpretation of MSS LANDSAT Imagery under Arid Conditions

Land use category mapping units	Best MSS band	Local conditions and characteristics of imagery
Settlements, road, railway lines and other built-up land	7	Contrast, ground reflectance from surroundings, Trees, tanks help in identification.
Water bodies (wet)	7	Most suitable period of imagery is Sept to Nov free from cloud coverage.
Drainage (river, streams)	5	More clear if the spectral signature of surroundings is different.
Permanent pasture or Oran	5	Coverage of grass, shrubs and trees is essential.
Forest	5	-do-
Cultivated Land		
Double cropped land	5	Successive imagery of Rabi and Kharif periods.
Irrigated land	5	Imagery of the period of standing crops.
Dry farming mono-cropping	5	-do-
Fallow land (dry)	5	-do-
Wasteland		
Sand waste/dunes	7	No thick vegetative coverage is required.
Saline waste	5&7	-do-
Hills/rocky stony and gravelly waste	6&7	-do-
Scrub land	5	Sufficient vegetative coverage is needed.

Table 1a
Present Land Use in Siwana Tehsil (based on
Survey and Remote Sensing Techniques)

S. No.	Mapping Units	Land use classification	Area (ha)	Percent area
Cultivated Land (also used as grazing land when not cultivated)				
1.	A11	Double cropping (intensity of cultivation above 100%)	11005	5.38
2.	A1	Monocropping cultivation in rotation (intensity of cultivation 80-100%)	17482	8.55
3.	A2	Monocropping cultivation in rotation (intensity of cultivation 60-80%)	71057	34.74
4.	A3	Monocropping cultivation in rotation (intensity of cultivation 30-60%)	40678	19.89
5.	A4	Monocropping cultivation in rotation (intensity of cultivation 20-30%)	4132	2.02
6.	A5	Monocropping cultivation in rotation (intensity of cultivation 10-20%)	63	0.03
7.	A6	Monocropping cultivation in rotation (intensity of cultivation below 10%)	360	0.18
Total..			144777	70.79
Wastelands (also used as grazing ground)				
8.	B1	Sandy waste	4713	2.30
9.	B1X	Sandy waste with shrub and trees	575	0.28
10.	B2	Saline waste	1793	0.88
11.	B2R	Ranns	673	0.33
12.	B3	Rocky and stony waste	14235	6.96
13.	B4	Stony and gravelly waste	5450	2.68
14.	B4x	Stony and gravelly waste with shrubs and trees	1060	0.52
Total			28499	13.95
Miscellaneous Land Use				
15.		Permanent pastures and orans	13138	6.42
16.		Water bodies	4362	2.13
17.		Settlements	2120	1.03
18.		Reserved forests	11237	5.49
19.		Protected lands	400	0.19
Total			31239	15.26
Grand total			204515	100.00

Cropping Pattern

Data on cropping pattern (1977-78 to 1982-83) (Table 3) reveal that on an average out of the total cropped area Kharif crops constitute 79.2 per cent and Rabi crops 20.8 per cent, respectively. Out of the total Kharif cropped area Bajra, Bajra + Moth, Moong, Sesamum and fodder crops constitute 49.2, 15.9, 8.6, 7.4 and 17.81 per cents respectively. Other crops are Moth, maize, castor, cotton, chillies, and vegetables. In Rabi crops wheat, Raida, Taramira, and Jeera are important crops constituting 24.2, 25.5, 8.3 and 31.4 per cent respectively. Other crops are barley, gram, Menthi, Isabgol, vegetables and fodder crops. Over the past two decades, amongst the Kharif crops, area under fodder crops increased from almost nil to 17.81 per cent which is followed by Moong (8.6 per cent). Area under wheat decreased from 87.5 per cent to 24.2 per cent within 20 years whereas area under Jeera cultivation increased from 3 per cent to 31.4 per cent and that under oilseeds (mainly Raida and Tarmira) from 0.3% to 34%. As such Jeera is the most promising cash crop. Isabgol and Menthi are also newly introduced cash crops. To maintain the fertility of soil wheat, Raida, and Jeera are taken alternatively in a field, then it is kept fallow for a year.

Application of LANDSAT Imagery

Apart from the interpretation of aerial photographs visual interpretation of LANDSAT imagery (band 4,5,6 and 7) of 14.2.75 was done through additive colour viewer by permutation-combination method. Gautam et al (1983) laid down various parameters for land use inventory through LANDSAT MSS data. The best false colour composite for land use studies is made from bands 4, 5 and 7. Paper print of band 4,5,6,7 on scale 1:250,000 were also interpreted. Through the visual interpretation of LANDSAT imagery, only broad land use classification can be done subject to fulfilment of certain local conditions and period of imagery. Under arid conditions, dry monocropped land cannot be classified into different levels of intensity of cultivation. Fallow lands of different categories are also difficult to delineate. Rocky, stony and gravelly wastes also can not be distinguished. The details of MSS bands suitable for mapping various land use units are given in Table 1.

CONCLUSION

The main findings regarding the feasibility of remote sensing techniques in land use mapping are as follows:

Only broad land use classification is possible over a large area through visual interpretation of MSS LANDSAT imagery subject to certain local conditions and period of imagery. Knowledge of nature of terrain and environmental conditions of

Table 2
Cropping Pattern in Siwana Tehsil Percentage
to Total Cropped Areas

S. No.	Kharif crops	1960-61	Average 1977-78 to 1981-82	Rabi crops	1960-61	Average 1978-79 to 1982-83
1.	Maize	--	0.02	Wheat	87.5	24.2
2.	Jowar	--	0.2	Barley	5.3	0.7
3.	Bjara	59.8	49.6	Gram	--	1.8
4.	Bajra + Moth	13.7	15.9	Wheat+barley	--	0.9
5.	Moth	0.4	0.2	Wheat+gram	--	3.7
6.	Moong	--	8.6	Mustard	0.3	0.2
7.	Sesamum	7.5	7.4	Raida		25.5
8.	Castor seeds	--	0.02	Taramira	--	8.3
9.	Chillies	--	0.05	Castor		0.5
10.	Cotton	--	0.03	Jeera	3.0	31.4
11.	Fodder crops	--	17.81	Menthi	--	0.3
12.	Vegetables	--	0.1	Isabgol	--	0.7
13.	Others	2.9	0.07	Vegetables	2.8	0.5
14.	Guar	15.7	--	Fodder crops	0.9	1.0
15.				Others	0.2	0.3

Table 3
Land Use changes in Siwana Tehsil Percent to
Total Areas

S.No.	Land use	1951	1961	1971	1981
1.	Forest	+	1.06	0.79	++
2.	Area not available for cultivation	34.8	19.58	14.35	19.18
3.	Culturable waste	3.07		8.16	8.12
4.	Tree groves and orchards	-	-	0.13	-
5.	Fallow land	28.70	29.92	24.34	18.64
6.	Irrigated land	1.91	2.54	2.34	9.08
7.	Unirrigated land	32.66	43.34	49.89	51.54
8.	Double-cropped land	0.28	0.44	1.07	6.73
9.	Net area sown	34.29	45.44	51.16	53.79

+ Percentage of the total area of 17 villages with an area of 29442.76 ha.

++ Five years' average (1977-78 to 1980-81).

a region is essential for interpretation of LANDSAT imagery. Otherwise misinterpretation is possible. To get better results for land use mapping, a common approach involving interpretation of aerial photographs, topographical maps, satellite imagery, field survey, local knowledge and selected secondary data is needed. Under arid conditions, time factor of LANDSAT imagery and aerial photographs is most important. Land use changes can be mapped through study of sequential aerial photographs and satellite imagery of a particular period.

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**APPLICATION OF SHUTTLE IMAGING RADAR DATA (SIR-A)
FOR LAND USE/LAND COVER AND GEOMORPHOLOGICAL STUDIES
- A CASE STUDY FROM CENTRAL INDIA**

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ABSTRACT

Space shuttle Columbia during its second flight in November 1981 collected synthetic aperture radar data over a part of the Indian landmass. This data has been analysed and evaluated for assessing its potential in mapping various earth resources. Comparative evaluation of SIR-A data vis-a-vis LANDSAT data has also been attempted. The present paper discusses the applicability and limitations of SIR-A data for land use/cover and geomorphological studies.

Land use/cover maps depicting various categories of USGS classification system like agricultural land, built-up land, forest land, barren land, water bodies and communications etc. have been mapped. It is seen that apart from the above stated six major categories at level-I, 18 other categories at level-II of USGS classification system could be delineated using SIR-A data. The geomorphological maps depict various geomorphic units. This analysis shows that the microwave frequencies at L-band are sensitive to surface roughness variations. Hence, various land cover and geomorphic units show up distinctly on SIR-A images. Comparative evaluation shows that single-band SIR-A data is better than any individual band of LANDSAT MSS/RBV data. More comprehensive results can be achieved using radar data as complementary to LANDSAT data.

INTRODUCTION

The space shuttle Columbia during its second test flight in November 1981 collected Shuttle Imaging Radar (SIR-A) data at L-band frequency over parts of the Indian landmass. The 1700-km long and 50-km wide linear strip of the radar images has been divided into three segments for convenience in data analysis and the data are being analysed in different phases. Fig. 1 shows SIR-A coverage over India. In the first phase the western segment comprising mainly the desertic part of the Indian landmass had been analysed. Results of this analysis have been brought out in the form of an ISRO report (Sood et al 1984).

METHODOLOGY

SIR-A images are available as hard copy in the form of a strip of 12.5 cm width. Fig. 2 gives the layout of the SIR-A image film.

Visual interpretation of the paper prints was done using simple hand lenses. From the paper prints negatives were made and the same were enlarged to generate transparencies at twice the magnification of the paper prints i.e. at a scale of 1:250,000. This helped in transferring onto and comparing the SIR-A data with topographical maps, at the scale of 1:250,000.

Multispectral and multitemporal LANDSAT images were studied in different forms and formats. For confirming the interpretation, panchromatic aerial photographs available at 1:60,000 and 1:40,000 scales were studied monoscopically by making mosaics, and stereoscopically using stereomodels.

The Survey of India topographical maps at the scale of 1:250,000 and 1:50,000 were used to trace the location and identity of physiographic features. Similarly the published maps and other literature were used as collateral data.

INTERPRETATION

Mapping of land use/land cover and geomorphology has been carried out using SIR-A, LANDSAT MSS and RBV images (Fig. 3,4,5 & 6), and a comparison of these has been attempted. The study area is characterised by mixed land use pattern. The land use/land cover is closely associated with the geology and geomorphology of the region. The plateaux, the dissected hills and the ridges are under forest cover. The plains and valley-fill depressions are under active agricultural use whereas undulating low grounds are either barren or covered by grass.

Land use/Land cover Studies

Anderson's (1976) land use/land cover classification system was adapted according to the requirements of the study area. Table 2 shows the legend prepared for land use/cover classification for SIR-A, LANDSAT MSS and RBV images. This study shows that it is possible to map six major land use/land cover types at Anderson's level-I classification. They are identified as: agricultural land, built-up area, forest land, barren land, water bodies and communications. These units could be further classified into 18 different classes at level II and level III of the classification system.

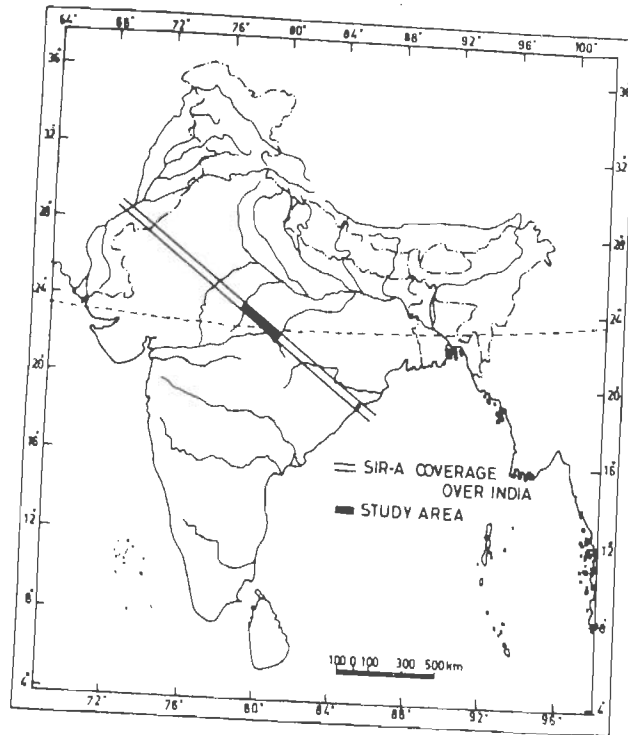


Fig. 1 SIR-A coverage over India

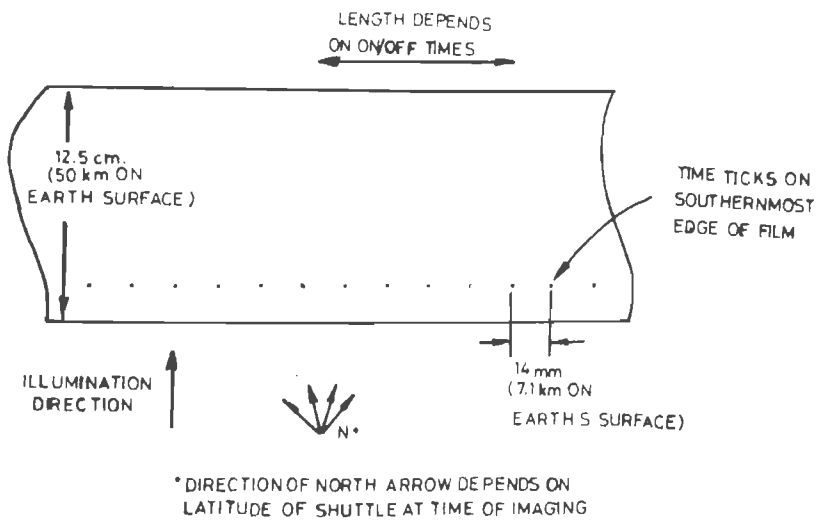


Fig. 2 Dimensions of SIR-A image film (Cimino 1982)

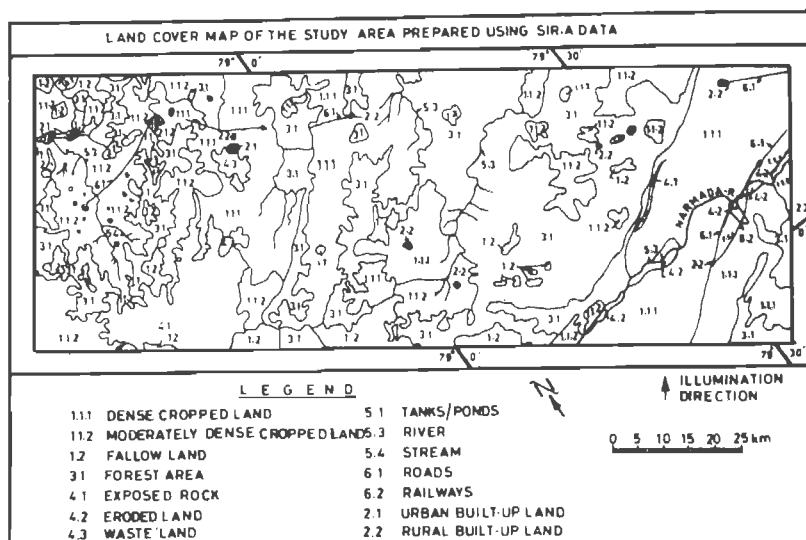


Fig. 3 Land cover map of the study area prepared using SIR-A data

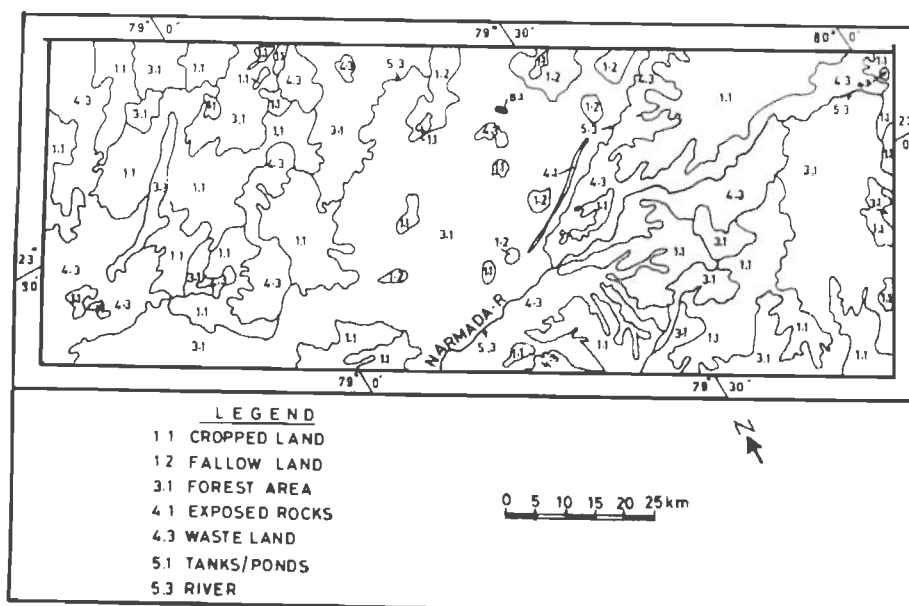


Fig. 4 Land cover map of the study area prepared using LANDSAT (MSS) data

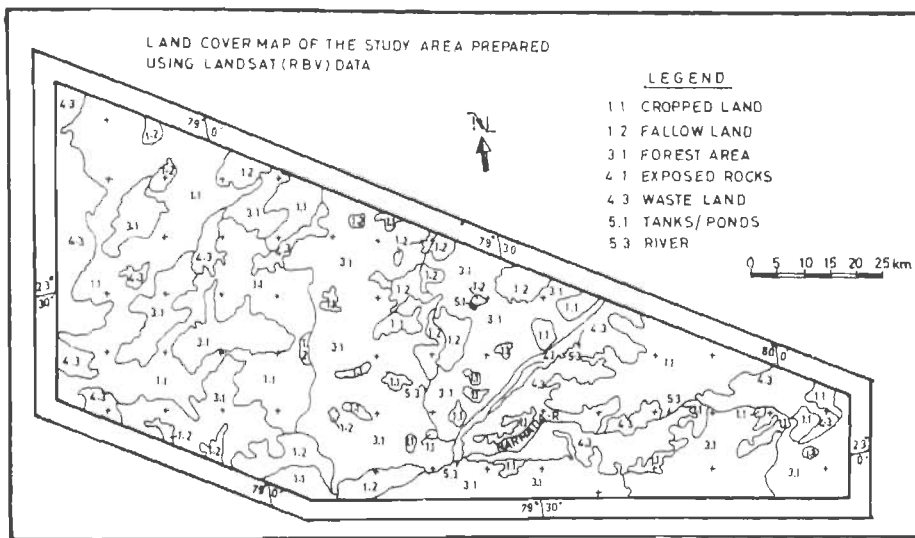


Fig. 5 Land cover map of the study area prepared using
LANDSAT (RBV) data

Table 1
The SIR-A Sensor Characteristics

Parameter	Value
Frequency	1.3 GHz
Wavelength	23 cm
Polarisation	HH
Look angle	47° ± 3°
Incidence angle at surface	43° ± 3°
Image swath width	50 km
Image resolution	40 x 40 m
Antenna site	2.1 x 9.5 m
Area covered	10 km
Average orbital altitude (km)	259 km

(Ref: Elachi et al 1982)

Table 2
Legend for Land Use/Land Cover Classification for Use
with SIR-A, LANDSAT MSS and RBV Data

Level-I	Level-II	Level-III
1. Agricultural land	1.1 Cropped land	1.1.1 Dense cropped land
	1.2 Fallow land	1.1.2 land
2. Built-up land	2.1 Urban built-up land	2.1.1 Urban planned built-up land
	2.2 Rural built-up land	2.1.2 Urban unplanned built-up land
3. Forest land	3.1 Dry deciduous forest	
4. Barren land	4.1 Exposed rock	
	4.2 Eroded land	
	4.3 Waste land	
	4.4 Sand dunes	
	4.5 Salt pans	
5. Water bodies	5.1 Tanks/ponds	
	5.2 Canal	
	5.3 Rivers	
	5.4 Stream	
	5.5 Lakes	
6. Communication	6.1 Roads	
	6.2 Railways	

[Ref: Modified version of Anderson et al (1976)]

Geomorphological Studies

Physiographically the area under investigation comprises parts of the Malwa plateau, Bhandar plateau, Narmada valley and the Satpura range. The Malwa plateau and the Satpura range are built up of extrusive rocks and have given rise to diverse landscapes ranging from rolling surface to flat-topped hills, sharp-crested ridges and intervening shallow depressions. The Bhandar plateau is made up of sandstones of Bhandar group of Vindhyan super group. The Narmada valley is probably a structural depression filled with alluvium of the Narmada river.

The interpretation of SIR-A images at the scale of 1:250,000 was attempted to delineate different geomorphic units developed over different lithological types. Figure 6 is a geomorphological map of the study area prepared from SIR-A images. This study shows that it is possible to map four geomorphic units. They are identified as: geomorphic units of extrusive, structural, denudational and fluvial origin.

The present study shows that microwave frequencies are very sensitive to relief changes and hence the geomorphic details associated with above stated geomorphic units like plains, hills, structural ridges, scarps, denudational depressions, and residual hills stand out better on SIR-A images than on the LANDSAT MSS and RBV images. However, fluvial details are relatively less on SIR-A images.

CONCLUSIONS

- i) SIR-A images, in general, have better contrast and are good for mapping land use/cover categories.
- ii) This study shows that it is possible to map six major land use/land cover types. These units could be further classified in 18 different classes.
- iii) Microwave frequencies are very sensitive to surface roughness and various geomorphic units could be easily delineated.
- iv) SIR-A images are certainly better than any individual LANDSAT MSS band, but LANDSAT FCC has an upper edge over SIR-A data especially in mapping vegetation and water bodies.
- v) Unique advantages of SIR-A data is observed in detecting and mapping urban and rural built-up areas and also roads and railway lines.
- vi) The two properties that influence the radar backscattering from terrain features most are the physical and electrical. The effect of physical properties is clearly perceptible, but the effect of electrical properties could not be ascertained due to lack of synchronous ground truth data.

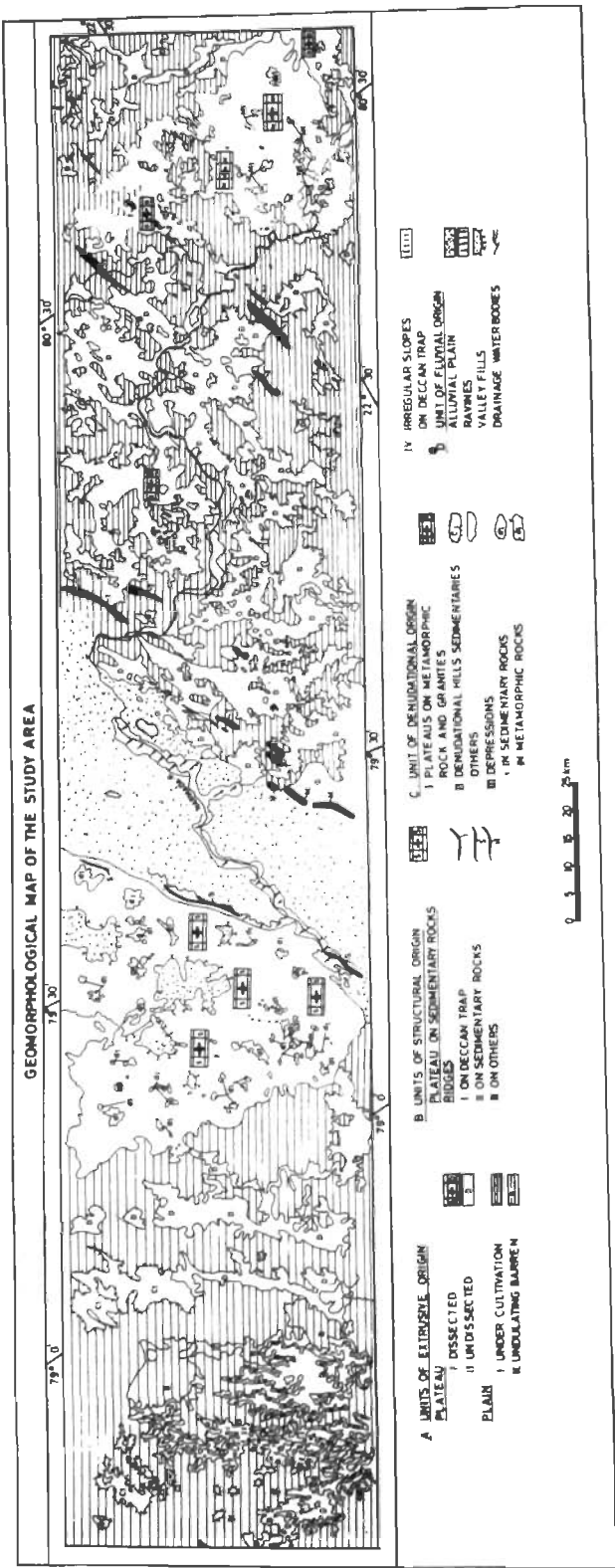


Fig. 6 Geomorphological map of the study area from SIR-A data

- vii) SIR-A data when used in conjunction with LANDSAT MSS band 5 provides more useful information.

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REMOTE SENSING IN PLANNING AND MONITORING OF LAND USE IN KERALA

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ABSTRACT

Kerala state which enjoys a tropical moist overgreen climate has its unique problems in the planning and monitoring of the land use. The pressure on land, coupled with frequently changing nature of cropping pattern, demands rapid methods of survey and interpretation of data within the minimum possible time. This paper briefly describes how remote sensing technology has aided this task for the formulation of a viable land use plan.

INTRODUCTION

Kerala State, having a tropical moist evergreen climate has its unique problems in the planning and monitoring of its land use. Land, in this sense, includes soil, water and vegetation as well as the products and processes of their interaction. The high pressure on land and the frequently changing nature of cropping pattern make quick and rapid methods of survey and interpretation of data necessary within the minimum possible time. The Idukki land use survey conducted by the State Land Use Board in 1978-79 in collaboration with the Space Applications Centre (SAC), Ahmedabad, had proved that it was possible to have the desired data within a reasonable time through the application of remote sensing techniques and their timely interpretation for the formulation of a viable land use plan. The aerial survey of Idukki had revealed that much of the so-called cardamom hill area had no cardamom left out and was under mixed crops as a consequence of the wide spread clearing in the part of both the cardamom and its evergreen forest cover.

Further, hydroelectric schemes planned for a life span of fifty or one hundred years would serve their purpose only for less than half their life due to the silting of reservoirs and lack of inflow of the rivers as a result of the clearing of the catchment areas taking place on an increasing rate. The survey had identified large blank areas which could be brought under an ideal scheme of afforestation.

The conditions in other hilly tracts of the state are more

or less identical to those of Idukki which demand comprehensive survey, scientific evaluation and proper planning for the future so that the already depleted natural resources would at least be preserved for the posterity. Though the satellite imagery gives a synoptic view, due to the highly undulating terrain with a multiplicity of crops and forests of evergreen nature, the present resolution of the scanners gives only a broad outline of the vegetative cover which is quite insufficient for micro or middle level planning.

In the coastal area of the State, especially in the flat plains where the low-lying paddy fields are situated, the effect of tidal waves and monsoon floods could be monitored through satellite imagery.

LAND USE PLANNING - PRESENT STATE OF AFFAIRS

Optimum land use plan for one of the districts in the State - Idukki - was prepared based on the aerial survey conducted in 1978-79 as a joint project by the Kerala State Land Use Board in collaboration with the SAC, Ahmedabad, as mentioned earlier. The technical know-how was imparted to the State Land Use Board by the Space Applications Centre in using aerial photography and satellite imagery with regard to gathering of data on land and land use. Panchromatic black-and-white and colour infrared photographs were simultaneously taken, the former for stereoscopic interpretation and the false colour infrared diapositives for land use mapping. The scale of mapping was selected at 1:15,000 considering the average size of the holding which is less than 0.25 hectares and the heterogeneous cropping pattern in the area. This scale facilitated to map as small an area as 0.25 hectares. LANDSAT imagery obtained from NASA was made use of for the preparation of land use, geomorphological and structural maps. Thus a set of land use, geomorphological and structural maps were prepared. For a proper land use planning, the land use and physiography form the basis on which other factors like climate, soil characteristics, altitude, socio-economic conditions, and to a certain extent socio-political situations and their interactions have to be taken into account and modelled out.

The base was prepared by incorporating all the details of land use, geomorphology and structural geology, in the desired mapping unit. This model was further improved by the secondary data of climate and other factors mentioned above. The basic map unit, both for the Idukki land use survey and for the land use plan cover 5' x 5' geographical area, which is convenient to handle and had direct bearing on the Survey of India topographical maps. All the three thematic maps are on 1:15,000 scale.

The land use classification followed in the mapping was:

- a) Agricultural area: which was further sub-divided into paddy; sugarcane, rubber, both freshly planted and well-grown; tea; coconut; tapioca; mixed crop and fallow land
- b) Forest : sub-divided into man-made plantation, i.e. eucalyptus and teak; mixed forest; forest blanks or grassland.
- c) The wasteland : subdivided into rock outcrops, highly eroded lands i.e. rills and gullies, marsh and barren areas.
- d) The water bodies : subdivided into lakes, rivers and streams
- e) The public utility : habitations, roads, buildings etc.

Geomorphological maps depict

- a) crest of hill ranges, sharp, rounded or conical, and
- b) slopes with five subcategories ; very gentle, gentle, moderate, steep and very steep; shape of the slope: convex, concave straight and the erosion status of the area as gully erosion and land slides.

The structural maps depict the major topographic trend, the fault and the fractures.

The created model using the above maps and auxillary data were further modified by the soil-conservation-priority maps of the area prepared from the aerial survey data. The acceptability of the local population, the demand projection in the national and international market for the products were also taken into consideration while preparing the optimum land use plan for Idukki.

Though the survey and planning was done within the least possible time, the past experience with the land use of the area shows that it has to be further monitored at shorter intervals. This is revealed by Table 1 which presents the important land utilisation classes of Idukki during the two years: 1975 and 1979. The figures under column 2 are TRS estimates and the results of the aerial survey are given in column 3. Though these two sets of figures differ in degree of accuracy, they are the only data that are available for purpose of comparison.

Table 1
Changes in Land Utilisation in Idukki during 1975-1979

Crop	1975 area (ha) (TRS) ⁺	1979 aerial survey (ha)	Area under proposed land use plan (ha)
Rice	8218	7740	6600
Mixed crops	78881	103860	105250
Tea	27337	31341	39430
Rubber	15357	21974	23850
Cardamom	42231	34633	40530
Forest	297626	263438	259170

+ TRS - State Directorate of Economics & Statistics.

It is seen from the Table 1 that the area under rice had come down by 6 per cent in a period of 4 years and a further fall is expected. In case of mixed crops, an increase of 32 per cent in area and a further limited increase was envisaged if the proposed restrictions could be enforced. In case of tea, 15 per cent increase was noted during the four-year period and a further increase in the area was recommended. Cultivation of rubber has increased by 43 per cent during the period and a marginal increase was allowed in the plan; but the present indication is that it may surpass all expectations unless some restrictions are imposed. As regards cardamom a reduction in area of 18 per cent was noticed during the period. An increase in area was recommended; but the indications are that it may not materialise unless some drastic measures are taken against conversion of cardamom area and the provision of attractive incentives is made to the cultivators for fresh planting. A reduction of 11.5 per cent in area under forest had been noticed during the period. An increase of 2 per cent in this area was recommended for the district under the proposed plan. The above data bring out the highly dynamic nature of land use and the rapid speed at which evergreen forest has been vanishing, a situation which demands periodic monitoring at proper intervals.

Idukki Land Use Survey (Sahai et al, 1983, 1985) was taken up as one of the end-to-end experiments under the NNRMS and the results revealed that the land use maps prepared could achieve a classification accuracy of 86 per cent whereas the accuracy of slopes in geomorphological maps was 72 per cent. The studies on soil erosion had shown that 23 per cent of the cultivated area was severely eroded and control measures had to be taken up, irrespective of cost, if the productivity of the land had

to be improved as well as for saving the hydro-electric projects in the district; 19 per cent of the areas was identified for the measures to be taken up at top priority basis and 56 per cent of the cultivated area was marked for soil conservation measures for checking the degradation of soil and the silting up of hydel reservoirs.

The Idukki Land Use Survey has proved that only through remote sensing techniques the depleting forest resources could be assessed as most of these areas were unapproachable and large tracts of blank areas existed within the forests. The details presented in this paper indicate how rapid the forest was being cleared in Idukki district during the period 1975-1979. The National Commission on Agriculture had recommended the norm of 60 per cent of forest area in the hilly tracts whereas the latest study conducted by the Centre for Earth Science Studies, Trivandrum in 1984 based on LANDSAT imagery and topographic sheets brought out the alarming fact that the forests account for only 17 per cent of the total area.

FUTURE PROSPECTS

An important field requiring the application of this technique in the State is the assessment of the loss of crops due to natural calamities like floods and also due to the incidence of diseases. The vast paddy lands of Kuttanad, known as the rice bowl of Kerala, which lie on an average 3 m below Mean Sea Level as well as the 'pokkall' and 'kole' lands adjoining the coastal belt are highly affected by the monsoon floods and tidal waves, the former by the flooding by monsoon waters and the latter through the inundation by sea water. The damages caused to the crop result in a heavy burden to the exchequer by way of compensation as subsidy and grants to the cultivators. At present there is no method for accurate evaluation of the crop damage or about the flooded area at the time of the incidence. The repetitive coverage of the area offered through the satellite imagery could be used to monitor the damages correctly.

Study of two satellite views of the same site, one on the 5th December, 1978 at the time of the flash floods and the other under the normal crop was conducted. The area could be clearly distinguished due to the presence of wide channels and bunds and extensive padasekharams (blocks of paddy lands). During the floods, it was seen from the imagery that four blocks or padasekhrams were unaffected by the floods whereas according to the official records, these areas were also flooded.

As early as 1970, the technique of remote sensing was attempted to detect and delineate areas affected by coconut rootwilt disease in the State. Perhaps this was also the

pioneering attempt in the field of remote sensing in India under the guidance of Professor Pisharoty. Coconut being the most important cash crop of the State, accounting for 30 per cent of the agricultural income and providing employment to over a million people, the decline in its productivity has adversely affected the very economy of the State. The recent survey (December 1984) conducted by the Central Plantation Crop Research Institute and the State Department of Agriculture had estimated the loss due to the root-wilt disease at 900 million nuts per year valued at more than Rs. 2250 million. It is proposed to include coconut disease detection also in the forthcoming aerial survey planned in some districts of the State. Individual coconut palms are easily distinguishable in the 1:15,000 scale photoaographs. The 1:6000 scale photography proposed for the Urban Survey in Kerala will enhance the detection and delineation of the affected palms.

In Kerala where there is no village system as elsewhere in India, the urban-rural distinction in land use is not so clearly marked. The most productive coconut gardens and agricultural activity are in and around urban areas. Hence urban development has to go hand in hand with agricultural planning and development.

Large scale physiographical maps are a necessity for the formulation of conservation and development plans on a watershed basis. The geomorphological maps enable easy delineation of micro and macro watersheds for formulation of the microlevel land use plans with suitable cropping patterns. Based on the experience already gathered the State Land Use Board of Kerala proposes to undertake the aerial survey of the entire State for land use and urban planning as well as for the formulation of irrigation and other catchment area development projects. The scale of photography proposed being 1:15,000 for land use and 1:6000 for urban planning. Both black-and-white and colour infrared photography is envisaged. Based on these products, it will be the earnest endeavour of the board to formulate comprehensive district-wise land use plans within the seventh five year plan period itself.

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MICROWAVE REMOTE SENSING OF SOIL MOISTURE OVER BARE FIELD AT 31.4 GHZ

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ABSTRACT

Results of radiometric measurements over bare soil with dual polarized microwave radiometer at 31.4 GHz frequency are presented. Radiometer measurements were made with incidence angle varying from 10 to 50 degrees. Ground truth acquisition of soil moisture in the top 0-0.5 cm layer and soil temperature near the surface was made concurrently with radiometric measurements. The observed brightness temperature can be predicted fairly well by emissivity model with known relationship between dielectric permittivity and soil moisture content.

INTRODUCTION

The soil moisture content in the near-surface region is of major importance in a number of disciplines including hydrology, agriculture and meteorology. Microwave remote sensors aboard earth-orbiting satellites have potential for providing soil moisture information over large areas. In order to facilitate the interpretation of data obtained by airborne or satellite-borne sensors, ground-based investigations of the interaction of microwave radiations with soil at different moisture contents is essential. A large number of ground-based experiments on the remote sensing of soil moisture content have been conducted with active (Ulaby 1974, 1976) and passive (Njoku and O'Neill 1982, Newton and Rouse 1980, Schanda et al 1980, Schmugge 1983, Wang et al 1982) microwave sensors in the past two decades.

A programme of comprehensive study of emission properties of sandy loam soil, under controlled conditions, has been undertaken. Microwave radiometric measurements were made over bare soil with different moisture content at 19 GHz during January-February, 1984. In continuation of this work, an experiment was conducted over the same plot at 31.4 GHz in June, 1984 and results are reported in this paper. A dual

polarized 31.4 GHz radiometer was mounted on the top of a building overlooking the sample field. The emission properties were studied for different moisture content and look angles. The field was irrigated in the beginning of the measurements and observations made with the instrument during the soil drying cycle. Soil moisture was determined in 0 - 0.5 centimeter layer coincident with each sensor measurement. Due to the dry environmental conditions and sandy nature of soil, drying out of the soil surface after irrigation was quite rapid.

EXPERIMENTAL DETAILS

The measurements were conducted on a test site in the Gujarat University Campus, Ahmedabad. A plot of 35 m x 20 m was prepared near Physics Department of the Gujarat University and the radiometer was mounted on the top of the Physics Department building (height 35') overlooking the plot. The field soil is sandy loam with average texture (in the top 5 cm), 64 % sand, 29 % silt and 7 % clay. The plot is surrounded by grassland. The field was irrigated in the beginning of the measurements and observations were made with the instrument during soil drying cycle. Soil samples were acquired manually. Nearly forty samples were collected on each day from different locations uniformly distributed over the plot, at the time of radiometric measurements. The soil samples were sealed and weighed. Their moisture content was determined gravimetrically through oven-drying at 105°C and reweighing.

A 31.4 GHz radiometer, an engineering model version of the Satellite Microwave Radiometer System (SAMIR) which was flown on the Bhaskara II, the second Indian Satellite for Earth Observations was used for the measurements. The radiometer system was designed and developed at the Space Applications Centre (SAC), Ahmedabad. The radiometer has been realised in conventional Dicke configuration. The system specifications are given in Table 1. The 3-dB beam width of the antenna is 10 degrees. The radiometer measures the brightness temperature T_B of the target in horizontal and vertical polarization. The radiometer was calibrated by simulating different brightness temperatures at the radiometer input by connecting a liquid-nitrogen-cooled termination followed by a precision variable attenuator maintained at ambient temperature.

RESULTS AND DISCUSSION

A typical variation of measured brightness temperature T_{BP} (θ) (subscript P can be either V for vertical polarization or H for horizontal polarization) with incidence angle θ is shown in Fig. 1. It is evident from the figure that there is a decrease in brightness temperature with look angle in case of

horizontal polarization while there is a little increase in brightness temperature with look angle in the case of vertical polarization.

The variation of brightness temperature T_B as a function of soil moisture is shown in Fig. 2 for 30 degree incidence angle (horizontal polarization). The brightness temperature decreases with moisture content. A linear regression has been done to obtain correlation between T_B and surface soil moisture. Excellent correlation coefficient of 0.93 is found between T_B and surface soil moisture content.

THE MICROWAVE EMISSION MODEL CALCULATIONS

Various theoretical models have been developed to compute microwave emission from surfaces. These models include emissivity model (Peak 1959), radiative transfer model (England 1974) and Coherent model (Stogryn 1970, Wilheit 1978). The emissivity model is the simplest to use with reasonable accuracy at higher microwave frequencies, where the radiation arises from within a region close to the surface. Since the present investigation was carried out at 31.4 GHz, the brightness temperature of the soil was calculated by emissivity model. In this model the brightness temperature T_B observed outside the soil medium is given by

$$T_B(\theta) = e_p(\theta) T + r_p(\theta) T_{sky} \quad \dots(1)$$

where $T_B(\theta)$ is the brightness temperature, $e_p(\theta)$ is the emissivity of the surface layer, p refers to either vertical or horizontal polarization, T is the surface temperature and r_p is reflectivity at air-soil interface. T_{sky} is the brightness temperature equivalent of sky and atmospheric radiation incident on the soil.

Equation (1) can be written as

$$T_B(\theta) = [1 - r_p(\theta)] T + r_p(\theta) T_{sky} \quad \dots(2)$$

In the case of smooth surface over a homogeneous medium $r_p(\theta)$ is obtained from the Fresnel's reflection coefficient $R_p(\theta)$ (Kong 1975) •

$$r_p(\theta) = |R_p(\theta)|^2 \quad \dots(3)$$

and
 $R_p(\theta) = \frac{\cos\theta - \sqrt{K - \sin^2\theta}}{\cos\theta + \sqrt{K - \sin^2\theta}} \quad \dots(4)$
 for horizontal polarization and

$$R_p(\theta) = \frac{K \cos\theta - \sqrt{K - \sin^2\theta}}{K \cos\theta + \sqrt{K - \sin^2\theta}} \quad \dots(5)$$

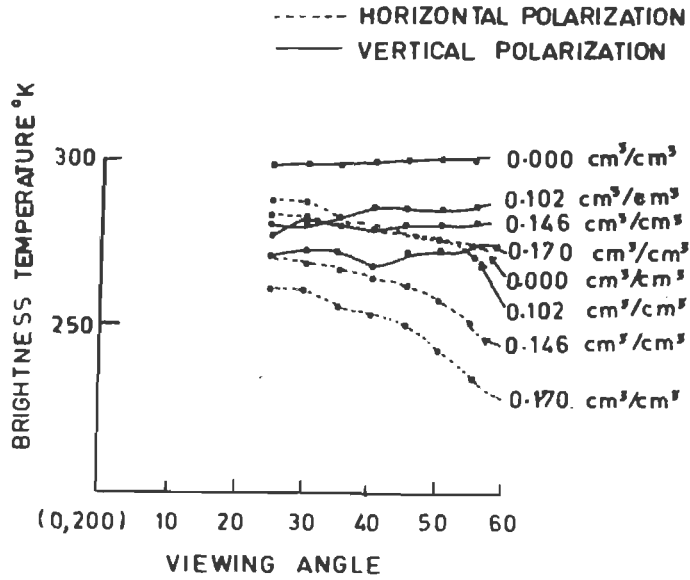


Fig. 1 The variation of the measured brightness temperatures as a function of incidence angle for various moisture contents

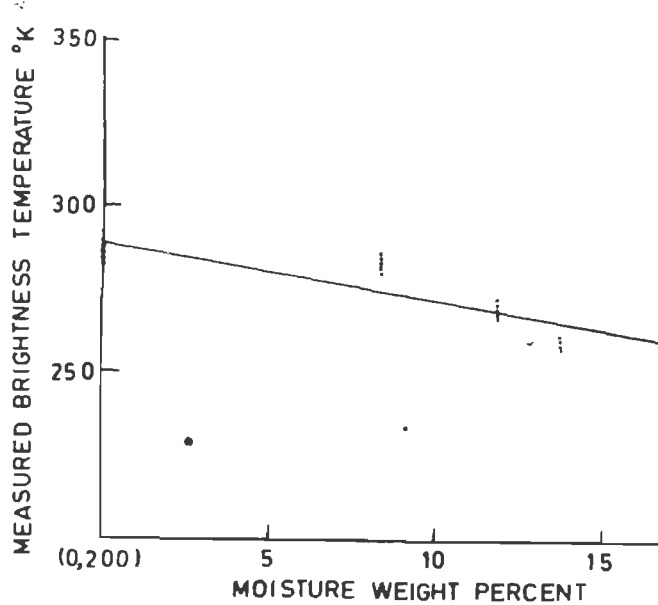


Fig. 2 Measured brightness temperatures at 31.4 GHz for horizontally polarized emission at 30 viewing angle as a function of soil moisture

for vertical polarization

where θ is the angle of observation from nadir and K is the dielectric constant of soil. Equations 3, 4 and 5 can be used for calculation of emissivity provided the dielectric constants of soil with moisture content is known.

The dielectric constants of soil in the present work were calculated by dielectric permittivity model of Wang and Schmugge (1980). From these values of dielectric constants emissivity was calculated using equations 2 - 5. The brightness temperature T_B was computed using equation 1. T_{sky} was measured by pointing the radiometer antenna towards the sky.

The computed T values are compared with the observed values in Fig. 3 for incidence angle of 30 degree for both the polarizations. It is evident from the figure that the calculated brightness temperatures are in reasonable agreement with the measured values. When soil is relatively wet, there is a slight difference between calculated and observed brightness temperatures. This slight difference could be due to deficiency in the emissivity model or the dielectric permittivity model. Another reason could be uncertainty in the measurement of soil bulk density, which can easily make a few degrees difference in the calculated brightness temperatures.

CONCLUSION

It may be concluded from the present experiment that the observed brightness temperatures over smooth bare soil at higher microwave frequencies can be predicted fairly well by emissivity model (Peak 1959) with known relationship between dielectric permittivity and soil moisture content.

Table 1
Specification of Radiometer

Frequency (GHz)	31.4
R.F. bandwidth (MHz)	250
Integration time (ms)	300
RMS sensitivity ($^{\circ}$ K)	1
Beam width (degree)	10

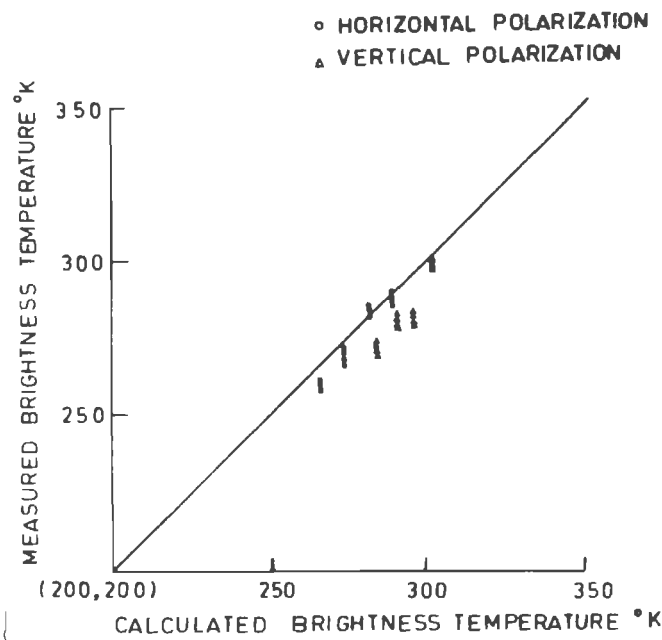


Fig. 3 A comparison of the calculated and measured brightness temperature at 31.4 GHz for horizontal and vertical polarizations at 30° incidence angle

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COMPLEX PERMITTIVITY OF SANDY-SOILS OF GUJARAT AT MICROWAVE FREQUENCIES

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ABSTRACT

Permittivity and dielectric loss of sandy loam soil samples with varied moisture content have been measured under laboratory conditions at K-band microwave frequency. The observed dielectric constant increases only slowly with moisture content upto a transition point. Beyond transition point, it increases rapidly with moisture content. The complex permittivity of sandy loam soil has also been calculated using empirical model of Wang and Schmugge with moisture content at X-band microwave frequencies. For dry soil the model gives higher values of dielectric constant in comparison to the experimentally determined values. The soil-water mixture dielectric constants from the model are found to be in reasonable agreement with the measured values.

INTRODUCTION

Microwave emission and backscatter characteristics of soil depend on its complex permittivity, texture and roughness. The complex permittivity of soil is highly affected by the presence of moisture in the soil. Considerable interest has been evoked to measure the complex permittivity of soils with varying moisture content in laboratory at microwave frequencies. A programme of comprehensive study of different type of soils found in different parts of Gujarat State has been undertaken. The complex permittivity of sand and sandy loam soil with varying moisture content in laboratory conditions has been measured at X-band microwave frequency and reported earlier (Vyas 1982). In continuation of this work, the complex permittivity of sandy loam soil has been measured with moisture content at K-band microwave frequency and the results are reported in this paper. The complex permittivity of sandy loam soil has also been calculated using the empirical model of Wang and Schmugge (1980) with moisture at X-band and K-band

frequencies. The calculated values of complex permittivity and laboratory determined values have been compared.

EXPERIMENTAL DETAILS

The soil used in present investigation was sandy loam collected from Gujarat University Campus. It was passed through a sieve of mesh No. 50 and then collected in a metallic tray. It was saturated with water and left open. The samples at different moisture content were used for measurement of permittivity and dielectric loss as well as for measuring moisture content. The soil samples was collected in a metallic box. The weight of the soil alongwith the box was taken immediately after collection, and then again keeping the sample overnight in oven at a temperature of 100° C to determine the moisture content of the soil.

The moisture content as weight (wt) per cent of the soil was calculated by the formula:

$$\% \text{ moisture content} = \frac{\text{wt of wet soil} - \text{wt of dry soil}}{\text{wt of dry soil}} \times 100$$

A K-band microwave bench operating at 19 GHz was used for measurement of permittivity and dielectric loss. The microwave source was a Klystron (RK 6253). A slotted line was used for measurement of VSWR and shift in minimum. The cell containing the sample was kept vertical and connected to main line by an E-plane bend. The permittivity and dielectric loss were calculated by two points (Sucher and Fox 1963) method, using the relation

$$\epsilon' = \frac{G_E + (\lambda_g/2a)^2}{1 + (\lambda_g/2a)^2} \quad \text{and}$$

$$\epsilon'' = \frac{S_E}{1 + (\lambda_g/2a)^2}$$

where G_E is the conductance and S_E is the succceptance; λ_g is the guide wavelength and 'a' is the wider dimension of waveguide. The estimated accuracy for ϵ^* is $\pm 2\%$ for dry soils while for soil water mixture it is $\pm 5\%$.

EMPIRICAL MODEL CALCULATIONS

Many mixing formulae have been reported in the literature to describe the dielectric behaviour of soil-water mixture, but they do not match with the experimental results. Recently, Wang and Schmugge (1980) gave an empirical model to develop an analytical expression for complex permittivity of soils as a function of moisture content. In this model the expressions for complex permittivity ϵ^* of soil water mixture are given by:

$$\epsilon = W_c \epsilon_x + (P - W_c) \epsilon_a + (1 - P) \epsilon_r \dots\dots\dots(1)$$

$$\text{for } W_c < W_t$$

with

$$\epsilon_x = \epsilon_i + (\epsilon_w - \epsilon_i) \frac{W_c}{W_t} \gamma$$

and

$$\epsilon = W_t \epsilon_x + (W_c - W_t) \epsilon_w + (P - W_c) \epsilon_a + (1 - P) \epsilon_r \dots\dots(2)$$

$$\text{for } W_c > W_t$$

$$\text{with } \epsilon_x = \epsilon_i + (\epsilon_w - \epsilon_i) \gamma$$

where P is the porosity of dry soil ϵ_a , ϵ_w , ϵ_r and ϵ_i are the dielectric constants of air, water, rock and ice respectively, ϵ_x stands for dielectric constant of initially absorbed water. W_c is the volumetric water content in the soil and W_t is the transition moisture. γ is a parameter which can be chosen to best fit equation (1) and (2) to experimental data. The values of W_t and γ can be related with the wilting point WP by the relations

$$W_t = 0.49 WP + 0.16$$

$$\gamma = -0.57 WP + 0.48 \dots\dots\dots(3)$$

While WP can be calculated from the texture of the soil using the relation.

$$WP = 0.068 - 0.00064 \times \text{sand} + 0.0048 \text{ clay} \dots\dots(4)$$

The mechanical and chemical analysis were made on the soil samples. Based on soil texture information wilting point was estimated using the equation 4 and listed in Table 1. From these values of WP and with the help of equations 1,2,3, dielectric constants of the samples were calculated at microwave frequencies.

RESULTS AND DISCUSSION

The measured value of permittivity and dielectric loss for sandy loam soil samples at 19 GHz have been plotted against moisture content and shown in Fig. 1, the earlier reported values at X-band (8.97 GHz) have also been shown for comparison. The values are in agreement with the studies of radar response of laboratory prepared soil samples of Lundien (1966). There is small increase in permittivity upto 8% after which it increases sharply with moisture content. This has been observed (Ulaby and Bativala 1976) due to the fact that with the increase of water content there are more free water molecules in comparison to absorbed water molecules which have much smaller permittivity than that of free water molecules. The measurements at 19 GHz, show same permittivity for the same moisture content upto 10% but for higher moisture content permittivity decreases for 19 GHz in comparison to 8.97 GHz. The relaxation frequency of water molecule lies in the microwave part of electromagnetic spectrum and its permittivity decreases with increase of microwave frequency. It appears that increase in moisture content increases the free available water molecules in soil samples which makes the permittivity, frequency dependent.

The calculated values of complex permittivity at 8.97 GHz and 19 GHz using empirical model are shown in figs. 2 and 3, respectively. The experimentally determined values have also been shown for comparison. The experimentally determined permittivity of dry soil at 8.97 GHz and 19 GHz is 2.88 while the empirical model gives

$\epsilon' = 3.25$ at $W_c = 0$. The calculated values of complex permittivity of soil-water mixture for $W < W_t$ and $W > W_t$ are in reasonably good agreement with the $\epsilon_{\text{experimental}}$ values. However, the small difference is comparable with the precision of the dielectric constant measurements.

With the view of using these data to study the response of microwave for sandy loam in field, we have computed the emissivity from the values of permittivity using the relation,

$$e = 1 - \left| \frac{1 - \sqrt{\epsilon}}{1 + \sqrt{\epsilon}} \right|^2$$

where 'e' is the emissivity and ϵ is the complex dielectric constant. The calculated values of emissivity (e) for sandy loam soil at 8.97 GHz and 19 GHz with moisture content is presented in Table 2. It is evident from the table that the emissivity closely follows the variation of moisture content. The emissivity at 8.97 changes from 0.93 to 0.60 for the moisture content 0-20% is in agreement with the literature values (Reeves 1975). The emissivity at 19 GHz changes from

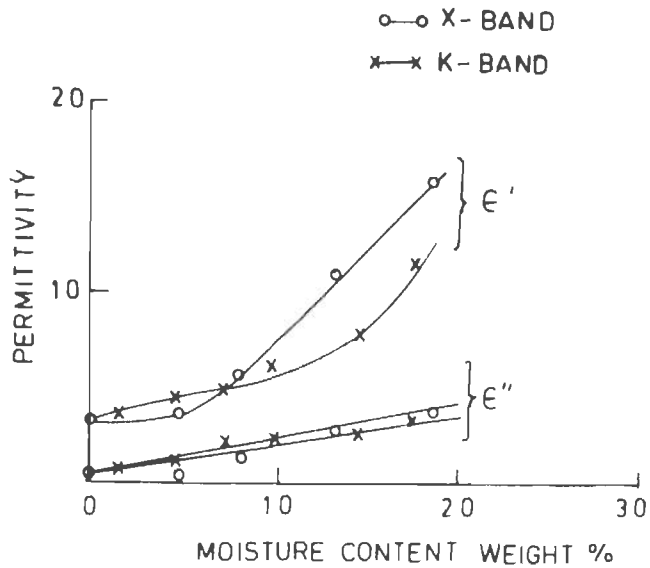


Fig. 1 Permittivity and Dielectric loss of sandyloam for different moisture contents at microwave frequencies

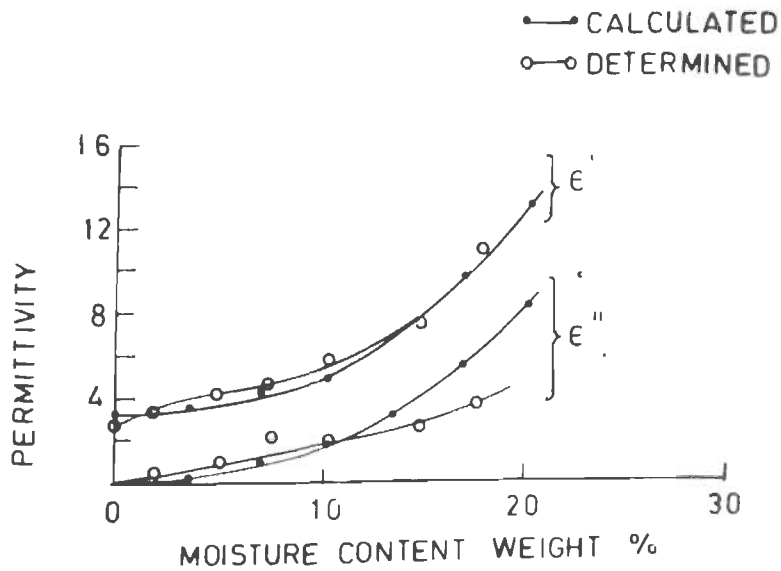


Fig. 2 Experimentally determined and calculated values of complex permittivity of sandyloam soil at 8.97 GHz

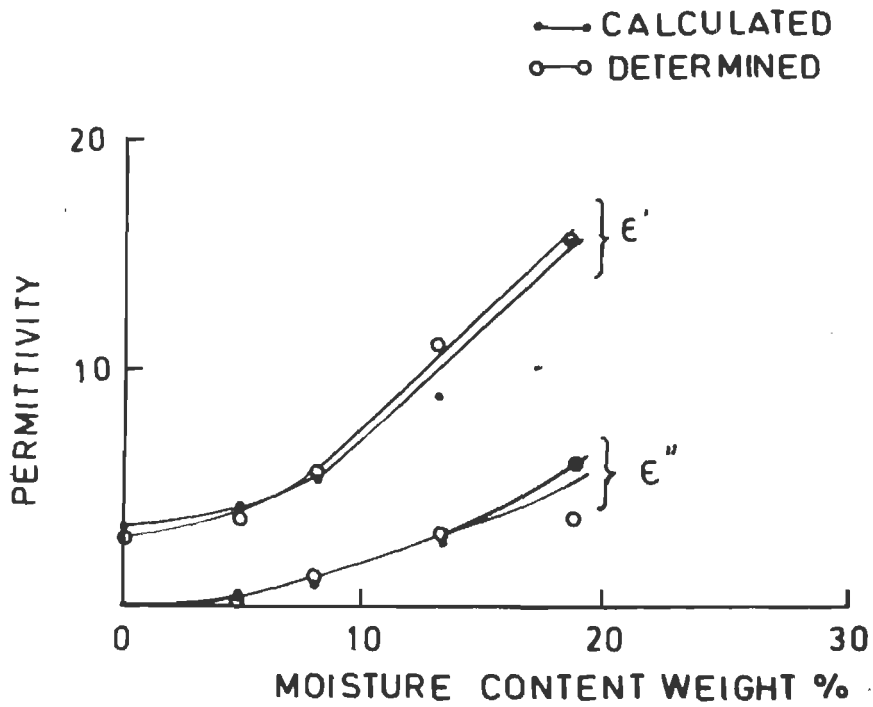


Fig. 3 Experimentally determined and calculated values of sandyloam soil at 19GHz

Table 1
The Characteristics of the Soil used for Dielectric
Constant Measurements

Soil type	Soil texture (%)			Computed wilting point cm^3/cm^3
	Sand	Silt	Clay	
Sandy loam	85	8	7	0.08

Table 2
Emissivity of Sandy-loam Soil for Different Moisture
Contents Calculated from Experimentally Determined
and Calculated (Model) Values of Dielectric Constants

8.97 GHz			19 GHz		
Moisture content (%)	Emissivity		Moisture content (%)	Emissivity	
	Exp.	Model		Exp.	Model
0.00	0.93	0.92	0.00	0.93	0.92
-	-	-	1.57	0.91	0.91
4.77	0.90	0.89	4.60	0.88	0.89
7.93	0.83	0.84	7.26	0.85	0.85
-	-	-	10.00	0.82	0.83
13.26	0.71	0.75	14.61	0.75	0.74
18.69	0.64	0.63	17.62	0.69	0.68

0.93 to 0.71 for the moisture content 0-13%. The decrease in emissivity with moisture content is due to increase in permittivity which causes a total increase in reflected energy and thereby a decrease in emitted energy.

CONCLUSIONS

The conclusions resulted from this study are as follows:-

- 1) The laboratory measured permittivity and dielectric loss of soil with moisture content at microwave frequencies may be used for interpretation of remotely sensed microwave data.
- 2) The real part ϵ' of dielectric permittivity of dry soil samples from present and previous measurements is 2.88 while the empirical model of Wang and Schmugge gives $\epsilon' = 3.25$ at $W = 0$. This affects ϵ' of soil-water mixture at low W and hence may cause a change of $2 - 5^\circ \text{K}$ in brightness temperatures.

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QUANTIFICATION OF SOIL MOISTURE THROUGH PASSIVE MICROWAVE REMOTE SENSING

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ABSTRACT

Though Remote Sensing is currently possible in the three regions of electromagnetic spectrum, namely visible, thermal and microwave, quantitative study of soil moisture is fruitful only in the microwave region. A review of the work carried out (both theoretical and experimental) in India and abroad has been summarized in this paper. It also gives an account of the work being undertaken by the authors at the Centre of Studies in Resources Engineering, Indian Institute of Technology, Bombay.

INTRODUCTION

Soil moisture is one of the essential parameters for agriculturists and hydrologists. It is also a useful information for meteorologists. The microwave emission characteristics of soils greatly depend on soil moisture which, in turn, depends on various physical properties of soil. The microwave emission will be modified by the surface roughness, soil cover and atmospheric constituents. Therefore, a multifrequency approach may lead to fruitful results in the quantification of soil moisture.

Various laboratory, field, airborne and satellite data analyses indicated beyond doubt a definite correlation between soil moisture percentage and the microwave emission. It is clear from the publication of Njoku and Kong (1977) that even the vertical profiles of soil moisture and physical temperature will be possible to be determined from satellite platforms by multi-microwave frequency approach. However, detailed investigations into the accuracy of such estimates and applicability of the models in the context of Indian environmental conditions are required to be carried out.

Here, an attempt is made to summarize the salient theoretical models proposed by various authors and the results of the experiments by various investigators. The summary includes the work done by the authors of this paper which has been published in international journals and presented in international and national symposia. The proposed plan of work

being carried out by the authors has also been projected.

A microwave radiometer measures the thermal emission from the surface. At these wavelengths, the intensity of the observed emission is essentially proportional to the product of the temperature and emissivity of the surface (from Rayleigh-Jeans' approximation). This product is commonly referred to as brightness temperature (T_B). The net brightness temperature measured by the radiometer is a sum of contributions from sky temperature T_{sky} , soil temperature T_{soil} , and atmospheric temperature T_{atm} and is given by

$$T_B = t[r \cdot T_{sky} + (1-r) T_{soil}] + T_{atm} \quad \dots 1$$

where r is the surface reflectivity and t is the atmospheric transmissivity. The first term is the reflected sky temperature which depends on wavelength and atmospheric conditions. The second term depends on soil emissivity and the third term is the contribution from the atmosphere between the surface and the receiver. For land-based studies, the influence of the atmosphere can be neglected and, therefore, the T_B measured by satellite-borne sensors is essentially the T_B of soil.

THEORETICAL MODELS

Planck's law of radiation emission states that all objects whose physical temperature is above 0°K will emit radiation at all wavelengths. The extent of emission from soil depends on the dielectric constant of soils which is a strong function of its moisture content. Therefore, thermal microwave emission from soils is generated within the soil volume. As this energy propagates upward through the soil volume from its point of origin, it is affected by the dielectric gradients along the path of propagation. In addition, as the energy crosses the surface boundary, it is reduced by the effective transmission coefficient which is determined by the dielectric characteristics of moist soils.

The emission from the soil surface can be expressed as

$$T_B = \int_{-\alpha}^0 T(z) \alpha(z) \exp \left[\int_z^0 (z') dz' \right] dz$$

where $T(z)$ is the temperature profile and $\alpha(z)$ is the absorptivity as a function of depth which depends on moisture content.

A direct solution of the above equation is very difficult to obtain and often numerical techniques are employed for this purpose.

To develop numerical models for microwave emission

characteristics of soils, with different vertical profiles of moisture and physical temperature, it is generally assumed that the soil can be sliced into a number of stratified horizontal layers, each layer characterised by its mean physical temperature, mean dielectric constant and mean permeability. The dielectric constant can be calculated theoretically for given the characteristics of soils.

Each stratified soil layer emits radiation in both upward and downward directions. This radiation will undergo reflection, transmission and attenuation by the surrounding layers. This process will continue for all the layers. A cumulative effect of such multiple phenomena finally leads to a resultant emission into air at the soil-air boundary.

Stogryn (1970) formulated the solution for the brightness temperature in terms of a two-point boundary problem by solving second order ordinary differential equations together with the evaluation of an integral. Later Tsang et al (1975) extended the propagation matrix formulation (Kong 1975) and solved for the brightness temperature of a stratified medium.

Burke et al (1979) presented an emission model based on the radiative transfer equations. Moisture and temperature gradients are represented by step functions across soil layers of infinite thickness. The model appears 1) to provide physical insight into the significance of the data, 2) to be in reasonable agreement with radiometric observations, and 3) to require relatively little computer time. The formula given by Burke et al (1979) is as follows.

$$T_p(1^+, \theta_0) = \sum_{i=1}^N T_i \exp - (\gamma_i(\theta_0) \Delta Z_i) \times$$

$$(1 + R_{p, i+1}(\theta_0) \exp - (\gamma_i(\theta_0) \Delta Z_i))$$

$$\prod_{j=1}^i (1 - R_{p, j}(\theta_0)) [\exp(- \sum_{j=2}^i \gamma_{j-1}(\theta_0) \Delta Z_{j-1})]$$

REVIEW OF THE EXPERIMENTAL INVESTIGATIONS

The experimental investigations in microwave remote sensing can be summarized into three categories namely; i) ground-based, ii) air-borne, and iii) satellite-based.

Ground-Based Investigations

This comprises laboratory and field experiments. Most notable of them are the experiments conducted by Poe et al (1971), Blinn and Quade (1972), Schanda et al (1978), and Newton (1977). The important conclusions of the various experiments is that the lowest emissivity of the moist soils is

only 0.6 though much less value is expected theoretically. This is due to the roughness of surface which generally has a tendency to increase the effective emissivity. The brightness temperature dependence on frequency, look angle, polarization, soil moisture, soil cover, and roughness have been investigated. However, there is a need to repeat such experiments to arrive at definite conclusions.

Aircraft Experiments

There are not many detailed aircraft investigations with microwave sensors. The results from the 1975 aircraft over irrigated agricultural fields are presented by Chaudhury et al (1979). The important conclusions are:

1. The T_B response to soil moisture depends on the soil texture.
2. The vegetative canopy acts as an absorbing layer whose effect will depend on the amount of vegetation and wave length of observation.

The above conclusions were further confirmed by the aircraft experiments of Basharinov and Shutko (1978) and Kirdiashev et al (1979).

Satellite Experiments

Not much rigorous work is reported in literature on the results of satellite data analysis. However, the attempts made by McFarland (1976) and Eagleman et al (1976) showed definite correlation between brightness temperature and soil moisture in spite of various limitations of the data. The results obtained through the analysis of Bhaskara-I and II satellite data have been summarised below.

SUMMARY OF THE WORK CARRIED OUT IN INDIA

India entered into the field of passive microwave remote sensing by launching Bhaskara-I Satellite during the year 1979 with radiometers operating at 19.1 GHz and 22.235 GHz frequencies. Though these frequencies give attention to atmospheric studies, its ability to extract soil moisture information has been demonstrated through publications in International symposia proceedings.

Gopalan et al (1980) made an attempt to analyse Bhaskara-I microwave brightness temperature data in terms of temporal signatures of various land covers. Aruna and Shah (1979) generated brightness temperature and emissivity maps of India taking into account the seasonal effects on the data.

As 19.1 GHz is very close to water vapour absorption band (22.235 GHz), Rao et al (1983a) developed quasi-statistical

model to correct T_B at 19.1 GHz for atmospheric water vapour influences with the help of the measurement at 22.235 GHz.

With a view to study soil moisture over Indian sub-continent, Rao et al (1983b) adopted statistical approaches to analyse Bhaskara-II microwave data acquired during Feb. 1983. There was an indication for the possibility of gross study on soil moisture, but definite conclusion could not be drawn as the wet snow signature resembles the signature of moist soils.

Subsequently Rao et al (1984a) made another attempt to resolve the problem of mixing of snow data through a geographical threshold and obtained the brightness signatures which are reproduced below.

Table 1
Radiometer Signatures
(Brightness Temperatures are in $^{\circ}\text{K}$)

	R1 (31.4 GHz)	R2 (19.35 GHz)	Corrected R2 (19.35 GHz)	R3 (22.235 GHz)
1. Complete data				
Sea peak	165 ± 7	140 ± 7	134 ± 8	183 ± 6
Land peak	265 ± 6	246 ± 6	246 ± 7	260 ± 4
2. Excluding snow/ice				
Sea peak	165 ± 7	142 ± 8	134 ± 8	183 ± 6 197 ± 6
Land peak	265 ± 7	245 ± 6	243 ± 7	260 ± 4
3. Snow/ice regions	228	213, 227, 237	215	229
4. Moist soil range	210-276	211-256	217-261	225-270
5. Snow/ice range	217-249	201-245	198-245	215-260

From the above table, it was concluded that 19.1 GHz T_B data responded to soil moisture variations.

The analysis of data acquired during March-June 1982 by Rao et al (1984 b) has shown single peak corresponding to average moisture conditions indicating that there were no surface soil moisture variations during summer months as expected. However, the analysis of individual pass data indicated reasonable amount of decrease in T_B when the pass was over water bodies.

PLAN OF WORK BEING CARRIED OUT AT CSRE

As reflected by the theories of Stogryn (1970) and Burke (1979), the effective brightness temperature depends on the soil moisture and physical temperature profiles. Also it can be seen that the depth where the maximum emission takes place depends on the frequency of observation. Therefore, it will be possible to estimate the vertical soil moisture through multi-frequency approaches and by adopting inversion statistical profile techniques. With this in view, the following programme of work is planned.

1. The microwave emission from soils mainly depends on dielectric properties and temperature. These parameters are functions of depth of the soil and therefore vary from point to point in the soil. Therefore, it is proposed to develop theoretical models for:
 - a. The frequency dependence of the total microwave emission from soils.
 - b. The vertical profile of moisture content of soils by studying the emission at different frequencies.
 - c. The effective depth upto which the soil moisture information can be obtained.
2. The microwave emission from the soils will be modified by the surface roughness, soil cover etc. Hence study of the percentage dependence of these parameters as a function of frequency, polarization etc. is planned.

CONCLUSION

The field of microwave remote sensing for soil moisture studies is multidisciplinary in nature. Therefore, the authors express their desire to collaborate with any organisation/agency interested in this field of research.

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APPLICATION OF VISUAL REMOTE SENSING TECHNIQUES FOR EXTRAPOLATED SOIL MAPPING OF ALIGANJ TEHSIL, UTTAR PRADESH

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ABSTRACT

Conventional reconnaissance survey was conducted for the Etah, Jalesar and Kasganj tehsils of Etah district Uttar Pradesh, but the fourth tehsil Aliganj could not be surveyed.

With the setting up of the remote sensing centre in All India Soil & Land Use Survey Organisation, the systematic visual interpretation of the LANDSAT imagery and FCC was taken up for salt-infested Etah district. The reconnaissance soil map of the 3 tehsils furnished reliable ground truth to correlate image characteristic viz. tone, colour, texture, pattern, association, etc. It was then translated into an FCC-based image interpretation key and a soil mapping legend, which helped to prepare a reconnaissance soil map of Aliganj tehsil. The remote sensing extrapolation techniques for mapping and classification of soils of recent and old flood plain and dunes of Aliganj tehsil, Etah district are discussed.

This attempt demonstrates a new use of remote sensing technology for covering gaps in the National soil mapping and further postulates, that the available soil map could be advantageously used for interpreting similar adjoining areas.

INTRODUCTION

With the establishment of the Remote Sensing Centre in the All India Soil and Land Use Survey, LANDSAT imagery and false colour composites (FCC) were largely employed in mapping soils and land use. Training in India and abroad convinced the merits of the synoptic view and added advantages of the multirate and multispectral nature of imagery for soil and land use mapping. During the last decade several Indian studies have shown the usefulness of imagery for soil mapping (Singh 1979, 1980, Venkataratnam 1980, Manchanda and Hilwig 1981, Murthy et al 1982, Singh and Subramanian 1982, Karale et al 1982).

Our organisation is primarily engaged in soil and land use survey in the Centrally Sponsored River Valley Projects (RVP's) and some special projects in the non-RVP areas. In past, one project of reconnaissance survey of salt-affected Etah district

of Uttar Pradesh was undertaken but had to be abandoned after completing 3 of the 4 tehsils, because of the policy constraints. The reconnaissance soil map of the 3 tehsils was published for the official use (R. No. AGRI 530). The unsurveyed Aliganj tehsil has been always a hurdle to present the soil and land resource data on the district level. This gap was completed by wisely utilizing the available ground truth in the form of the reconnaissance soil map of the 3 tehsils for formulating image interpretation key and for translating Aliganj tehsil imagery into a most needed and useful reconnaissance soil map at 1:250,000 scale. This attempt demonstrates a new use of remote sensing technology for covering gaps in the National soil mapping and further postulates that the available soil map could be advantageously used for interpreting similar adjoining areas.

PHYSICAL SETTING

Geographically, the Etah district of Uttar Pradesh lie between 27°18' and 28°02' north latitude and 78°59' east longitude and covers about 4.44 lakh hecatres area of the Indo-Gangetic plain. It is made up of 4 tehsils namely Jalesar, Etah, Kasganj and Aliganj and enjoys a semi-arid monsoonic climate. The mean annual rainfall is 692 mm with slight tehsil-wise variations. The temperature regime is hyperthermic with 25.7°C as mean annual temperature. In land use, nearly 68 per cent area is cultivated, of which 75 per cent area is under irrigation mainly by canals and at places supplemented by tube wells, open wells and tanks.

There is not much of natural vegetation, as much of the area is under cultivation for centuries. The common Kharif crops are sorghum, pearl millet, rice, black gram (mash), green gram (moong) and pigeonpea (arhar) and Rabi crops are wheat, barley, mustard, pea, gram and sugarcane.

RECONNAISSANCE SOIL SURVEY

A reconnaissance soil survey was conducted for Jalesar, Etah and Kasganj tehsils of Etah district and soil association map was prepared by adopting standard methods (Soil Survey Manual, 1971). Representative soil series profiles were studied and soil samples were analysed as per the methods suggested in Soil Taxonomy (USDA 1975). Topographically, the landscape of Etah district is a vast, nearly level alluvial plain with the following three perceptible forms which are further divisible into 9 facets with characteristic soil series.

The salient features of each soil series are given below:

Recent Flood Plain

Kachlaghat series (swales): Very deep, greyish brown to dark greyish brown, calcareous, sandy loam to loam, stratified soils - Typic Ustifluvent.

Shahpur series (ridges): Very deep, greyish brown to yellowish brown, sandy soils - Typic Ustipsamment

Old Flood Plain

Akbarpur series (old levees): Very deep, yellowish brown to dark brown, loamy sand to loam, non-calcareous, well-drained soils - Udic Haplustalf

Naurangabad series (peripheral basin): Very deep, greyish to yellowish brown, non-calcareous sandy loam to loam, moderately well-drained soils-Udic Haplustalf.

Malawan series (local depression basin): Very deep, greyish brown to dark grey, sandy loam to clay loam, non-calcareous, poorly-drained soils - Aeric Ochraqualf.

Hasanpur series (peripheral basin): Very deep, light brownish grey to greyish brown, sandy loam to clay loam with Kankar layer - Typic Natrustalf.

Sakit series (peripheral basin): Very deep, greyish to light brownish grey, calcareous, sandy loam to loam, saline-sodic soils - Typic Natrustalf

Kazinangla series (peripheral basin): Very deep, greyish brown, sandy loam to loam, moderate to well-drained soils with calcic horizons - Typic Haplustalf

Sand Dunes

Bhoorh series (sand dune/dunal plain): Very deep, yellowish brown to dark yellowish brown, sandy soils - Typic Ustipsamment.

AN APPROACH FOR AN EXTRAPOLATED SOIL MAPPING

The reduced reconnaissance soil map on 1:250,000 scale, the soilscape features described above, the general knowledge about the area, particularly the crop calendar, months of flooding, and the changing scenario of the salt-infested lands were utilized in image interpretation. Besides, the criteria in the Manual of Remote Sensing (Estes and Simonett 1975) and other guidelines provided by Singh (1979) and Hilwig (1980) were utilized in the interpretation of the LANDSAT MSS bands 5 and 7 and false colour composites of bands 4, 5 and 7 of two

scenes of path no.156 and row 41 (February 11, 1973 and August 16, 1977). The August scene showed abundance of water and helped to demarcate flood prone and water logged area and cropped area. On the contrary, the February scene showed only remnant features of water logging and extensive hues of red colour. The superimposition of both scenes and by adopting subtraction techniques together with reconnaissance soil map - a key to identify different facets of lands supporting specific series was framed (Table 1). With the help of this image interpretation key and local knowledge, the subscene of the unsurveyed Aliganj tehsil of Etah district, Uttar Pradesh was translated into "A Reconnaissance Soil Map of Aliganj Tehsil" (Fig.2). In soil associations, the concept of major (75%) and minor (25%) helped to further workout the individual soil series area. Table 2 displays the extent of soil series in the 3 tehsils of Etah district, Uttar Pradesh by two different techniques: (1) Conventional reconnaissance survey, and (2) Remote sensing techniques. Besides, it also includes the extent of soil series in Aliganj tehsil mapped by extrapolated techniques. This, thus furnishes the requisite site-specific information on soils. Since knowledge of productivity potential and problems of each soil series of Etah district are well known (R.No. AGRI-530), it is now possible to plan soil-based agricultural developmental programme for hitherto unsurveyed tehsil through the remote sensing techniques.

RESULTS AND DISCUSSION

Experience gained in the image interpretation of the two temporal FCC scenes of August 1973 and February 1977 have been projected in Fig.1 and displays a soil scape of Etah district, Uttar Pradesh. It exhibits broad physiographic divisions into recent and old flood plain and sand dunes. Further subdivision was attempted by employing image interpretation criteria viz. shape, size, association, colour, tone, texture, etc. into smaller facets corresponding to soil series or association of series. Temporal image characteristics have been very interesting and provided useful keys to differentiate one from another.

In India, the month of August is characterised by heavy rains causing floods, filling up of the depressional areas with water, whereas highlying areas are cropped. Similar supporting observations have been observed in the August FCC scene. Overall, almost entire scene was marked with the bluish tinge in the recent flood plain and basins of the old flood plain, except the levees and the sand dunes, which had the brownish red and light red colour, respectively, implying cultivated crops. This corroborates with the finding of Hilwig (1980) that in the wet/hot season in India, July imagery is useful for interpretation of drainage pattern, wetlands (Tarai) etc. while the February scene in moist/cool season is good for interpretation of land use with crops such as wheat and

Table 1
Visual Image Interpretation Key for Soil Mapping
based on False Colour Composite Scenes of
August 1977 and February 1973

Sr. no.	Soil series & associations	Physio-graphy	Land use/ Land cover	FCC August tone	February FCC tone	Size and shape texture
KH-SP	Kachalaghat (75%) Shahpur (25%)	Recent point bar complex	Partly cultivated	Reddish blue Fluish white with reddish brown mottle	Light reddish brown white with reddish mottles	Irregular Coarse
KH	Kachalaghat	Swales	Cultivated	Reddish blue	Light reddish brown	Irregular Medium
SP	Shahpur	Recent levees	Partly cultivated	Bluish white with reddish brown mottles	White with reddish mottles	Linear Medium
A	Akbarpur	Levees	Cultivated	Brownish red	Dark red	Linear Fine
A-S	Akbarpur (75%) Sakit (25%)	Levees and basins	Partly cultivated	Brownish red Bluish white	Dark red & white	Irregular Coarse
S-A	Sakit (70%) Akbarpur (30%)	Basin and levees	Mostly fallow	Bluish white & Brownish red	White & Dark red	Irregular Coarse

S	Sakit	Basin	Fallow	Bluish white	White	Irre- gular Irre- gular blue Linear	Smooth Medi- um Medi- um
S-H	Sakit(75%) Hasanpur (25%)	Basin	Partly cultivated	Bluish white & faint brown in Kharif	Whitish grey with streaks		
M	Malawan	Basin	Partly cultivated	Bluish with dark brown mottles	Bluish dark red		
S-M	Sakit(75%)	Basin	Mostly fallow	Bluish white & with dark brown mottles	Whitish Bluish dark red	Irre- gular um	
B	Bhoorh	Sand dune	Partly cultivated	Light red	White	Rounded/Fin- Linear e	
B-A	Bhoorh (75%) Akbarpur (25%)	Dunal Plain	Cultivated	Light and brownish red	White & dark red mixed	Rounded/Coa- Linear rse	

Table 2
Comparative Study of Extent of Soil Series in Etah
District, Uttar Pradesh by Different Techniques:
Reconnaissance Soil Survey & Visual Interpretation
of Multidate False Colour Composites

Sl. no.	Soil series	Symbol	Results of reconnaissance survey of three tehsils			Results of visual image interpretation of three tehsils			Extrapolated soil mapping of Aliganj Tehsil		
			Area (ha)	Per cent		Area (ha)	Per cent		Area (ha)	Per cent	
1.	Akbarpur	A	130219	41.9		159015	51.2		56167	42.1	
2.	Bhoorh	B	23659	7.6		24911	8.0		14265	10.7	
3.	Hasanpur	H	24902	8.0		19803	6.4		2021	1.5	
4.	Kazinagla	K	3360	1.1		-	-		-	-	
5.	Kachlaghat	KH	30662	9.9		25348	8.2		32226	24.2	
6.	Malawan	M	15890	5.1		20819	6.6		2972	2.2	
7.	Naurangabad	N	3602	1.2		-	-		-	-	
8.	Sakit	S	46438	14.9		42125	13.6		3031	2.3	
9.	Shahpur	SP	9263	2.0		17439	5.6		16345	12.2	
	Miscellaneous river bed		22734	7.3		1269	0.4		6344	4.8	
			310729	100.0		310729	100.0		133371	100.0	

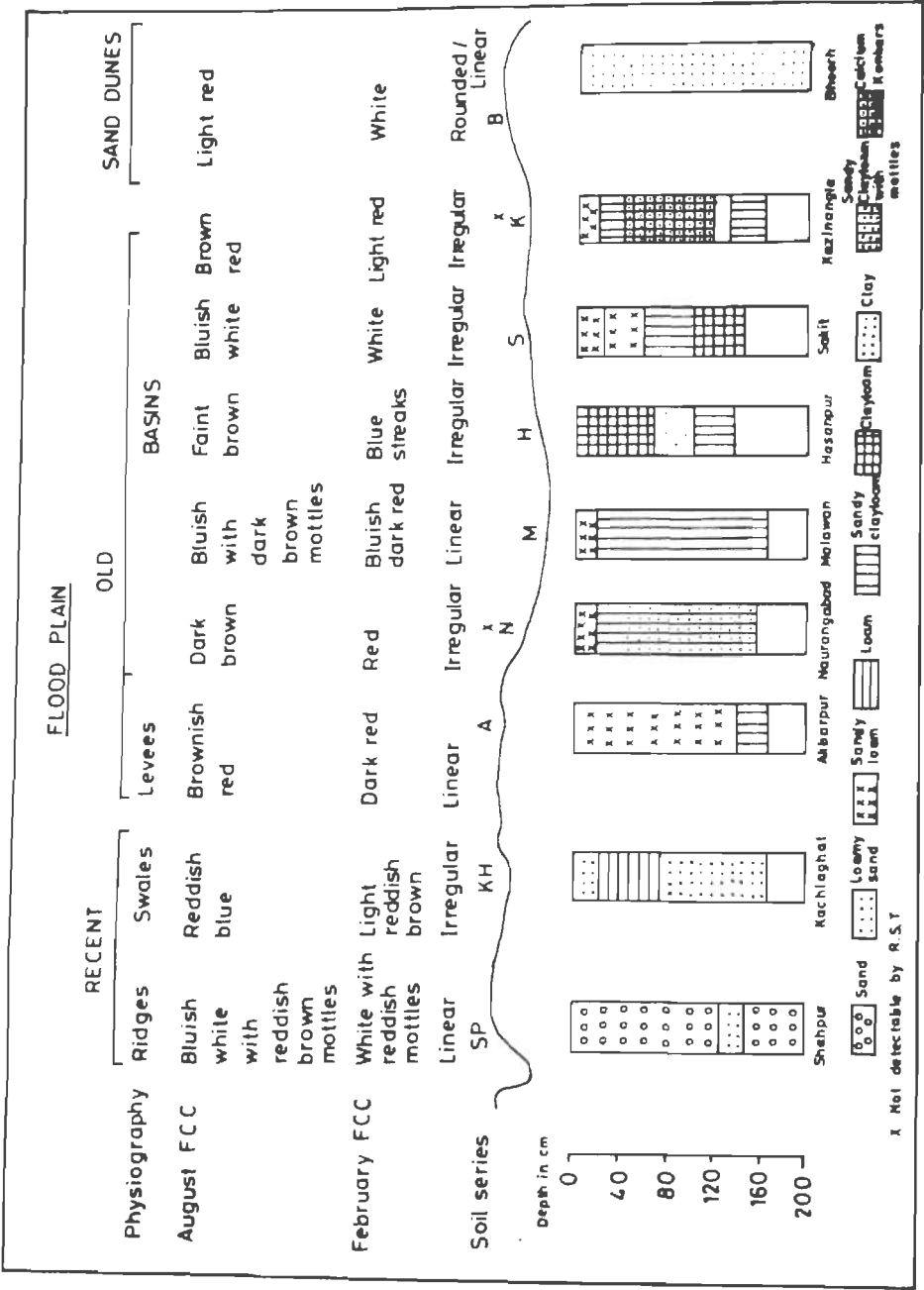


Fig. 1 Soilscape of Etah district as viewed on multilate false colour composites

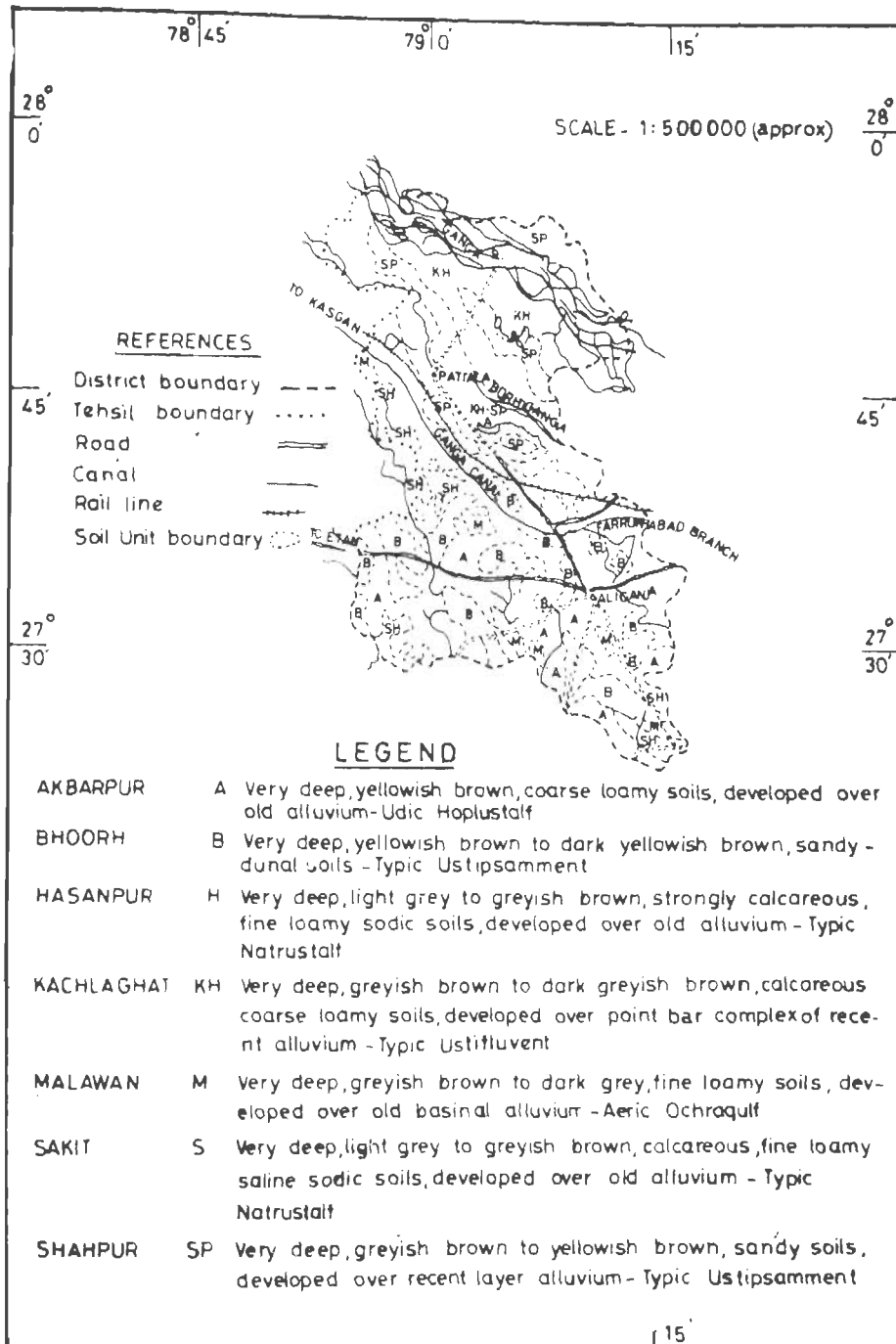


Fig. 2 Soil map of Aliganj tehsil of Etah district (U.P.)

sugarcane. Ample irrigation facilities and cool season transforms Etah landscape into a vast wheat bowl of India. Almost all non-saline non-alkali coarse loamy soils with irrigation facilities are put to wheat cultivation. The look of February FCC scene is a replacement of the blue colour by an exhilarative red mask all over the scene with shrinking of river courses and diminished sizes of wet areas into linear roundish bluish streaks. Conspicuously, whitish greyish areas appear to have increased in February scene. This whitish colour is associated with 3 different kinds of soils : (1) saline-alkali soils (Sakit series - benchmark soils, (2) sand dunes (Bhoorh series), and (3) point bar/ridges (Shahpur series-sandy) and all can be distinguished by shape, size and association and also by subtraction technique as both the latter landforms are under Kharif crops recording brownish red colour during August but salty areas maintain bluish white/white complexion in both the seasons. Similar observations have been reported by Singh and Venkataratnam (1980) while studying identical landscapes in Haryana and Uttar Pradesh.

In basins, five soil series are met with (Fig.1). Depressional areas are occupied by Malawan series while the peripheral areas having alternate dry and wet moisture have Hasanpur and Sakit soil series both differing only in degree of sodicity. Former is put to occasional paddy cultivation in Kharif and wheat in Rabi season. Slightly above and below the levees are the Naurangabad and Kazinagla soil series and have moderately good amplitude for both kharif and rabi crops. In most cases, it is difficult to segregate these two series from the double cropped extensive levee soils of Akbarpur series.

COMPARATIVE STUDY OF DIFFERENT TECHNIQUES

Table 2 furnishes the series-wise extent by two techniques: (1) conventional, and (2) remote sensing. By and large, there appears to be a good agreement and results are promising in favour of remote sensing techniques. It, however, records about 9 per cent higher area in Akbarpur series and 3.6 per cent higher in Shahpur series. The higher figures in Akbarpur may possibly be due to inclusion of Kachlaghat and Naurangabad series in image interpretation. As explained elsewhere, all the three series have similar image colours in both the seasons. On the other hand, similar colours of saline-sodic Sakit and Bhoorh series pose problems of separation from Shahpur series. Remote sensing technique records very low areas over the conventional method in miscellaneous and river bed category and this possibly may be due to omission of areas under habitation, road, canal, distributary, etc.

With this presage, the extent of soil series data of Aliganj tehsil computed by remote sensing technique can thus be

dependable for all practical purposes and agricultural planning. Comparatively, Aliganj tehsil records equal percentage of good agricultural land with just 3.4 percent area under saline-sodic soils as against 22.9 percent in the other three tehsils. Thus, agriculturally Aliganj tehsil appears to be better than its neighbouring three tehsils of Etah district.

CONCLUSIONS

1. The available soil maps can be used to prepare image interpretation keys for soil mapping and could be advantageously used to extrapolate soil mapping in the gaps or in similar adjoining areas.
2. The temporal false colour composites help to delineate broad physiographic zones. Local knowledge of crop calendar, irrigation potential, soil characteristics and their problems help to delineate further soil based units.
3. With the ground truth and local knowledge, it is possible to map series/subgroups of their associations by remote sensing techniques.

ACKNOWLEDGEMENTS

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SOIL RESOURCES DATA FOR LAND USE PLANNING - A CASE STUDY USING AERIAL PHOTO-INTERPRETATION TECHNIQUES

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ABSTRACT

Soil survey was conducted in the Hansat area of Bharuch district (Gujarat) under the Ukai right bank canal command using the black and white aerial photographs of 1:25,000. The physiographic units encountered in the area are mainly buried pediment, alluvial plains, pointbar complex, flood plain and valleys. The valleys and buried pediment have been further divided, based on the topographic variation and the extent of salinity. The soils under each mapping unit have been classified as per the Soil Taxonomy (USDA 1975).

Out of the total area of 21203 hectares, 15.3 per cent of the area is slightly salt-affected, 12.3 per cent moderately salt affected, and 9.6 per cent is strongly salt-affected. The mapping units of the area have been evaluated for their suitability for various land utilization types such as summer paddy, wheat, moong, vegetables and groundnut by using both soil and land characteristics such as soil texture, drainage, inherent fertility (C.E.C), pH, E.C., salinity, relief, slope, flooding hazard, erosion etc. as the criteria.

INTRODUCTION

The State Government of Gujarat has established an Area Development Authority for the integrated development of the Tapi basin. Under the above development programme the waters of the Tapi river were first utilized for the development in 1968 by constructing a weir at Kakrapar. Initially, the irrigation was based on the live storage of water. Later a reservoir was constructed 24 km upstream from Kakrapar at Ukai and water for perennial irrigation was made available in the Kakrapar system from 1971-72. Two main canals were constructed along with the reservoir, one among them is the Ukai right bank canal, which has been planned to irrigate the areas north of Ulpad, and Ankaleswar and Hansat Taluka of Bharuch District. The area under study falls in the above command. After the introduction of irrigation in the command areas, soil salinity and waterlogging problems have come up in some of the areas.

Therefore, it was proposed to take up soil survey using serial photo-interpretation technique with the idea to identify the problem areas such as saline and alkali areas and also to evaluate the suitability of different mapping units for different land utilization types such as summer paddy, vegetables, wheat, moong and ground nut.

GENERAL DESCRIPTION OF THE AREA

The survey area is located within the latitudes of $21^{\circ} 25'30''$ and $21^{\circ} 32'$ and longitudes of $72^{\circ} 45'$ and $72^{\circ} 37'30''$. The location of the area is given in Fig. 1. It covers an area of 21203 ha. The underlying rock is basalt with intrusions of sedimentary rock at some locations. It is overlaid by thick sediments and is called buried pediment. The climate of the area is mainly humid sub tropical with 144.6 cm rainfall and with a mean annual soil temperature of 24.4° . The natural vegetation of the area consists of Babul (*Acacia arabica*) and the tiger grass (*Thysonobaena maxica*).

SOIL SURVEY METHODS AND TECHNIQUES

Soil survey was conducted using the aerial photointerpretation technique adopted by the Indian Institute of Remote Sensing as described by Shamacharya and Srinivasan (1972). Black-and-white aerial photographs of 1:25,000 scale were used for studying the areas. The soil profiles were described (FAO 1966) and classified according to Soil Taxonomy (USDA 1975). Soil samples were taken from each of the representative soil profiles and were analysed for physical and chemical properties according to standard methods (Jackson 1958, Piper 1966).

A base map of the area was prepared on 1:25,000 scale using the Survey of India toposheets. The soil boundaries from aerial photographs were transferred to base map photogrammetrically.

By adopting the concepts given by FAO (1976) for land evaluation various mapping units were evaluated for their suitability for different crops such as summer paddy, wheat, vegetables, moong and groundnut.

RESULTS AND DISCUSSION

The survey area has been divided into three landforms namely, buried pediment, alluvial landform and valleys. The above landforms were further divided into various physiographic units and subunits based on the topography and salinity. A

table showing the above unit along with the soil composition is given (Table 1). Some sample strips of the area are shown in Figs. 2a & 2b with their mapping units. The mapping units of the area have been evaluated for their suitability for five land utilization types, namely, summer paddy, wheat, moong, vegetables and groundnut using soil and land characteristics such as texture, drainage, inherent fertility, pH, E.C. salinity, relief, slope, flooding hazard etc. as the criteria. The soil and land characteristics of the project area are given in Table 2. Table showing the evaluation of different mapping units for different land utilisation types is given in Table 3.

The non-salt affected nearly-level buried pediments have the soil composition of Fine Typic/Entic Chromuderts and do not have any major limitation and are categorised as moderately suitable for all the crops under study.

Salt-affected nearly-level buried pediments have slightly saline alkali soils of Chromuderts great group and are grouped under moderately suitable category for summer paddy, wheat, moong and vegetables and as marginally suitable category for groundnut. Moderately salt-affected buried pediments have moderately saline soils of Chromuderts great group under marginally suitable for all the land utilization types under study. Strongly salt-affected nearly-level buried pediment (B123) have strongly saline Typic Chromuderts. They are rated as unsuitable for all the crops under consideration. Non-salt affected and salt-affected undulating buried pediments have Fine Typic Chromuderts without/with slight saline phase, respectively, and are grouped as moderately suitable for all the land utilization types.

Alluvial plains (A1) are gently sloping with Typic Hapludalfs/Dystric Eutrochrepts and have good internal drainage. They have the limitation of slightly high pH and are grouped under moderately suitable category (S2).

Pointbar complex (A2) has the soil composition of both Fine/Fine loamy Typic Eutrochrepts. It is grouped as moderately suitable category for all the land utilization types. Flood plains (A3) are seen mainly along the river Wandkhadi and have the soils with very stiff clays. They are flood prone and are included under the non-suitable category for moong, vegetables and groundnut. It is rated as moderately suitable for summer paddy and as marginally suitable for wheat (S3).

Salt-affected valleys (V1) are grouped as unsuitable class for summer paddy, wheat, moong, vegetables and groundnut due to the salt problems. Non-salt affected valleys with fine loamy Aquic Udorthents/Eutrochrepts are grouped as moderately suitable for summer paddy. However, they are rated as marginally suitable for wheat and unsuitable for other crops due to severe problems of flood hazard, relief and slope. A table showing the extent of problem area is given in Table 4. Out of the total area of 21203 ha, 15.3 per cent is slightly

Table 1
Physiography and Soils-Hansat Area

Mapping unit	Physiography	Soil composition	Area (ha)
B	Buried pediment		
B1	Nearly level		
B11	Non-salt affected	Fine Typic Chromuderts Fine Entic Chromuderts	10757
B12	Salt affected		
B121	Slightly salt affected	Fine (slightly saline) Typic Chromuderts Fine (moderately saline) Typic Chromuderts	2899 2899
B122	Moderately salt affected	Fine (moderately saline) Aquic Chromuderts Fine (moderately saline) Typic Chromuderts	2505
B123	Strongly salt affected	Fine (strongly saline) Typic Chromuderts	231
B2	Undulating		
B21	Non-salt affected	Fine Typic Chromuderts	748
B22	Salt affected	Fine (slightly saline) Typic Chromuderts	355
A	Alluvial land-scape		
A1	Plain	Fine loamy Typic Haplu-dalfts	768 768
A2	Point bar complex	Fine loamy Typic Eutrochrepts Fine Typic Eutrochrepts	152
A3	Flood plain	Fine Typic Chromuderts	211
V1	Salt affected	Fine loamy (alkali) Aquic Udorthents	1710
V2	Non-salt affected	Fine loamy Aquic Udorthents Fine loamy Aquic Eutrochrepts	320 320
Miscellaneous (settlements, canals, roads etc)			548
Total			21203

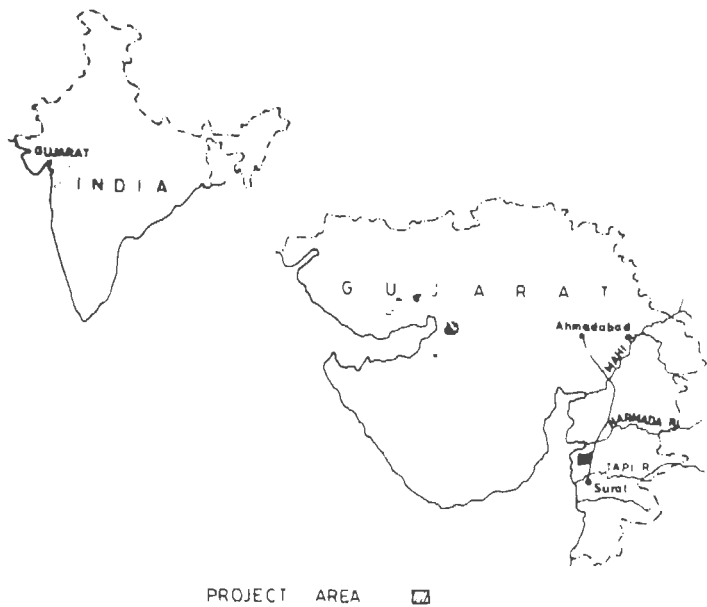


Fig. 1 Index map of Hansat area

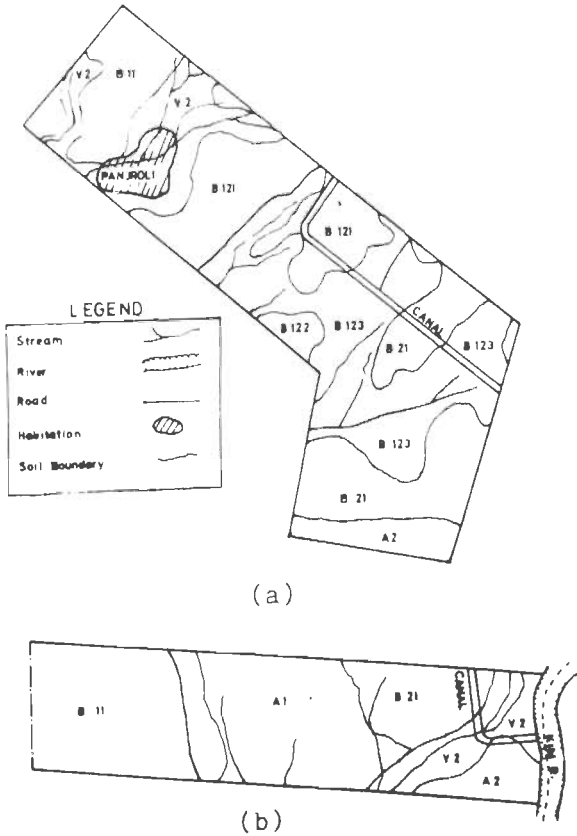


Fig. 2 Sample strip of (a) village Panjroli (b) Village Elav

Table 2
Land Qualities of the Mapping Units-Hansat Area

Mapp- ing unit	Texture	Drainage	Flood- ing hazard	Inher- ent ferti- lity	Relief	Slope	pH	E.C. mmhos/ cm	Extent of salinity
B11	Clayey	Mod.well	Low	High	Normal	Nearly Level	8.2	0.40	Nil
B121	Clayey	Imperfect	Medium	High	Flat	Level	8.3	3.00	Slight
B122	Clayey	Imperfect	Medium	High	Flat	Level	8.1	4.00	Moderate
B123	Clayey	Imperfect	Medium	High	Flat	Level	7.8	8.20	Strong
B21	Clayey	Imperfect	Medium	High	Normal	Undu- lating	8.2	0.4	Nil
B22	Clayey	Imperfect	High	High	Normal	Undu- lating	8.3	3.0	Slight
A1	Fine loamy	Mod.well	Low	Medium	Normal	Gently sloping	7.8	0.50	Nil
A2	Fine loamy	Mod.well	Low	Medium	Normal	-do-	8.0	0.45	Nil
A3	Fine loamy	Imperfect	High	High	Flat	Level	8.1	1.00	Nil
V1	Fine loamy	Poor	Very high	Medium	Concave	Gently slop- ing	8.5	0.9	Strong (alkali)
V2	Fine loamy	Poor	High	Medium	Concave	Gently slop- ing	7.3	0.29	Nil

Table 3
Relative Suitability of Mapping Units for Summer Paddy,
Wheat, Moong, Groundnut and Vegetable in Hansat Area

Symbol of the map- ping unit	Physiography	Suitability for different				
		Summer paddy LUT-1	Wheat LUT-2	Moong and vegetables LUT-3 and 4	Groundnut LUT-5	Poten- tial LUT
B	Buried pediment					
B1	Nearly level					
B11	Non-salt-affected	S2	S2	S2	S2	1,2
B12	Salt-affected	-	-	-	-	-
B121	Slightly salt- affected	S2	S2	S2	S3	1,2
B122	Moderately salt- affected	S2	S3	S3	S3	1
B123	Strongly salt- affected	N	N	N	N	Nil
B2	Undulating	-	-	-	-	-
B21	Non-salt-affected	S2	S2	S2	S2	1,2
B22	Salt-affected	S2	S2	S2	S3	1
A	Alluvial landscape	-	-	-	-	-
A1	Plain	S2	S2	S2	S2	5,4
A2	Point bar complex	S2	S2	S2	S2	1,2
A3	Flood plain	S2	S3	N	N	1,2
V	Valley	-	-	-	-	-
V1	Salt-affected	N	N	N	N	Nil
V2	Non-salt-affected	S2	S3	N	N	1

Table 4
Nature and Extent of Salinity Problems in Hansat Area

S.no.	Nature of salinity	Mapping units	Extent of the area (ha)	% of the total area
1.	Slightly salt-affected	B121, B22	3254	15.3
2.	Moderately salt-affected	B1222	2505	13.4
3.	Strongly salt-affected	B123,V1	1941	9.6
Total			7700	38.3

salt-affected, 13.4 per cent is moderately salt-affected and 9.6 per cent is strongly salt-affected.

The potential land utilization types (crops) for all the mapping units have been given in Table 3. They are recommended for taking up in the respective land mapping units. The potential land utilization types for each mapping unit have been worked out based on the micro-level comparison among the various land utilization types with respect to their requirements of climate and other local conditions.

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**PROBLEMS OF WATERLOGGING AND SALINITY IN
THE IRRIGATED COMMANDS IN GUJARAT STATE
WITH A CASE-STUDY OF KAKRAPAR PROJECT**

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ABSTRACT

The hazards of waterlogging and/or salinity are inevitable in any perennial irrigation system as a result of excessive water application. The author has dwelt on the concept of waterlogging, its theoretical aspect, definition and other causative factors. He has also enumerated the main causes of such problems and the recommended remedial measures. The areas under various major and medium irrigation schemes, which have indicated water levels within 1.5 and 3.0 m are also given.

In the case-study of Kakrapar Irrigation Scheme in South Gujarat, the author has given full account of the types of soils, causes of waterlogging and has indicated the measures adopted by the State authorities so far.

The paper concludes with a caution that the menace of waterlogging needs to be identified well in advance and suitable preventive or curative measures need to be adopted in time to maintain the soil fertility.

INTRODUCTION

Construction of a dam across a river brings a 'Green revolution' in the area commanded by the scheme. Flow irrigation through canals supplements the moisture that falls short of the crop needs. Particularly, in the tropical countries like India, rainfall is restricted to the monsoon months of June to September and is often erratic. Usually the rains withdraw abruptly in the month of September, severely affecting the crop yields in the Kharif season (even upto 50%). Supplemental irrigation through river valley projects can make good this moisture deficit at this critical stage and facilitate maximum production of crops per unit of water applied.

Notwithstanding all the benefits, irrigation through canals is not an unmixed blessing, in as much as, its improper use and poor soil and water management lead to hazards of

waterlogging and/or salinity development. The lands which are once fertile become saline and alkaline and are ultimately rendered unfit for agriculture. The valleys of the Euphrates, the Tigris and the Nile, which once flourished, were rendered barren due to this malady. In India, the States of Punjab, U.P and the old Bombay State have been practicing canal irrigation for more than a century. Large tracts of lands went out of cultivation within a short period of the inception of these canals, due to waterlogging and/or salinity in these States also.

The hazards of waterlogging and/or salinity are bound to occur in any perennial irrigation system as a result of excessive water application. The causes for such problems of irrigated agriculture and the remedial measures thereto need to be carefully understood by the irrigation engineers, soil scientists, agronomists and the farmers themselves. Correct assessment and distribution of water alongwith proper soil-water management is the key for successful irrigated agriculture without damaging the arable lands.

As per the Agricultural Census, in 1970-71, out of an area of nearly 1.86 crore ha of land in Gujarat State, about 96 lakh hectares were under cultivation. Out of these, approximately 13 lakh ha received irrigation through various sources of which area irrigated through canals was nearly 3 lakh ha. There has been a rapid progress in the construction of various major, medium and minor irrigation schemes in the State and as per the assumption made by the National Commission on Agriculture, (1976), nearly 26 lakh ha of land in Gujarat State is likely to be brought under canal irrigation by the end of this century.

Problem of waterlogging in Gujarat was not severe since the major rivers were harnessed by weir schemes only. But with the construction of reservoirs like Shetrunji (1965), Ukai (1972), Kadana (1976), Panam (1978) and Dharoi (1979) enormous quantities of water are likely to be flown over the command areas and hence such problems of irrigated agriculture will have to be faced with great care. In fact the projects like Kakrapar and Mahi R.B. Command have already started showing indications of waterlogging and/or salinity in quite a sizable areas since about a decade.

CONCEPT OF WATERLOGGING , ITS DEFINITION, CAUSES AND REMEDIAL MEASURES

Plant Metabolism

Water in an optimum quantity, is a 'must' for the plant flora during all its metabolic activities. But in excessive quantity, it becomes enemical to the plant life. Carbon, oxygen, hydrogen, nitrogen, potash, phosphorous, calcium,

magnesium, sulphur and iron are the ten major elements which are essential for the plant growth.

The plant food in the form of soluble salts is dissolved in the capillary water and held in solution as films around the soil particles. Root hairs absorb the water and this food material by the process of 'Osmosis' and the 'selective capacity' of plants. The water is transpired through leaf pores and food material is assimilated for plant growth.

It is not only the water that is required by the plants, but the metabolic activities of plants depend upon other important factors like air, soil temperature and the quantity of organic matter present in the soil which, in turn, helps dissolution of plant food through organic acids.

Waterlogging Definition

When the rise in water table is caused to such an extent, that the root zone is saturated to effectively cut-off the normal circulation of the air within the soil, the soil is considered as waterlogged.

This results in the following:

- i. Bacterial activity is inhibited.
- ii. The availability of plant food material decreases.
- iii. Soil temperature is affected.
- iv. 'Osmosis' comes to a stand still due to imbalance in moisture conditions.
- v. Prolonged waterlogging conditions cause permanent damage to plants.

Harmful Depth to Water Table

The depth of water table at which it tends to make the soil waterlogged and harmful to plants depends upon the normal height of capillary fringe. The crop yield is adversely affected when the capillary meniscus surface rises within 2 ft. from ground surface (1962).

The normal height of capillary fringe is estimated as 5 to 8 ft. in the case of heavy soils and 3 to 5 ft. in the case of light and medium soils. When the capillary meniscus surface reaches within 2 ft. from ground, the conditions of waterlogging occur. Thus, in the case of heavy soils the waterlogging may start when the water table is even 10 ft. (8 ft. fringe and 2 ft. of meniscus) from the ground whereas in the coarse soils the waterlogging may occur when the water table is 5 ft (3' + 2') from ground. This indicates that any area having water table within 5 ft. (or 1.5 metres) can be considered as waterlogged.

Nature of Crops Grown

The advance effects of high water table also depend upon the nature of crops grown and depth of rooting. Deep rooted crops are easily susceptible to high water table than shallow rooted crops.

The upper limits for some of the crops are given below:

i.	Wheat	3' - 4'
ii.	Cotton	5' - 6'
iii.	Rice	2'
iv.	Sugarcane	3'
v.	Fodder crops	4'
vi.	Lucerne	7' - 8'

Factors Inducting Waterlogging and/or Salinity

The factors causing rise in water table after the introduction of flow irrigation through canals are as follows:

- i. Losses due to conveyance of water through unlined channels.
- ii. Inefficient methods of irrigation leading to deep percolation below the root zone.
- iii. Too frequent irrigation resulting in excessive losses through fields.
- iv. Blocking of the natural underground drainage due to impermeable barriers like rock, clay pan, or a caliche layer.
- v. Non construction of field water courses leading to uncontrolled irrigation.
- vi. Inadequate natural drainage such as streams or rivulets, leading to stagnation of surface runoff.

Problem of salinity in soils in irrigated areas is linked up with water logging, particularly so in arid and semiarid regions.

Remedial Measures

- i. Preventive measures
Preventive measures are those which prevent over-irrigation and thereby help in reducing the damage. They are enumerated as follows:
 - a) Lining of canals
 - b) Pre-irrigation soil surveys
 - c) 'x' limits for perennial irrigation
 - d) Block system

- e) Volumetric supply
- f) Adjustment of cropping pattern
- g) Varabandhi
- h) Conjunctive use of water resources

ii. Curative measures

Curative measures are those which effect to remedy the damage caused due to waterlogging and/or salinity. They are enlisted below :

- a) Surface drainage takes care of rainfall runoff and excess water on the soil surface.
- b) Subsurface drainage reduces water table and helps in improving subsurface soil condition.
- c) Pumping is resorted to when outfall conditions are poor.

The pre-requisite for the method of pumping is the good quality of underground water (to be pumped) otherwise the method becomes costly.

ASSESSMENT OF THE AREA OF WATERLOGGED & SALT-AFFECTED LAND IN

GUJARAT STATE

In Gujarat following measures are adopted to assess the extent of waterlogging and/or salinity in the irrigation commands.

- a) Observations of subsoil water table
- b) Pre-irrigation soil surveys
- c) Remote sensing technique

Observation of Subsoil Water Table

Observations of subsoil water table are being carried out since last two decades in almost all the major irrigation schemes during pre-monsoon (May) and post-monsoon (November) periods. The water levels are being observed from existing open dug-wells almost equispaced throughout the command area. The latest data available for such major schemes is given in Table 1.

The data reveals that the problem of waterlogging and/or salinity has already crept in Ukai L.B.C., Kakrapar, Mahi R.B.C., Shetrunji and Panam Schemes and the extent of areas coming under waterlogging/salinity are on the increase year by year. The rate of rise in water table in Kakrapar and Mahi commands has been recorded as 0.3 m per year.

Pre-Irrigation Soil Survey

All the projects in Gujarat viz. major, medium or minor are being covered by a systematic reconnaissance and detailed pre-irrigation soil surveys, as per criteria laid down in the IS-5510 of Oct 1969 and Soil Survey Manual IARI-1970. These surveys are based on the actual field observations and collection of data as well as the analytical results of soil and water samples, as laid down in the standard survey procedures. The land irrigability classification so arrived at gives an idea about the existing soil and land characteristics and their interpretation for various land uses under irrigation. Such land irrigability classification, in turn, helps in identifying areas which are likely to be affected by waterlogging after canal inception. In fact, an area of about 6000 ha in Shetrunji R.B. Command in Bhavnagar district could be identified as waterlogged even before the canal inception and remedial measures of a surface and subsurface drainage was implemented during 1964-65 successfully.

Remote Sensing

Multiband/Multiband LANDSAT satellite imagery from 1972 onwards were used to identify areas which are waterlogged and/or salt-affected with the help of Space Applications Centre (ISRO), Ahmedabad. The technique evolved included close and careful examination of the scenes covering Kakrapar (1982), Mahi R.B.C (1983) and Fatewadi (1984) commands and identifying (i) dark spots indicating water ponding (ii) high moisture areas indicating waterlogging and (iii) permanent vegetation indicating waterlogged lands infested with grasses like typha. Three papers have been published (Baldev Sahai et al 1986) so far at the various seminars held on Remote Sensing viz. at Dacca in Bangladesh (1982), Ahmedabad (1983) and Bhopal (1984). This technique can help to identify a smallest waterlogged area of even 5 ha on the earth.

A CASE STUDY OF KAKRAPAR IRRIGATION PROJECT IN SOUTH GUJARAT

The Project

With the construction of a weir at Kakrapar on the river Tapi in south Gujarat a gross area of 4.06 lakh ha was brought under the command since 1957-58 (Fig. 1). Although the Kakrapar weir was predominantly expected to cater irrigation during Kharif and Rabi seasons only, the areas under Bardoli, Kamrej and Chalthan talukas between the rivers Tapi and Mindhola have been getting water during all the three seasons through perennial river flow. With the construction of the second stage (viz. Ukai Reservoir) in 1972, quite a large area under the command of Kakrapar Project has been receiving waters perennially. The irrigation intensity which varied between 35

to 40 per cent before 1971 has now increased to 78.7 per cent during 1981-82.

Soils

Soil surveys in the Kakrapar Command were carried out during 1957-58 and land irrigability classification was arrived at. This classification was updated to 1978 pre-monsoon water table conditions (Fig. 2). The soils under the command are deep black clayey soils having 'montmorillonite' as the predominant clay mineral. They owe their origin to the (basaltic) Deccan trap rock occurring in the eastern hill range (viz. the Sahyadris). The detritus brought down by the west-flowing rivers formed this recent and subrecent alluvial deposits which are shallower in the east, becoming deep to very deep in the west. During their transport the soils got mixed up with the gritty material and hence the subsoils are comparatively coarser in texture. These montmorillonitic heavy soils have a very high potential fertility, high moisture holding capacity as well as high cation exchange capacity and can sustain increased crop production under irrigation. But, at the same time, the soils being slowly to very slowly permeable, have inadequate vertical and horizontal drainage. Moreover, they lie on a very slightly undulating land in the east, becoming flat to very flat towards the sea coast. Consequently, due to poor outfall conditions and impeded drainage, the soils need a very careful attention after the introduction of canal irrigation.

Crop Pattern Under Irrigation

Taking into consideration the soils, climatic conditions, existing cropping systems and the anticipated trends in cropping etc, a diversified cropping pattern was proposed for the Kakrapar Irrigation Project.

This proposed crop pattern provided an overall 15 per cent crops under perennials.

Development of Sugar Industry

In view of the suitability of the soils, climatic conditions and the availability of a reliable source of water through Kakrapar weir (and Ukai reservoir from 1972 onwards) there was a heavy demand for the installation of large number of sugar factories in the area under the command. The demand for the cultivation of sugarcane crop, therefore, increased rapidly. This crop needs water throughout the year and hence, but for proper soil and water management, the area is likely to get waterlogged soon. Such indications were first noticed in the second zone viz. between rivers Tapi and Mindhola, where the cane concentration started increasing very rapidly. By 1962-63 the area in this zone indicated high rate of rise in water table. In certain areas under Bardoli, Kamrej and Chalthan talukas, there was a significant increase in the areas having water table between 1.5 to 3.0 metres by 1971-72.

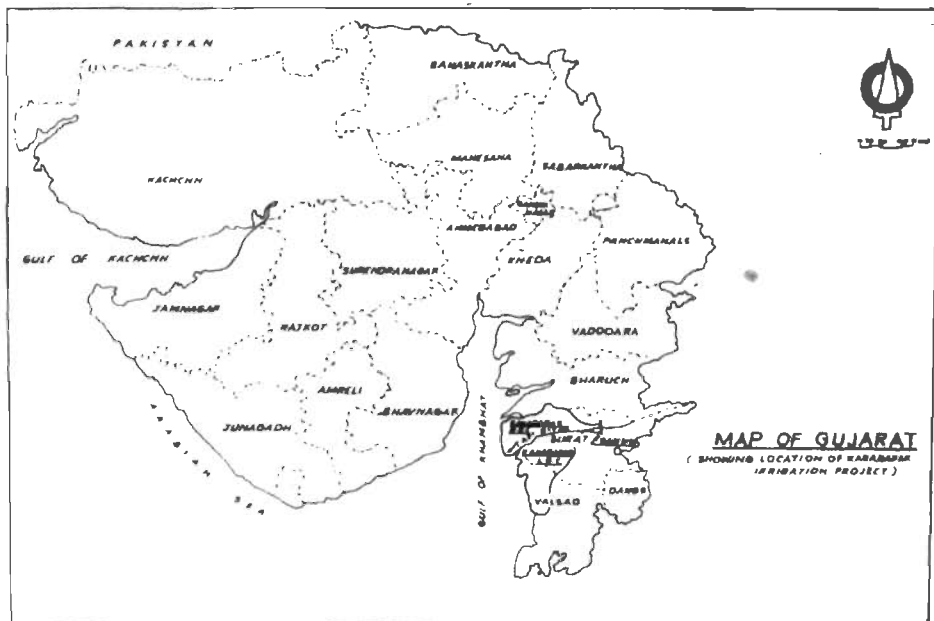


Fig. 1 Map of Gujarat showing the location of Kakrapar irrigation project

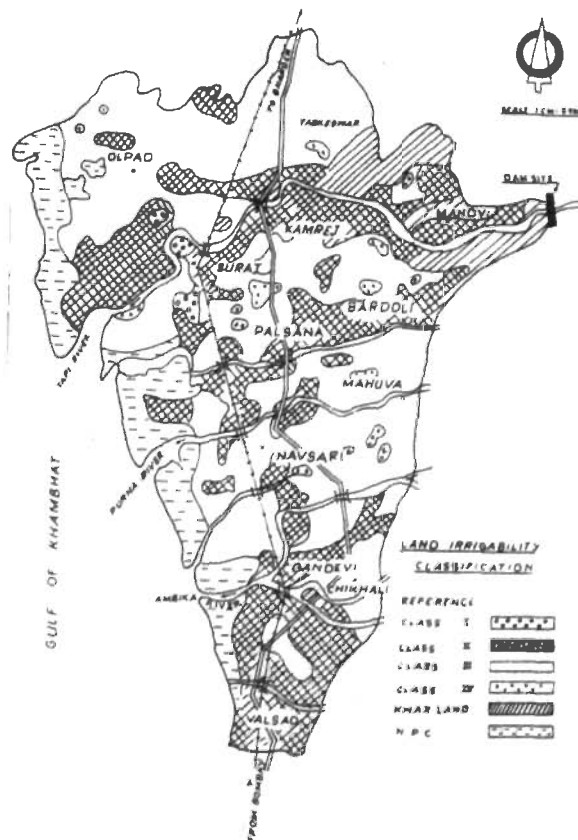


Fig. 2 The land irrigability classification map of the area under Kakrapar irrigation project

This has attracted the attention of authorities and detailed investigations for causes and remedial measures had to be undertaken.

Problems of Irrigated Agriculture

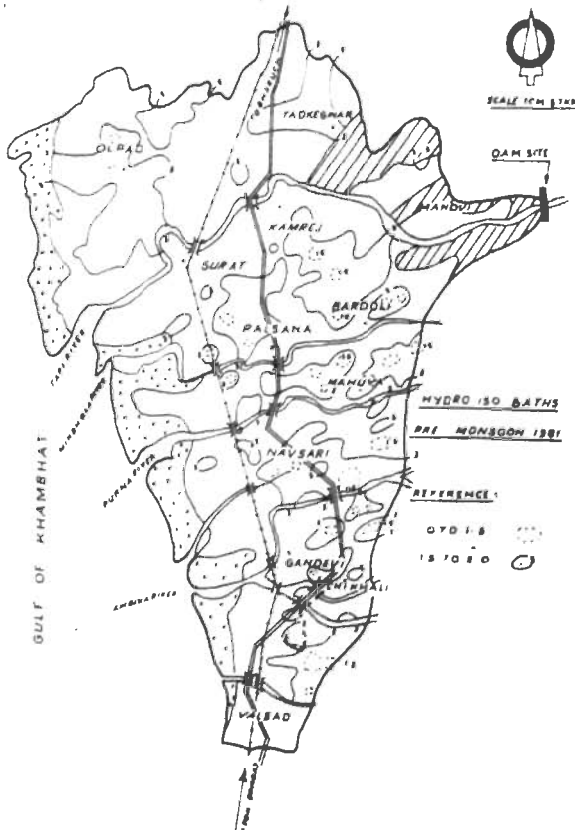
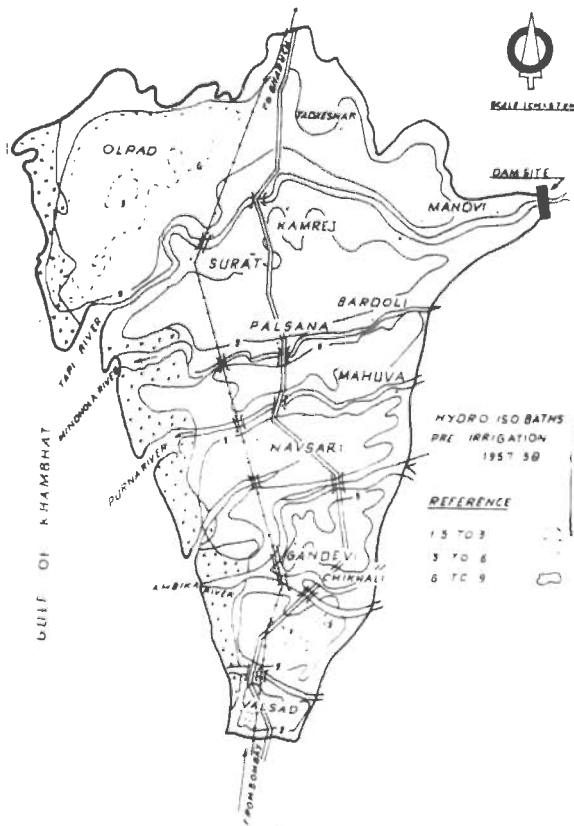
The area under the command of Kakrapar Project has been kept under observation for the behaviour of subsoil water table since 1960-61. The water levels are being observed for every post monsoon (May) and premonsoon (November) periods in about 1500 open dug-wells. The data for the period of 1980-82 as compared with that of pre-irrigation conditions (1957-58) is shown in Fig. 3 to 6 and is given in Table below.

Depth to water table from ground	Pre-irrigation 1957-58 area		Pre-monsoon 1981 area		Post-monsoon 1981 area		Pre-monsoon 1982 area	
	ha	%	ha	%	ha	%	ha	%
0-1.5	Nil	Nil	4677	1.1	28926	71.0	7434	1.9
1.5-3.0	1036	0.3	63536	15.6	185102	45.7	74735	18.4
3.0-6.0	41417	10.2	185767	45.8	89570	22.1	180764	44.5
6.0-9.0	363555	89.5	71717	17.8	22099	5.5	62664	15.5
Kharland	-	-	64449	15.9	64449	15.9	64449	15.9
Area not properly commanded	-	-	15862	3.8	15862	3.8	15862	3.8
	406008	100.0	406008	100.0	406008	100.0	406008	100.0

It can be presumed that an area of 7534 ha developed water table within 1.5 m till pre-monsoon 1982 (see Fig. 6). During pre-irrigation conditions (1957-58), there was not a single ha of land within this range. (see Fig. 3). Similarly, 74735 ha (18.4 per cent) of command developed water table between 1.5 and 3.0 m during pre-monsoon 1982 as compared to only 1036 ha (0.3 per cent) during pre-irrigation condition. The detailed study of Kakrapar command reveals that in the second and the third zone (viz. between the rivers Tapi and Purna) considerable areas developed high water table. Some of these areas have now indicated problems of waterlogging and/or salinity.

Causes

The studies carried out in the Kakrapar Command revealed that the main causes to induce waterlogging were as follows:



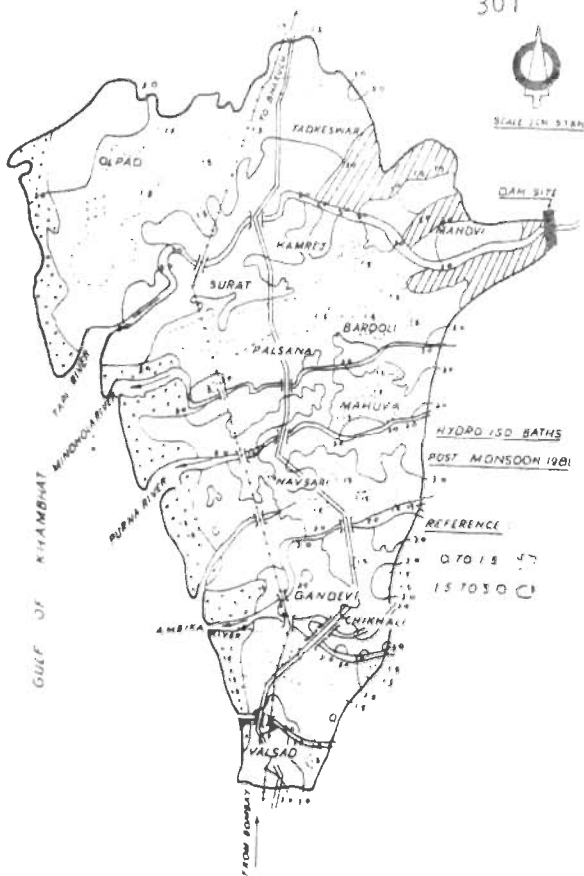


Fig. 5
Hydro-isobaths observed
during post-monsoon of
1981

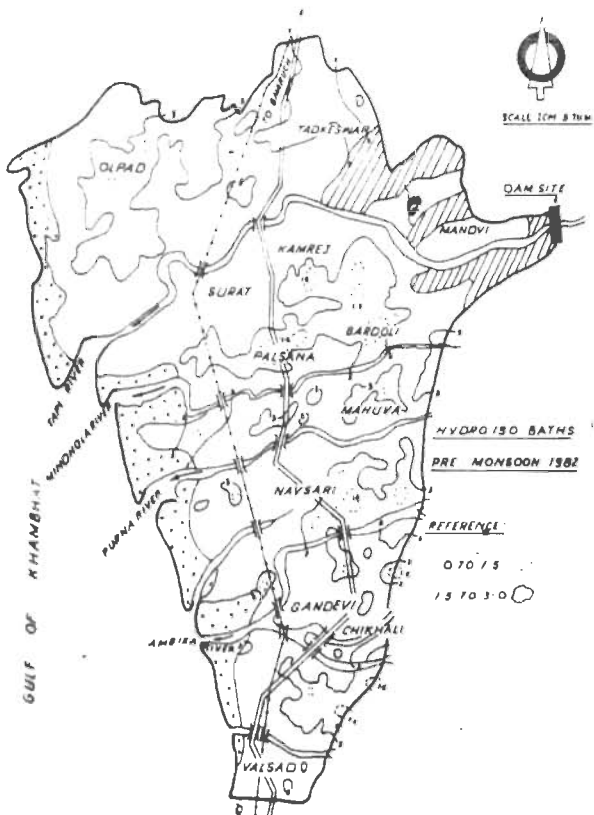


Fig. 6
Hydro-isobaths observed
during pre-monsoon
of 1982

- i. Losses due to conveyance of water through unlined channels.
- ii. Heavy concentration of sugarcane cultivation in the factory areas.
- iii. Too frequent irrigation resulting in excessive losses through fields.
- iv. Inadequate natural drainage such as streams and Nallas.
- v. Heavy clayey soils of the command with flat gradient, imperfect internal drainage, and poor outfall conditions.
- vi. In the high water table areas the waterlogging is accompanied by salinity in soils.

The problems enumerated above needed immediate attention of the administrators as well as the farmers themselves.

Remedial Measures

The Government of Gujarat has been alive to problems of waterlogging and/or salinity in the Kakrapar command. The following preventive measures have been tried:

a) Soil Studies

Pre-irrigation soil surveys help to indicate the areas likely to be affected after irrigation through canals and serves as a reliable preventive measure. The land irrigability classification map was updated to 1978 pre-monsoon water level conditions (see Fig. 2). This map facilitated to identify the locations which need immediate attention.

b) 'x' Limit Surveys

These surveys bring out the capacity of the soils under every minor, sub-minor or even an outlet, to respond to sugarcane cultivation. Surveys for such 'x' limits were carried out in the zones 2 and 3 of Kakrapar command during 1964 and 1970. These surveys have indicated that the maximum capacity for bearing sugarcane in the Kakrapar Command (Zone 2 and 3) varied between 15 to 25 per cent. But the actual areas under sugarcane had increased to even more than 50 per cent in certain minors. The main cause of the damage was thus found out as excessive cane cultivation in the command. The cane concentration under canal irrigation thus needs to be reduced to 'x' limits immediately.

c) Geohydrological Investigations

The study of Kakrapar command through geohydrological surveys indicated that the substrata in the eastern portion of the command as well as near the sea-coast has bands of tertiary rock series. The central bowl comprises heavy clay in the upper surface, followed by lenses of coarser and clayey alluvial deposits, alternately. The water levels in this central region only has, therefore, indicated waterlogging and/or salinity

conditions. The study further revealed that "pumping" of underground water through clusters of shallow tube wells could be the solution to this problem.

d) Master Plan for Surface Drainage

Master plan for surface drainage has been prepared for Kakrapar Command. This includes remodelling of existing drains and excavation of additional drains. This Master Plan is estimated to cost about 10.6 crores of rupees. The surface drainage has, however, limitations for available outfall conditions which are inadequate in this alluvial tract. Hence, it is expected to take care of surface runoff only. The surface drainage will have, therefore, to be supplemented with subsurface drainage and pumping wherever necessary.

e) Pumping as a Remedial Measure

The geohydrological and soil-topographical investigations in the Kakrapar command have indicated that the problem of waterlogging and/or salinity in Kakrapar needs to be tackled by "Lift-cum-flow" method only. The Government of Gujarat has, therefore, now undertaken further studies on these lines. These studies will be accompanied by additional anti-waterlogging measures like reduction in perennial crops, proper assessment and distribution of water to different seasonal crops through varabandhi system, implementation of Drainage Master Plan and reclamation measures, wherever, necessary. Fortunately, the quality of water in the eastern and central portion of the command is good and it can be used for irrigation, if applied through the available distribution system.

f) Modernisation of the Scheme

The Govt. of Gujarat has undertaken modernisation of four blocks under the Kakrapar command through World Bank Aid. The projects undertaken and their extent are as follows:

Sr.no.	Name of block	Area (ha)
1.	Karanj	9,820
2.	Hajira	28,200
3.	Surat Branch	57,450
4.	Umrath Branch	14,000
	Total.....	1,09,470

Under this modernisation scheme, the government aims at:

- i. Lining of canals upto a level of 8 ha block.
- ii. Varabandhi system to be adopted.
- iii. Remodelling and re-grading of existing canal system.
- iv. Revision of cropping pattern to suit availability of more water.
- v. Carrying out O.F.D. works including soil conservation, drainage, etc.

These measures will not only increase the efficiency but will also help reducing the losses due to percolation in the canals and fields through proper soil-water management and is expected to result in reducing and/or preventing the problems of waterlogging and salinity.

g) Leaching Trials

An area of about 600 acres (375 ha) near village Umrath in Navsari taluka which lies near the sea-coast was affected by high salinity and water logging. A pilot research project was undertaken in an area of about 14.5 ha out of the 375 ha in 1965. The area was protected by a coastal bund and was provided with various types of surface drainage systems. The pilot experiment included different sizes of drain, depth of drains and spacing. The lay out, therefore, comprised field drains, intercepting drains, carrier drains and a tail outfall drain, alongwith the required roads and water courses. Canal water available from the Kakrapar weir was used to leach these heavy montmorillonitic clayey soils through various leaching trials and amendment measures like gypsum, Ca-ammonium nitrate, organic measures, green manures and their combinations. These leaching trials continued for a period from 1965 to 1974. The results indicated that high salinity in soils which ranged from 5 to 6 per cent (10 mmhos/cm) could be reduced to less than 0.5 per cent through 72 inches (180 cm) of sweet water applied in six inundations. The treatment of gypsum with organic manure or green manure proved to be very successful.

The experiment has been quite useful in determining the leaching requirements in these montmorillonitic clayey soils and these results can be applied elsewhere in areas having such type of clayey soils. The drain spacing advocated after the experiment was of 100 m in heavy soils.

h) Remote Sensing Technique

With the help of LANDSAT multiband and multiband imagery available from 1972 onwards at SAC/ISRO, Ahmedabad, the areas affected by waterlogging, salinity and permanent green vegetation (like Typha) could be identified. Such spots were located on the command map and were corroborated with the data of water level observations being taken by the Irrigation Department. It was concluded that the locations of the waterlogged and/or salt-affected areas could be easily identified through LANDSAT imagery and followed up by a ground check, to confirm such areas in the field. The remote sensing

Table 1
Statement showing Areas indicating High Water Table in Major
Irrigation Schemes in Gujarat State

Sr. No.	Name of project	G.C.A (ha)	No. of open dug wells observed	Area				Period of observation pre-monsoon (May)
				0 to 1.5 (ha)	1.5 to 3.0 (%)	1.5 to 3.0 (ha)	3.0 to 4.5 (%)	
1.	2.	3.	4.	5.	6.	7.	8.	9.
1.	Mahi R.B.C.	2,93,860	1473	3820	1.3	43785	14.9	1983
2.	Kakrapar	4,06,008	1015	7534	1.9	74735	18.4	1982
3.	Shetrunji RBC	29,150	510	-	-	1908	6.5	1981
4.	Shetrunji LBC	30,161	521	21	0.1	615	2.0	1981
5.	Ukai RBC	85,875	377	40	Negligible	3275	3.8	1983
6.	Ukai LBC	1,21,392	446	1838	1.5	1134	9.3	1982
7.	Dantiwada	81,000	328	-	-	1870	2.3	1981
8.	Fatewadi	1,29,555	242	-	-	6628	5.1	1981
9.	Panam	62,750	250	-	-	175	0.3	1981
10.	Karjan	79,724	373	-	-	285	0.4	1983
11.	Damanganga	56,070	401	-	-	32	0.1	1983
				14,05,543	5,938	13853	0.94	144457 10.28

techniques were thus found to be quite useful in this respect. (Baldev Sahai et al 1982, Baldev Sahai et al 1985, Kalubarme et al 1983, Kalubarme et al 1985, Kalubarme et al 1986).

SUMMARY AND CONCLUSION

The problems of waterlogging and/or salinity in irrigated commands were not severe in Gujarat State since most of the major rivers were harnessed by weir schemes. However, after the construction of reservoirs on big rivers like the Shetrunji, the Sabarmati, the Mahi, the Tapi, the Panam etc enormous quantities of waters have now been made available perennially. Sequel to this, the problems of waterlogging and salinity have crept in the major projects like the Shetrunji, the Mahi, the Kakrapar, the Ukai and the Panam. The study of subsoil water table and that carried out through remote sensing indicates quite a sizable area (see Table 1) has come under high water table (viz. within 1.5 m and 1.5 to 3.0 m).

The paper describes a case study of Kakrapar giving the details of causes of waterlogging and the remedial measures adopted.

It is concluded that the problem of waterlogging is inevitable in any irrigation scheme where irrigation is available perennially. The causes of such a menace need to be identified in time by using the techniques of water level observations, remote sensing and soil surveys. The administrators as well as the farmers should wake up to the problem well in time and implement preventive or curative remedial measures to maintain the soil fertility.

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AGRICULTURAL EDUCATION, RESEARCH AND TRAINING IN GUJARAT

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ABSTRACT

The Gujarat Agricultural University has a mandate to take-up education, research and extension education activities in the State as per the Act. In Education under-graduate and post-graduate programmes in the faculties of Agriculture, Veterinary Science and Animal Husbandry, Agricultural Engineering and Dairy Technology are currently in progress. Besides, under-graduate programmes in the faculty of Home Science, Food Technology and Nutrition have also been initiated.

These activities of the University have helped to bring about considerable improvement in agriculture in the state. A brief account of the activities is given in this paper.

INTRODUCTION

Programmes connected with agricultural research, education and training are being conducted under the aegis of the Gujarat Agricultural University (GAU) since its inception in 1972. Research activities in the university are presently conducted in the fields of Plant Science, Animal Husbandry, Veterinary Science, Dairy Science and Agricultural Engineering through a network of 55 research centres/stations located in different agroclimatic zones of the State. Education in Agriculture, Veterinary Science & Animal Husbandry, Dairy Science, Home Science and Agricultural Engineering faculties is imparted through the following colleges.

Agriculture

1. B.A. College of Agriculture, Anand.
2. College of Agriculture, Junagadh.
3. N.M. College of Agriculture, Navsari.
4. College of Agriculture, Sardar Krushinagar.

Veterinary Science and Animal Husbandry

1. Gujarat College of Veterinary Science & Animal Husbandry, Anand.
2. College of Veterinary Science & Animal Husbandry, Sardar

Krushinagar

Dairy Science

1. Sheth M.C. College of Dairy Science, Anand

Home Science

1. ASPEE College of Nutrition, Home Science and Food Technology, Sardar Krushinagar

Agricultural Engineering

1. College of Agricultural Engineering and Technology, Junagadh

The extension education programmes are taken-up through the Krushi Vigyan Kendras, Sardar Smruti Kendras, Agricultural schools, Extension education institute, Home science schools, Livestock inspectors training, School of baking, Farm mechanic-cum-artisan training, Poultry training, Tribal training centre, Tribal upliftment project, Schedule caste upliftment project, Operational research projects, T & V System of training and Lab-to-Land programme, Surgical, clinical and gynaecological camps for cattle.

EDUCATION

During 1982-83, the College of Agriculture was established at Sardar Krushinagar. In addition, College of Veterinary Science & Animal Husbandry and College of Nutrition, Home Science and Food Technology also started functioning at Sardar Krushinagar during 1981-82. A total of 443 students were admitted to the agricultural faculty for Bachelor's degree, while 256 students graduated during 1983-84. In case of veterinary science and animal husbandry, 118 students were admitted to the course of B.V.Sc. & A.H. and 41 students got the Bachelors' degree. In the case of dairy technology, 64 students were admitted to the course, while 29 students were awarded degrees. The University has a post-graduate programmes in agriculture, leading to M.Sc. (Agri.) and Ph.D. degree in different disciplines. During 1983-84, 263 students were admitted to M.Sc. (Agri.) in Agriculture Faculty, whereas 96 students were awarded M.Sc. (Agri.) degree and 18 students were declared eligible for Ph.D. degree. M.V.Sc. and Ph.D. degrees are also offered in the disciplines of animal genetics and breeding, veterinary microbiology. Fourteen students were admitted to M.V.Sc. degree during the year. In dairy technology, four students were admitted to M.Sc. and 2 were declared eligible. The College of Agricultural Engineering started functioning at Junagadh in June 1984 with 30 students in the first year class. In education, emphasis has been on training the students in the relevant faculty so as to make

them useful to the farming community.

RESEARCH

The Gujarat Agricultural University conducts research on cereals, millets, pulses, cotton, tobacco, oilseeds, sugarcane, fruits and vegetables, forage, spices and medicinal crops etc. Besides special emphasis is laid on research in the disciplines of dry farming, water management, soil salinity, agronomy, plant pathology, agricultural entomology, soil science, agricultural economics, agricultural engineering, animal husbandry, animal nutrition and reproductive biology. As a result of intensive research effort, the University, since its inception, has released 86 improved varieties of different crops having better yield potential and quality characteristics. During 1983-84, nine improved varieties were released by the State Variety Release Committee for cultivation in the State.

A list of different crop varieties so far released through the research under GAU for cultivation in the State is given in Table 1.

Crop Science

Development of hybrids in bajra, castor and cotton have helped to improve the productivity of these crops in the State. With a view to tackle the emerging new problems, such as downy mildew in bajra, the University has evolved bajra Var. GHB-27, which has a high degree of resistance against downy mildew as compared to BJ-104 and CJ-104 released earlier. Efforts are in progress to evolve a high yielding ergot-resistant strain in bajra.

Rice crop accounts for 5 per cent of the gross cropped area and accounts for 14 per cent of the total foodgrain production in the State. During the last decade, seven high yielding varieties were released for general cultivation. These varieties mature in 100-135 days. Amongst the cultivators, traders and consumers, due to its high yield, good milling and grain quality. For coastal areas of the State a salt-tolerant variety has been developed. Rice variety GR-3 has been recommended for summer cultivation. Experimental findings have indicated a response to Zn and Fe application for increasing paddy yields.

In wheat, variety GE-1 released for unirrigated areas of Bhal region is found to be superior to existing varieties in yield and its seed does not mottle appreciably.

Table 1
Crop Varieties Released/Recommended by GAU from
1972-1984 (Upto 1st January, 1985)

			Total
1. Cereals			
Bajra	GHB-1399; GHB-27		2
Paddy	GAUR-1; GAUR-10; GAUR-100; GAUR-2; GR-3; GR-11; GR-4; GR-138-928; SLR 51214; GR-101.		10
Wheat	GAUW-10; GW-18; A-28; GW-40; Lok-1; GW-1; GW-2; GW-29.		8
Sorghum	CSH-5; CSV-3; GJ-108; CSH-6; CSH-8R; GJ-9, GJH-1; GJ-35; GJ-36.		9
Hill-millet	G.Nagli-1; G.Kodra-1; G.Vari-1; G.Nagli-2; G.Banti-1.		5
2. Oilseeds			
Groundnut	GAUG-10; GAUG-1; M-13; JL-24; GG-2.		5
Castor	GAUCH-1; GAUC-1.		2
Sesamum	G.Til-1		1
Mustard	Varuna (T-59)		1
Soybean	G.Soybean-1; G.Soybean-2.		2
3. Pulses			
Moong	PIMS-4		1
Urad	G.75; T.9		2
Moth	G.Moth-1.		1
Cowpea	G. Cowpea-1; V-16; G.Cowpea-2		3
Gram	ICCC-4		1
Guwar	HG-75		1
4. Cash crops			
Cotton	G.Cot.10; G.Cot.100; G.Cot.101; G.Cot.11; G.Cot.Hy.6; G.Cot.13; G.Cot.12; G.Cot.DH.7		8
Tabacco	GT-4; G.Calcutti T.1		2
Sugarcane	Co-6304; Co-6806; Co-A-7602		3
5. Spices & condiments			
Fenel	PF-35		1
Coriander	GAUC-1		1
Garlic	GAU.G-1; GG-10		2
Cumin	G.Cumin-1		1
Chillies	G.Chillies-1		1
Turmeric	Sugandham		1
6. Vegetable & fruit crops			
Brinjal	G.Brinjal-6; Junagadh Oblong;		3
Tomato	Junagadh Rabi		1
Bhinda	G.Bhinda-1		1
Muskmelon	GMM-1; GMM-2		2
7. Medicinal & aromatic			

plants		
Isabgul	G.Isabgul-1; G.Isabgul-2;	2
8. Forage crops		
Dharaf grass	G.Dharaf-1	1
Lucerne	G.Lucerne-1	1
Sorghum	G.Forage Sorghum-1	1

	Total.....	86

In addition to the recommendations regarding different sorghum hybrids such as CHS-5, CHS-6, CHS-8 R for different areas, University has developed an improved variety GJ-35 which is found to do well in Kharif. This variety has attractive grain and it is moderately resistant to shoot-fly, earhead worms and grain mould. For rabi cultivation, Gujarat Jowar-9 is recommended. Inter-cropping of sorghum with pigeon pea is found to be advantageous in South Gujarat.

In minor millets, improved varieties Nagli, Kodra and Vari were released for farmers in hilly areas.

In case of pulses, 11 improved varieties of different pulse crops grown in Gujarat were developed/recommended during the last decade. Recently a wilt-tolerant var. BDN-2 was recommended for the wilt-affected areas in the State which gives 16 per cent higher grain yield than local T-15-15. Investigations on different aspects such as microbiology and plant protection have also been extended to cover different pulse crops. Improved agro-techniques have also been recommended to the farmers. The gram varieties RS-244, JG-315 for irrigated conditions and GG-416, GG-234, JG-315 and GF-754 for dry areas have been found to be promising.

In oilseeds, four erect types and two spreading types were recommended for cultivation in the State. In weed management, Stomp and Ranstar have given promising results in controlling the weeds in Kharif groundnut. Considering the larger area coming under summer groundnut variety Gujarat-11 has been recommended for cultivation. This variety will fulfil the requirements of HPS as it has kernels of bold size. For summer groundnut, fertilizer and irrigation scheduling alongwith plant protection measures have been recommended.

Hybrid castor variety GAUCH-1 is grown extensively for which recommended agro-techniques are adopted by majority of the farmers. Gujarat til-1 (sesamum) released for cultivation is giving higher yield than Mrug-1 and Patan-64.

Farmers have adopted the recommended agro-techniques in mustard. As a result its yield has gone up substantially in recent years and area increased in North Gujarat and parts of Saurashtra.

With the development and release of new varieties and improved agro-techniques, Gujarat State has made impressive strides in cotton production both in terms of yield and staple length. For different cotton zones of the State, different types of cotton varieties suited to the area are released from time to time. Recently, a hybrid variety maturing early, giving better yields than H-4, superior in fibre strength and giving about 10 per cent better spinning count than H-4 was released. First budded cotton for perennial cultivation in tribal areas on marginal lands, in non-traditional cotton areas was also released. Cultivation techniques of cotton variety H-4 with ridges and furrows is recommended. Deshi hybrid DH-22 was recently recommended for cultivation as it is suited for all the four cotton zones in the State. This variety matures early by about two months than V-797 and Digvijay. Control measures for different cotton pests were recommended in the form of year round schedule.

In the case of tobacco, Gujarat Tobacco-5 (bidi-tobacco) and Guj. Tobacco-6 (Chewing) is under pre-release.

In sugarcane, CO-6671 early and giving 33 per cent higher, yield than CO-6806 was recommended for South Gujarat. CO-A-7602, being mid-late is superior to var. CO-419 and CO-6304 is also recommended for cultivation.

In chilli varieties, Gujarat chillies which yield 33 per cent higher than local variety was recommended. Fennel being one of the cash crops of North Gujarat a better yielding strain VC-14-3-3 is recommended for release. In the case of turmeric, new variety Sugandham was found superior in respect of quality and yield compared to local, which was better for inter-cropping in fruit orchards of South Gujarat.

In vegetations, research priority was given to work on brinjal, tomato, bottle-gourd, okra, cluster-bean, chillies, beans as per needs of the farmers. Improved varieties of above vegetables have been recommended to the farmers.

In dry-farming discipline, moisture conservation and other dry-farming techniques have been formulated. In fact, improved productivity of bajra, jowar, groundnut and rainfed crops has been a combination of use of high yielding varieties and dry-farming technology perfected in rainfed farming research in the GAU. Mixed cropping, companion cropping and contingency crop planning are some of the major thrusts in this programme which has gone a long way to stabilize the productivity of rain-fed farming at a reasonably high level in the State.

Water management is another field where GAU has achieved significant progress. Water requirement of important crops has been worked out and farmers are advised about the correct use of water for irrigating their crops. In fact, the techniques

formulated by the GAU are being demonstrated to the cultivators through operational research project in major irrigation areas.

As against the irrigation potential of 10.12 lakhs ha created by 79-80 in the State, actual utilisation was 5.29 lakh ha and it has been observed that the present distribution network involves considerable wastage of water. It is estimated that loss of water through seepage etc. may be of the order of 40 per cent. Gujarat has so far realized 35 per cent of the ultimate surface water resources as against 83 per cent of the ultimate potential of these resources.

The command area of some of the major irrigation projects has started facing problems of waterlogging and salinity. Efforts will therefore be made to evolve a more efficient system of water conveyance and management. This is particularly important since the investment in major irrigation projects is high.

Systematic efforts are also in progress to evolve and popularize new crop patterns, especially in command areas of major irrigation projects which can ensure more balanced crop profiles for the State as a whole and at the same time provide more attractive returns to the farmers.

Mango soft-wood grafting technique developed by the University is found successful for raising mango orchards in arid and semi-arid areas. Since the establishment of the University, the Department of Agricultural Engineering in the University has developed 8 implements/machines useful for suitable local conditions. In addition to this, recently Rural Engineering Department, Sardar Krushinagar has developed castor planter and potato planter for the use of the farmers.

The tool bar of these equipments can be used for attachment like indigenous plough bottom, bund former, sweeps, snowels, blades, seedings and fertilizing devices.

The technology for the preparation of instant tur dal powder has been developed. The "Instant Tur Dal Powder" is better than the conventionally prepared tur dal from the point of view of convenience and saving of time in cooking. It is acceptable with respect to taste, flavour and colour.

Animal Sciences

A strong base has been created for research in Veterinary and Animal Science to bring about all sided improvement in Kankrej and Gir cattle and Jaffarabadi, Surti and Mehsani buffaloes. The primary objective of this programme is to maintain an elite herd of the breeds which can be used for upgrading the local cattle and buffalo population in the state. It is observed that the milk production efficiency of the elite herd of cattle is about twice the local cattle population while in the case of buffaloes, it is about $1\frac{1}{2}$ time. Therefore, by

using the available germplasm and proper management techniques, it should be possible to bring about substantial step up in milk production of the local milk breeds.

In the all India Co-ordinated Research Project for Sheep to improve the production of wool in Patanwadi sheep, a cross-breeding programme with exotic breeds, namely Marino and Rambouillet has been undertaken. Cross-bred sheep is found to give better quality wool and higher production.

A programme for cross-breeding of Kankrej cattle with Jersey and Holstein is also in progress at Anand. Cross-bred cows with 62.5 per cent Jersey blood are found to give higher milk yield.

In the project on biological reproductive unit, techniques for heat detection in buffaloes have been formulated. These help in reducing the age of heifers at calving as well as calving interval.

Research in camel nutrition and genetic improvement in Kutchi camels is in progress.

In animal nutrition, findings pertaining to the use of non-traditional feeds, namely, seeds of Prosopis juliflora and other forest trees are of considerable value in reducing the feed cost.

A poultry unit has been established to develop suitable lines and economic poultry rations. This will help to reduce the feed cost of poultry raising.

In Dairy Science, efforts are underway to develop new milk products as well as methods for the preparation of Khova etc. Dairy technology unit has developed low cost 'Chullas' and also developed preservatives for dairy products for use by a common man.

EXTENSION EDUCATION

Gujarat Agricultural University has developed close linkages with the extension agencies in the State and it participates actively in the various extension activities conducted in the State. Entire responsibility of training the subject matter specialists and conducting monthly workshops in different zones of the State is shouldered by the GAU. Various extension education activities conducted by GAU are briefly enumerated here:

Agricultural Schools

The agricultural schools located at Anand, Bharuch, Chharodi, Dahod, Deesa, Dhari, Halvad, Jagudan, Junagadh,

Khedbrahma, Navsari, Vadodara and Vyara are engaged in imparting scientific and practical knowledge of agriculture and allied subjects through two years' diploma to the youths of the State. Each school has an admission capacity of 30 candidates per year.

Home Science School

The home science school located at Anand campus is engaged in imparting two years' diploma training to the farmers' daughters in various aspects of home economics, child care, food and nutrition, health and sanitation, civics, homemaking, agriculture, horticulture, kitchen gardening, etc. It has an intake capacity of 35 candidates per year. Only rural farm girls are admitted into the school.

Livestock Inspectors' Training

In order to make the veterinary services available at village level, there is a very heavy demand for the veterinary stockmen/livestock inspectors in the villages. In order to meet these needs, and to impart training to the veterinary stockmen/livestock inspectors so as to make them aware of the scientific development and practical aspects of animal husbandry and veterinary science, the Livestock Inspectors' Training Centre located at Sardar Krushinagar offers a course of 2 years' duration. The intake capacity of the Centre is 40 trainees per year.

Farm Mechanic-cum-artisan Training

The farm mechanic-cum-artisan training centres located at Anand and Junagadh are reorganized and strengthened by revising the course and strengthening the staff. The training is of nine months' duration and the sons of village artisans are admitted to the course.

School of Baking

The schools of baking located at Anand, Junagadh and Navsari impart training of 20 weeks' duration to the prospective and professional bakers for the development of baking industry in the area. It also aims at improving the nutritional standards of the community at large by introducing large varieties of nutritional and comparatively less expensive baked foods.

Bidi Tobacco Training

With a view to train the sons of tobacco growers in improved methods of tobacco cultivation, curing, marketing, the Bidi Tobacco Training Centre located at Anand Campus imparts training of nine months' duration. The intake capacity of the Centre is 30 trainees per batch. The programme also includes training personnel of Central Excise Department to familiarise

them with the practical aspects of bidi tobacco cultivation.

Poultry Training

The Poultry Training Centre located at Anand imparts 10 weeks' training in poultry production including management, nutrition, breeding, diseases, hatching, incubation and marketing of poultry products. The intake capacity of the centre is 30 trainees per batch and three such batches are organized each year.

Extension Education Institute

The Extension Education Institute established at Anand in 1962 prepares high quality professional teachers in the field of extension education to serve as instructors, professors, administrators, etc. The commercial banks and agro-based farms also avail of the facilities and the services of the Institute for their training programmes as and when required.

Training and Visit System

The University has accepted the responsibility of imparting training to the extension workers working under the Training and Visit System at various levels. The university is also actively associated with farm trials being conducted in the State in collaboration with the State Extension Department.

Krushvi Vigyan Kendras

The Krushi Vigyan Kendras at Deesa (Banaskantha) and Devgadhbaria (Panchmahals) have been started since February 1976 and January 1983, respectively, with the financial assistance from the Indian Council of Agricultural Research. They impart practical training to literate as well as illiterate farmers, farm women and farm youths.

Sardar Smruti Kendra

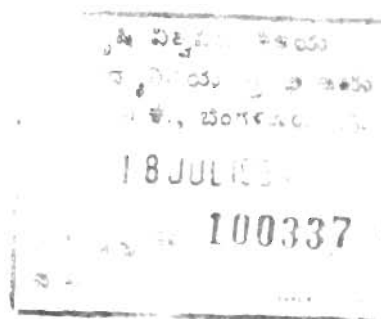
Sardar Smruti Kendras (SSK) are functioning at Anand, Navsari and Junagadh campuses. Each SSK consists of three units namely (a) Museum, (b) Information Centre, and (c) a Farmers Training Unit.

The University also undertakes programmes for the development of tribal areas by imparting training to tribal population in modern agricultural techniques as well as for scheduled caste upliftment.

Different programmes connected with agriculture conducted by the GAU have helped to improve the agricultural production in the State at an annual compound growth rate of 6.50 per cent. This is considered a satisfactory achievement.

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