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# Satellite Sensing of Irrigation Patterns in Semiarid Areas: An Indian Study

Areas irrigated by surface water could be distinguished from those irrigated with ground water by using single-date Landsat imagery, and temporal variations in the irrigated areas could be established from multidate satellite coverage.

ABSTRACT: *Landsat data have been used to identify the irrigation patterns in the semiarid southern districts of Tamil Nadu State in India. Areas irrigated by surface water could be distinguished from those irrigated with ground water by using single-date Landsat data. Temporal variations in the irrigated areas could be established from multidate satellite coverage. The complex cropping pattern, overlapping growth periods, and non-availability of suitable cloud-free satellite coverage, however, make it difficult to identify crop species. Photo interpretation and manual inventory methods using Landsat imagery could be advantageously used in the estimation of irrigated cropland acreage. The information in regard to the nature and extent of irrigated lands is needed to formulate meaningful water management policies in this semiarid area.*

## INTRODUCTION

AN INVENTORY of irrigated croplands is important for estimating agricultural production and for optimum management of available water resources for agricultural needs. Remote sensing techniques, using spaceborne sensors, can be gainfully employed in conducting such inventories. The repetitive coverage and synoptic view offered by Landsat (polar orbiting and sun-synchronous satellites) from an altitude of about 910 km makes them eminently suitable for studying the irrigation patterns over large areas.

Previous studies have given promising results for using satellite data to map and inventory irrigated lands in the U.S.A. (Draeger, 1976; Heller and Johnson, 1979; Johnson *et al.*, 1978). However, irrigated croplands inventory in tropical countries with highly heterogeneous cropping patterns, a complex cropping calendar, and fragmented agricultural fields require that studies be undertaken to prove and formulate the methodology.

The objective of this study was to identify the nature and extent of irrigated croplands in the southern part of the Tamil Nadu State in India from Landsat data. This region, comprising the districts of Madurai, Ramanathapuram, and Tirunelveli (Figure 1), is characterized by a semiarid climate. Dryland agriculture and rangeland dominate the land use in this area. Irrigation is prevalent where water is available. Information to be gained in this study is needed to formulate water management policies in this region.

## STUDY AREA

The southern part of Tamil Nadu State is effectively sheltered from the Arabian Sea monsoon by the Western ghats. It also lies off the track of the Bay of Bengal branch and hence does not experience the full effects of the retreating monsoon.

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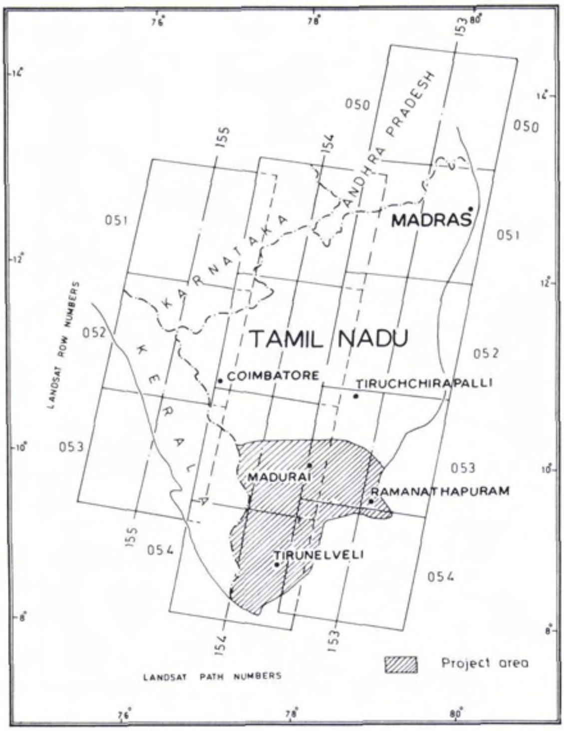

FIG. 1. Index to Landsat Coverage

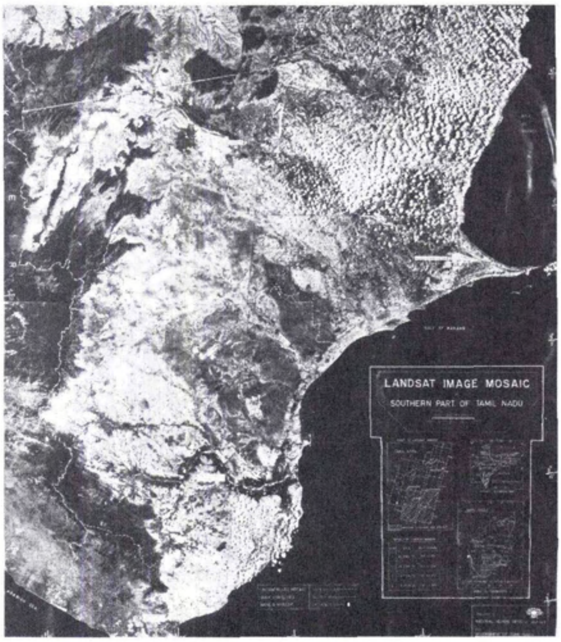

FIG. 2. Landsat image mosaic of study area.

The normal annual rainfall is about 750 mm, and fluctuates widely with variations ranging from about 40 percent along the coast to about 25 percent in the west. Most of the annual rainfall comes from the northeast monsoon in the October-December period. This monsoon contributes as much as 60 to 70 percent of the total precipitation in the coastal areas and decreases westwards to about 40 percent and less in the Ghats region. The southwest monsoon rainfall is very erratic, with variations as high as 100 percent in the coastal areas and about 40 percent near the Western Ghats. The northeast monsoon rainfall is relatively less erratic with variation ranging from about 50 percent in the coastal areas to about 35 percent near the Ghats.

The average annual potential evapotranspiration is estimated to be about 1800 mm, with actual rates dependent on seasonal precipitation. The Thorntwaite aridity index is as high as 50 percent, indicating serious water shortages. The agriculture, consequently, is essentially dry-land farming with irrigation limited to locations where water is available.

## DATA AND METHODOLOGY

The study area is covered in four Landsat scenes (Figure 2). The satellite data acquired in February, 1973, were used to generate information on the land use of the area, which included the cropland category. The other land-use categories were urban/built-up land, fallow agricultural land, mixed rangeland, forest, plantation, scrub, barren land, wet land, river/beach sand, and water. An analysis of the crop calendar giving the sowing and harvest dates (Tables 1, 2, and 3) indicated that all dryland crops would have been harvested by this time, leaving only irrigated crops. For optimum identification of irrigated croplands, it is desirable to obtain data during that period when the crops are nearing maturity and before harvesting has begun. The February imagery was considered suitable as it is the height of the growing season with maximum vegetation cover, and in this semiarid area if a crop is growing in February it can be reasonably assumed to be irrigated by surface water through canals in project areas and by ground water in garden lands. The selected data were analyzed digitally on the Multispectral Data Analysis System (MDAS) at the National Remote Sensing Agency facility in Hyderabad. This is an interactive computer designed to use data from satellite and airborne multispectral scanners to produce accurate results in quantity (Bendix, 1976). The time lag between satellite data acquisition in 1973 and ground truth collection in 1978 introduced some problems, which necessitated local enquiries and reference to historical records. The computer was trained to identify the required land-use categories by defining representative areas. After the area had been classified into land-use categories, cropland was separately filmed as a thematic map.

TABLE 1. CROP CALENDAR IN SURFACE WATER IRRIGATED LANDS

| Crop Sequence | Sowing period | Harvesting period |
|---|---|---|
| A. *Double Croplands* | | |
| Paddy | June–July | Sept–October |
| Paddy | Oct–Nov | Feb–March |
| Pulses or | Feb–March | May |
| Green gram | Feb–March | May |
| B. *Single croplands* | | |
| Paddy | Aug–Sept | Jan–Feb |
| Pulses or | Jan–Feb | April |
| Green Manure | Jan–Feb | April |
| or | | |
| Gingelly | Jan–Feb | April–May |
| C. *Tank irrigated areas* | | |
| Paddy | Sept–Nov | Feb–April |

## RESULTS AND DISCUSSIONS

The surface and ground water irrigated crops showed no difference in their spectral response, and hence could not be spectrally separated using existing computer programs. However, it may be possible to digitally classify them through future programs which use textural differences arising out of variations in irrigation density. While canal irrigated agricultural fields are clustered, ground water irrigated areas are widely dispersed. Separation of surface and ground water irrigated areas may be performed through interpretation based on supplementary information in regard to major surface irrigation projects, canal network maps, drainage patterns, and recorded groundwater utilization (Figure 3). Tank (small water impoundment) irrigation schemes could be delineated due to association with water bodies (Figures 4 and 5).

TABLE 2. CROP CALENDAR IN GARDEN LANDS

| Crop Sequences | Sowing Period | Harvest Period |
|---|---|---|
| A. *Seasonal Crops* | | |
| 1. Paddy | June–July | Sept–Oct |
| Paddy | Oct–Nov | Feb–March |
| Pulses | Feb–Sept | Jan–Feb |
| 2. Paddy | Aug–Sept | Jan–Feb |
| Millets | March | June |
| 3. Paddy | July–Aug | Dec–Jan |
| Bajra | January | March |
| Sorghum | April | June |
| 4. Groundnut | Jan–Feb | April |
| Paddy | July | November |
| 5. Cotton | Aug–Sept | February |
| Sorghum | March | June |
| 6. Paddy | July–Aug | Nov–Dec |
| Vegetables | Jan–Feb | May |
| 7. Paddy | October | Jan–Feb |
| Cotton | Feb–March | September |
| 8. Chillies | September | Jan–Feb |
| Bajra | February | April–May |
| B. *Annual crops* | | |
| Sugarcane | Jan–Feb | Dec–Jan |
| Banana | Nov–Feb | Nov–Feb |

TABLE 3. CROP CALENDAR IN DRY LANDS

| Agroclimatic Zone | Crop rotation | Sowing period | Harvest period |
|---|---|---|---|
| *Red Soil Areas* | | | |
| A. Early Sown Areas | Groundnut | Apr–May | Aug–Sept |
| | Sorghum or | Sep–Oct | January |
| | Minor millets | Sep–Oct | January |
| B. Midseason Areas | Groundnut | June–Jul | Sept–Oct |
| | Bajra or | October | January |
| | Horsegram or | October | January |
| | Gingelly | October | January |
| C. Normally Sown areas | Groundnut | Aug–Sep | Dec–Jan |
| | Sorghum | Aug–Sep | Dec–Jan |
| | Bajra | Sep–Oct | Dec–Jan |
| | Minor millets | Aug–Sep | Nov–Dec |
| *Black Soil Areas* | | | |
| A. Early Sown Areas | Groundnut | Aug–Sep | Dec–Jan |
| | Cotton | Aug–Sep | Jan–Feb |
| | Sorghum | Aug–Sep | Dec–Jan |
| | Bajra | Aug–Sep | Dec–Jan |
| | Minormillets | Aug–Sep | Dec–Jan |
| B. Late Sown Areas | Sorghum | October | January |

The study area depicts a diversity of irrigation sources and patterns. Major projects such as the Periar Scheme (Madurai District), the Vaigai Scheme (Madurai and Ramanathapuram Districts), the Manimuthar scheme, and the Marudur-Srivaikuntam System provide assured canal

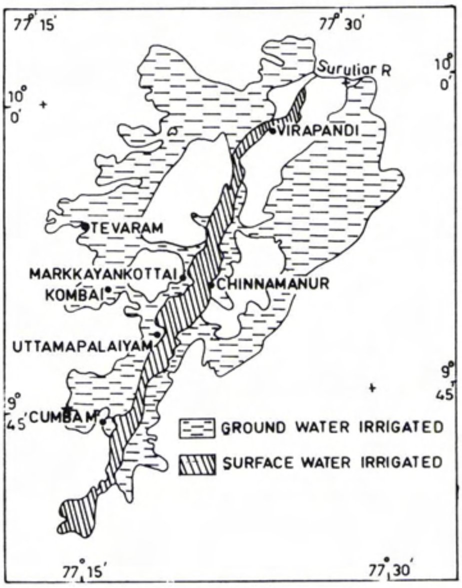

FIG. 3. Irrigated areas in Cumbum valley in Madurai district. Separation of surface and ground-water irrigated areas was obtained through interpretation of categorized crop thematic map.

FIG. 4. Categorized Landsat data showing irrigated area under Vijayanarayanam tank in Tirunelveli district.

irrigation. A special feature of the Periyar-Vaigai and Manimuthar schemes is the concept of system tanks in which canals supply water to tanks which are in turn used to irrigate crops in the command area. Rainfed tanks constitute an important source in the Ramanathapuram and Tirunelveli districts. Ground water irrigation is prevalent in all the districts, and especially well developed in Cumbum valley in the Madurai District.

While single-date data were used in the delineation of areas under irrigation, temporal data are needed to monitor the increase or decrease over a period of time in areas irrigated by various sources. For example, comparison of crop categorized Landsat data of February, 1973, (Figure 6) and February, 1980, data (Figure 7) indicates that there has been little, if any, increase in the ground-water irrigated area in Cumbum valley in Madurai district. This suggests that ground water may have already been fully exploited in this area. Discussions with State officers have confirmed this conclusion derived from the use of remotely sensed data.

The use of single-date Landsat data introduces difficulties in interpreting areas under different irrigated crops due to the overlapping growth periods. For instance, in February the ground-water irrigated crop may be paddy as first and second crop, pulses, bajra, ground-nut, cotton, vegetables, chilies, surgarcane, or banana. Similarly, under surface water irrigation, the crop may be paddy, pulses, green gram, green manure, or oil seeds.

Use of multidate data can, however, result in greater discrimination of irrigated crop lands, for instance into single and double cropped surface-water irrigated areas. Surface-water irrigated lands mapped in August/September denote double cropped areas while the absence of irrigation in August/September but presence in December/January may indicate single cropped areas (Table 1). The standing crop identified in double cropped areas from August/September and January/February Landsat data indicate the first and second crop of paddy, respectively. In the single cropped areas satellite coverage of December/January period may show paddy as the first crop. Standing crops in April/May may be pulses or green gram in double cropped areas and green manure and oil seeds in single cropped areas. Paddy is the only crop under tanks and can be easily mapped.

There is a greater complexity in ground-water irrigated cropping pattern. Paddy is the first crop if identified in August/September imagery and second crop if seen in January/February also in the first crop rotation sequence, and is the first crop if seen only in December/January under other crop rotation sequences (Table 2). Banana can be identified if present in August/July and April. High crop reflectance in July will mean sugarcane. Separation of other crops, such as pulses, millets, cotton, vegetables, etc., do not seem possible due to overlapping growth periods.

No crop species identification is possible in the drylands (Table 3). The dry land crops do not appear to have a unique phenological cycle, and also the growth period is too short to enable suitable selection of Landsat data (Table 3).

It is hoped to check the validity of the foregoing conclusions based on a theoretical analysis of the crop calendar with the 18-day repetitive data obtainable from the newly operational Indian Earth Station near Hyderabad. A major difficulty is however envisaged under Indian conditions due to the limited availability of cloud-free data during the southwest and northeast monsoon months of June to December. This constrains crop species identification.

The irrigated cropland inventory would provide data that could be used to determine water demand from existing water resources and to permit more realistic planning for future use of available supplies. Irrigation water demand may be estimated by using average water application rates in conjunction with cropland acreage data. More accurate estimates of agricultural water demand would, however, require information on crop type, acreage, and crop-specific application rates (Estes *et al.*, 1975).

Acreage estimation of irrigated croplands is essential for its use in hydrologic studies. While

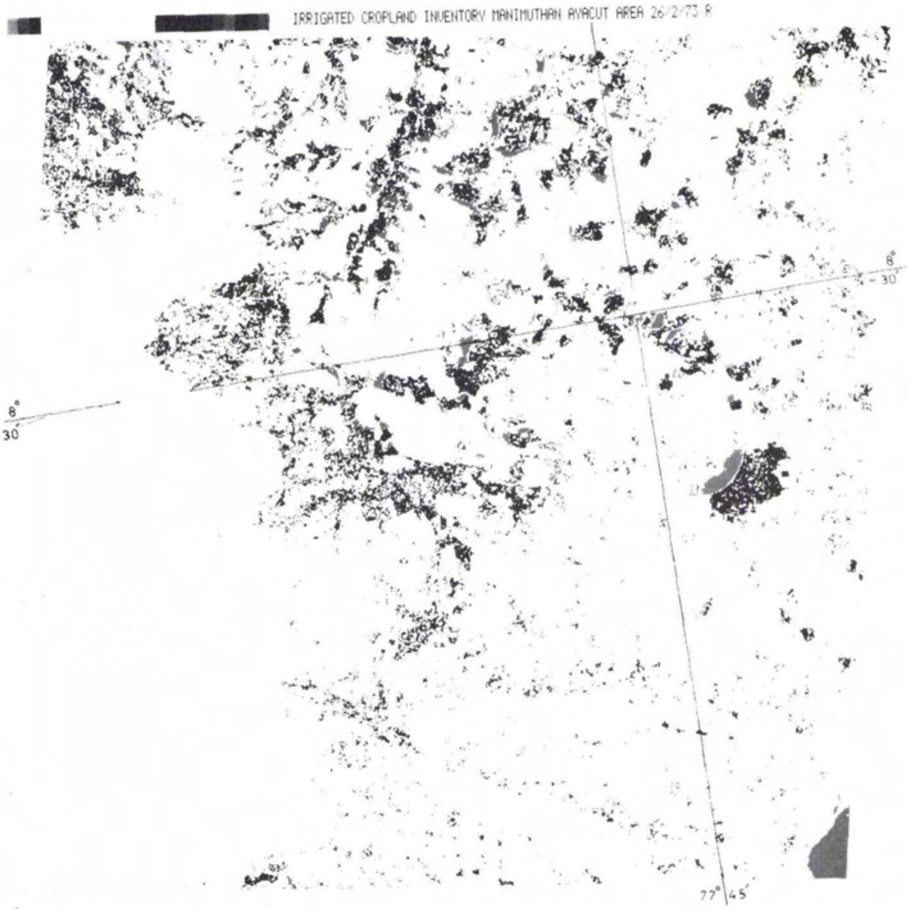

FIG. 5. Cropland thematic map of Manimuthan command area in Tirunelveli district showing system tanks (gray) and associated irrigated areas (black).

digital techniques could be used to estimate total irrigated lands, photointerpretation and manual inventory methods using imagery are preferable as they require less training and less expensive equipment and hence prove practical for adoption by State agencies.

Photointerpretation techniques using satellite imagery have proved successful in the inventory of irrigated croplands (Draeger, 1976; Johnson *et al.*, 1978; Heller and Johnson, 1979). Draeger (1976) used a dot grid with 400 dots per square inch over a Landsat false color composite (FCC) print enlarged to a scale of 1:250,000 to achieve sampling errors of 7 and 13 percent at the 95 percent confidence interval for the two interpreters involved in the study. Heller and Johnson (1979) inventoried irrigated croplands in southwestern Idaho at sampling errors of 6 to 10 percent. The promising results should however be viewed with caution as these have been limited to areas of intense agriculture. Widely dispersed agricultural land acreages have been excessively estimated at unacceptable accuracy levels (Johnson *et al.*, 1976).

Manual inventory methods using satellite imagery have used either dot grid (Draeger, 1976) or box grid (Heller and Johnson, 1979) sampling overlays. Both techniques involve statistical sampling on the ground for adjustment of Landsat based estimates.

The feasibility of the manual inventory technique was tested in the Cumbum valley in Madurai district where reported surface water irrigated cropland acreage figures were readily available and where acreage has remained steady without any change over years. This is an intensely irrigated area raising three crops in a year. The first two crops are rice of 180 and 105 days

FIG. 6. Categorized satellite data showing croplands in Cumbum valley in Madurai district. Black indicates crops. Scale is 1:500,000.

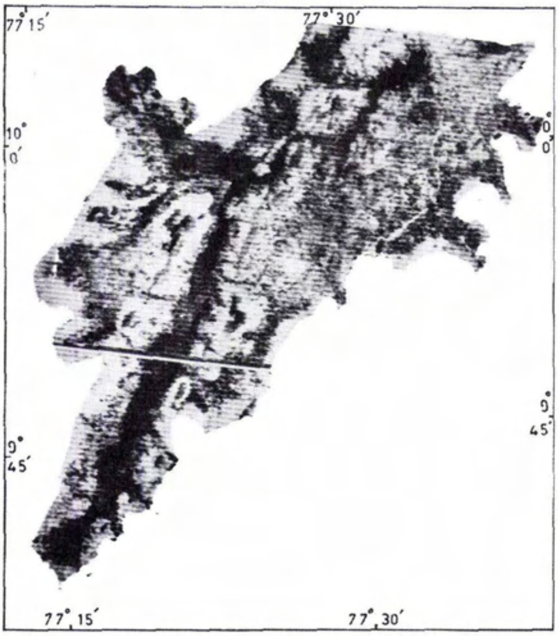

FIG. 7. Part of Landsat scene 154-053 in Band 5 showing crop cover in the Cumbum valley. Imagery outside Cumbum valley has been marked. Comparison with Figure 6 indicates status quo in sourcewise irrigation extent.

duration while the third may be of two to three months duration consisting of pulses, green gram, and green manure.

The Landsat false color composite of the area was interpreted and inventoried by two interpreters. A sampling grid corresponding to a map base of 1:1,000,000-scale was prepared with a block size of 5 by 5 km and overlaid on a 1:1,000,000-scale color print, and the interpreters visually estimated to the nearest 5 percent of the agricultural area. A smaller block size, say 2 by 2 km, may be more suitable in widely dispersed croplands such as in ground-water irrigated areas. The Landsat imagery, acquired on 9 February 1973, was selected since by this time all dry land crops would have been harvested, leaving only irrigated crops in-ground. Surface and ground-water irrigated areas were separated out using ground information. Irrigated fields appear bright red because of the high infrared reflectance of the vegetation and can be easily separated from the surrounding drylands due to the high contrast. The surface water irrigated acreage estimates were 6150 hectares for interpreter A and 5550 hectares for interpreter B, compared to the reported area of 5923 hectares. The ratios of 1.04 and 0.94 of estimated to reported acreage conform to results obtained elsewhere. For instance, the correction ratios for all major strata were between 0.90 and 1.04 in the study conducted in the Klamath River basin of Oregon (Draeger, 1976). Though in earlier studies ground enumerated or aerial photo interpreted acreage estimated or aerial photo interpreted acreage estimates were used as the base for evaluation and adjustment, in this case the reported figures could be conveniently used as the base since this is a traditionally irrigated area where the irrigated acreage has remained unchanged over a long time. The close agreement of the acreage estimates by both interpreters should be viewed in the background of the intensely irrigated area and the skilled photointerpreters involved, though only interpreter A was familiar with the area. Though a similar evaluation has not been made for other areas, it is expected that reduced estimation accuracies will result in widely dispersed irrigated lands.

The photointerpretation, measurement of areas, and computations took less than five minutes for this area of about 6000 hectares. The rapidity with which the inventory can be carried out augurs well for its adoption by State agencies with large areas to be covered.

## CONCLUSIONS

This preliminary investigation has indicated promising results on the use of satellite sensing techniques for mapping and inventory of irrigated crop lands in semiarid areas. Suitable single-date Landsat data may be selected from an analysis of the crop calendar, and used for delineating irrigated lands. Supplementary ground information may be used to discriminate areas irrigated by different water sources. A theoretical analysis of the crop calendar indicated that use of multi-date satellite imagery might enable separation of single and multiple cropped lands. Crop discrimination does not seem spectrally possible though temporal analysis, subject to availability of cloud-free multidate satellite data, may help to some extent. The extremely overlapping growth periods preclude crop discrimination in drylands. It also seems possible to identify temporal changes in cropland acreage through analysis of Landsat data separated by a few years.

A pilot study has demonstrated that manual inventory of irrigated croplands can yield quick and reliable results in intensely irrigated areas. Though this method has been evaluated over a small area of about 6000 Hectares, it can be extended to large areas with equally acceptable estimation accuracy levels. It is expected, however, that estimation accuracy will be less in widely dispersed irrigated lands.

The 18-day repetitive data from the newly operational Earth Station will it is hoped make it possible to confirm the aforesaid conclusions.

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