Improved water management: The IRS-1C contribution

S. Thiruvengadachari, S. Jonna, K. A. Hakeem, P. V. Raju, V. Bhanumurthy, G. Srinivasa Rao, P. R. Paul, E. Siva Sankar and A. T. Jeyaseelan

National Remote Sensing Agency, Balanagar, Hyderabad 500 037, India

Satellite remote sensing techniques are increasingly being employed to solve problems relating to water management both at national level and at local level. The first two Indian Remote Sensing satellites, IRS-1A & 1B, significantly contributed to improved water management in the country. The recently launched IRS-1C satellite with its suite of sensors – WiFS, LISS-III and PAN – would further enhance our capabilities to generate appropriate information for sustainable water resources development. The dynamics of water resources, its availability and utilization, will be effectively captured by WiFS sensor and the details required for locale specific action plans would be generated from LISS-III and PAN sensors. In this article we evaluate IRS-1C potential in four major areas of water resources management, namely, irrigation, flood, snow and drought.

WATER management in India, both in its conservation and in its control aspects, has significantly benefited from satellite remote sensing inputs. From its modest beginning with surface water inventory Satellite Remote Sensing (SRS) technology has progressed to more complex management tasks such as irrigation system performance evaluation and diagnostics, countrywide drought monitoring, snowmelt runoff forecasts, reservoir sedimentation and watershed treatment, flood mapping and management and environmental impact assessment. National and locale specific programmes have utilized space derived data to enhance the efficiency of water management. The spatial resolution of satellite sensors has significantly improved, the spectral coverage increased to cover middle and thermal infrared wavelengths and repetitivity improved with multiple satellites. Microwave remote sensing is helping to see through cloud cover, enabling monitoring through the monsoon months. The recently launched IRS-1C satellite with its suite of sensors—WiFS, LISS-III and PAN—would further enhance our capabilities to generate information inputs for better water management. An appraisal of new capabilities in four specific water resources areas has been conducted and the results are presented in this article.

Irrigation water management

Satellite remote sensing is being utilized for base line inventory of irrigated area, cropping pattern, crop condition, and productivity in irrigation systems, monitoring irrigation status through the season, optimum design of crop cutting experiments, staggering of sowing and transplantation of crops, evaluating system performance and diagnostic analysis of poorly performing pockets in the irrigation system[1]. The currently available Landsat and IRS satellites, however prove limiting in effectively capturing the irrigation dynamics through the season, particularly in the earlier stages and where small area crops are prevalent in the command. The IRS-1C satellite would lead to quantum improvement in our capabilities to monitor and manage irrigation systems. Concurrent monitoring through the irrigation season is a critical element in effective water management in the irrigation projects. Sowings of nonpaddy crops and paddy transplantation are seen to be staggered by as much as two months across a command area. Monitoring of crop condition is equally critical to ensure that the irrigation requirements are adequately met by canal releases. The five days repetitive coverage of WiFS sensor will provide the necessary surveillance capability across the command area through the season. The small swath (145 km) of LISS-I sensor and even the combined repetitivity of IRS and Landsat satellites have hitherto proved inadequate for effective temporal coverage of large irrigation projects. NOAA satellite's AVHRR sensor data, while providing the overview, obviously do not provide details in view of its coarse 1 km resolution at nadir.

WiFS data of three days in 1996—20 January, 25 January and 8 February—covering Bhadra Project in Karnataka have been analysed to evaluate the extent of concurrent monitoring capabilities. The data have been normalized for viewing angle, which was different for the three WiFS overpasses, through cosine correction. In view of the narrow swath of Bhadra Project pixel level correction was not attempted by opting for uniform correction along the scan. The three data sets were also calibrated for absolute radiance.

The false colour composite of WiFS coverage of Bhadra Project is shown in Figure 1 (in the left half)
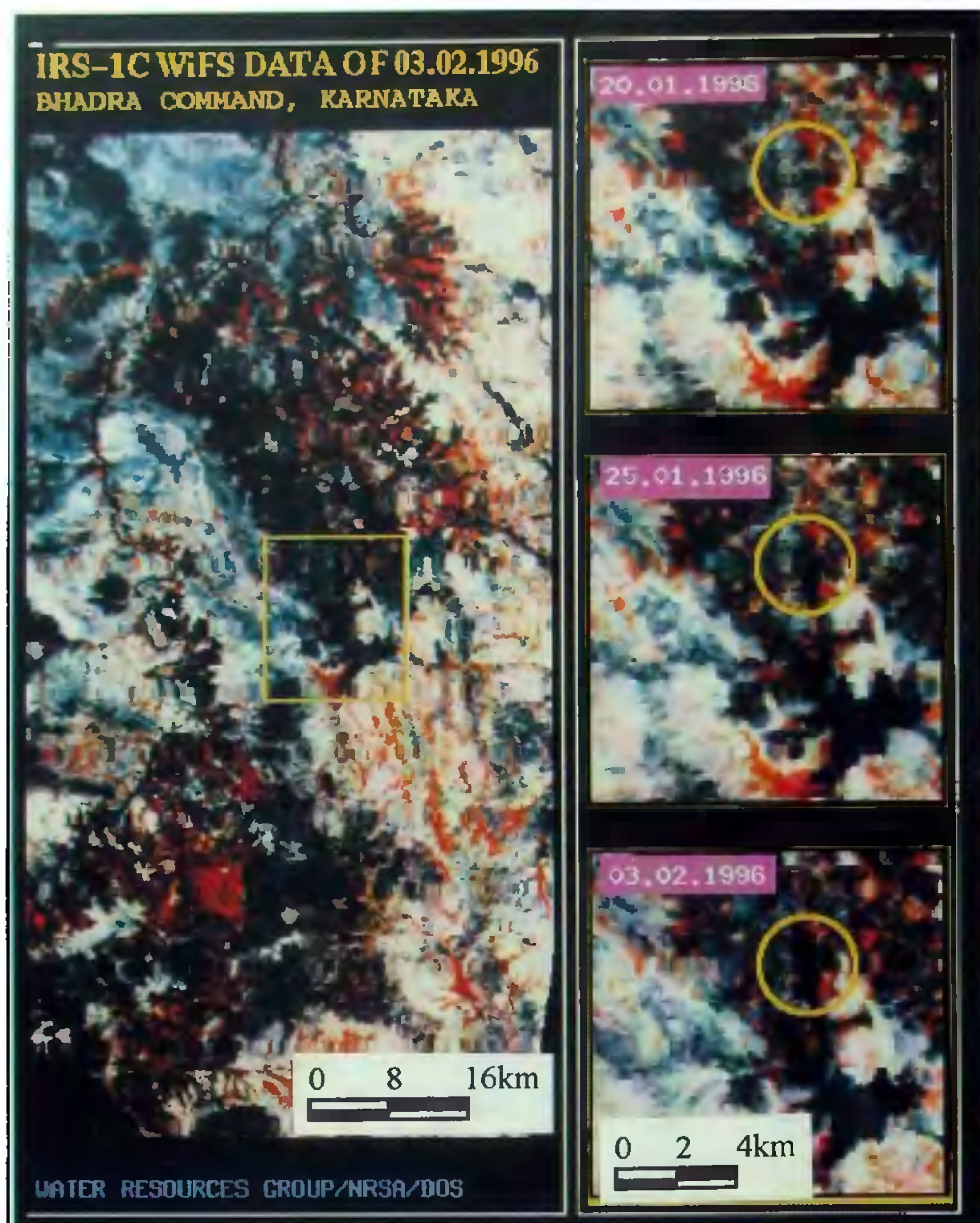
Figure 1. Repetitive WiFS coverage of Bhadra Project in Karnataka showing staggered agricultural operations.

while the portion of image within the rectangle on all three days is shown enlarged on the right half. The area enclosed by the circle in these three images is typical of the command and is characterized by staggered paddy transplantation. The newly transplanted areas after 25 January, are shown by dark colour within the circle in the 3 February image. The close repetitivity of WiFS data thus provides the irrigation systems manager the tool to monitor how paddy transplantation is progressing and to match water deliveries to the staggered paddy calendar across the command area. Monitoring of sowing progress of semidry crops such as groundnut and sugarcane could be similarly taken up after spectral emergence of the crop and would be indicated by increasing area under red colour in the false colour image.

Crop condition assessment at periodical intervals through the season is essential for improved water management and increased agricultural productivity. Comparison of Normalized Difference Vegetation Index (NDVI) over groundnut and other irrigated drycrops between the three WiFS coverages indicates its sensitivity to ground changes in crop growth and condition. In order to test that the perceived differences are not due to atmospheric effects, the spectral response of invariant features was extracted and compared. The NDVI differences observed over semidry crop areas are significantly larger than those observed over invariant ground features, ruling out noise contribution from atmospheric effects.

It is expected that the combined knowledge of spatial

variability in crop sowing/transplantation and the subsequent NDVI dynamics, would help in normalizing crop calendar differences in crop condition assessment. The WiFS generated seasonal NDVI profiles would also be useful in yield modelling and in identifying stress periods for better water management.

The 188 m resolution of WiFS however proves limiting in the detailed identification of small area crops distributed within the command area. Figure 2 shows LISS-III data of distributary 6B under the Davangere Branch canal division of Bhadra Project. The cadastral map has been digitized and shows excellent match with field boundaries and natural drainage features. Fields with transplanted paddy and standing semidry crops as small as 0.25 ha, could be noticed. Another interesting feature is the partly cultivated fields within the revenue survey number indicating staggered agricultural operations even within the farmer's holding. Farm holdings in Ramagondanahalli village irrigated by distributary, paddy transplantation (Nos. 17 and 43) and under-irrigated dry crops such as groundnut and sugarcane (No. 41) are clearly shown. Thus detailed inventory of cropping pattern within the irrigation command can be obtained from LISS-III data. This baseline spatial information can be combined with repetitive WiFS data to provide temporal monitoring of crop condition.

Panchromatic data of 5.8 m resolution is expected to be useful in delineating details of canal network and field level irrigated crop inventory, in addition to the contour information which is of use in preliminary planning of canal alignment and land shape.

Subsequent investigations would centre around comprehensive evaluation of WiFS temporal, spatial and radiometric sensitivity for concurrent monitoring and LISS-III sensor for detailed crop inventory at distributary/minor/water course level.

Flood management

Satellite remote sensing techniques have been providing in the last decade critical inputs on flood-inundated areas, damage to cropland and utilities, status of flood control works and flood hazard zoning which are vital for effective flood management[2]. However, limitations have been encountered in view of cloud cover during the flood period, long revisit period inadequate for
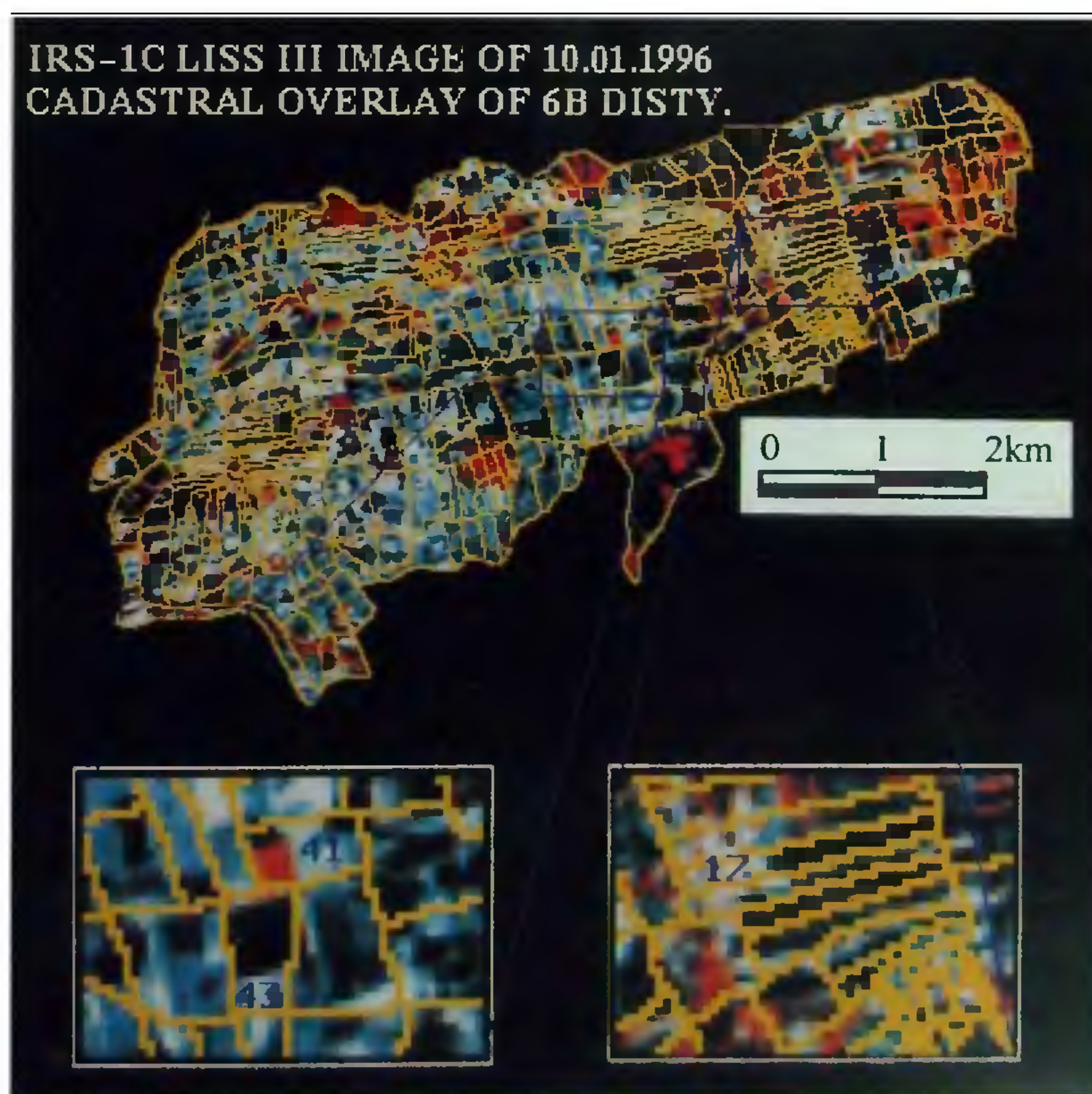

Figure 2. LISS-III image of typical distributary in Bhadra Project with cadastral overlay.

monitoring the flood dynamics and the spatial resolution not fine enough for looking at microlevel flood details. IRS-1C with its sensors – WiFS, LISS-III and PAN – will be providing the much needed close temporal coverage, large area synoptic viewing of the entire basin and more detailed view of ground conditions.

The limited swath of earlier IRS and Landsat satellites hampers flood monitoring over the basin or State as a whole. A review of satellite data utilization till date indicates that so far not a single cloud-free synoptic coverage of a river basin such as Brahmaputra was available. Cloud-free IRS-1A and 1B satellite data have been available only over selective areas within the basin, thus not providing a complete picture of flood conditions. This has hampered effective flood management. The Wide Field Sensor data with around 800 km swath provides an excellent opportunity to map and monitor floods, even over large river basins such as Ganga or Brahmaputra, and would help in the preparation of statewise and basinwise flood inventories (Figure 3). Since so far satellite data had been available only in patches in the basin, the hydraulic connectivity between the cause and effect of flood such as embankment breach, drainage congestion, etc. could not be studied comprehensively and hence could not give an input in flood management programmes.

Today, any specific ground area is repetitively covered effectively at 6 day interval considering the combined repetitivity of IRS-1B, P2 and Landsat-5 satellites. Thus, the total number of scenes (coverage) over any specific area during the flood months of June to October will be around 25. An analysis of statistics of recent eight years indicates that only a maximum of four scenes out of 25 possible coverages in any specific area are cloud-free and, hence, usable for flood monitoring. To cover a large river basin, such as Brahmaputra, about 6 satellite scenes are required and the maximum number of cloud-free scenes is normally around 24 for the entire basin. Further, such coverage will not be synoptic and for different areas could represent different time periods.

The 5 day repetitivity of WiFS data results in about 30 coverages over any specific area during the flood months. The availability of cloud-free data over Brahmaputra basin is estimated to be on an average of about 10 cloud-free WiFS scenes. This is equivalent to about 60 satellite scenes of IRS-1A, 1B, P2 and Landsat. Thus, the cloud-free coverage of flood conditions in Brahmaputra basin would improve by more than $2\frac{1}{2}$ times and this coverage will be synoptic and not patchy as hitherto been available. We would be able to monitor different waves of floods, extent of inundation during the flood wave, duration of floods, etc. which will form critical inputs for basinwise planning for flood management.

Since currently available WiFS data are acquired during non-flood period, IRS-P2, LISS-II data during 1995 floods in Kosi basin have been used to simulate WiFS data (Figure 4). Three cloud-free LISS-II scenes of 22 August 1995 and 10 September 1995 were mosaiced for WiFS simulation. It is observed that spatial resolution of 188 m of WiFS will not be limiting the accurate mapping of flood-inundated areas at regional level. The spectral characteristics of water in WiFS wave bands have been studied and found comparable with LISS-I data for land water discrimination.

The classification accuracy in mapping flood-inundated areas in Marigaon district in Assam State using simulated WiFS data is estimated at 90% compared to LISS-I data. Thus, acceptable flooded area estimates can be obtained from WiFS in spite of its 188 m resolution.
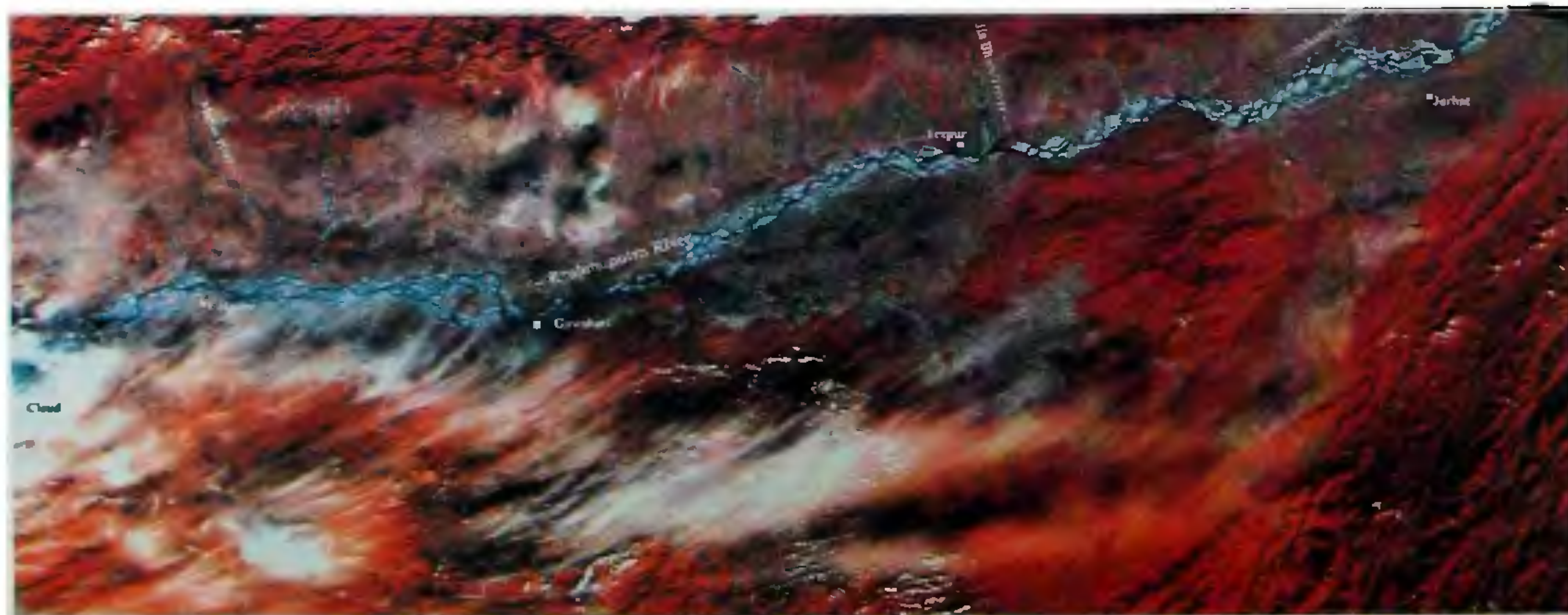

Figure 3. WiFS coverage of Brahmaputra river demonstrating potential for basinwise flood inventory.
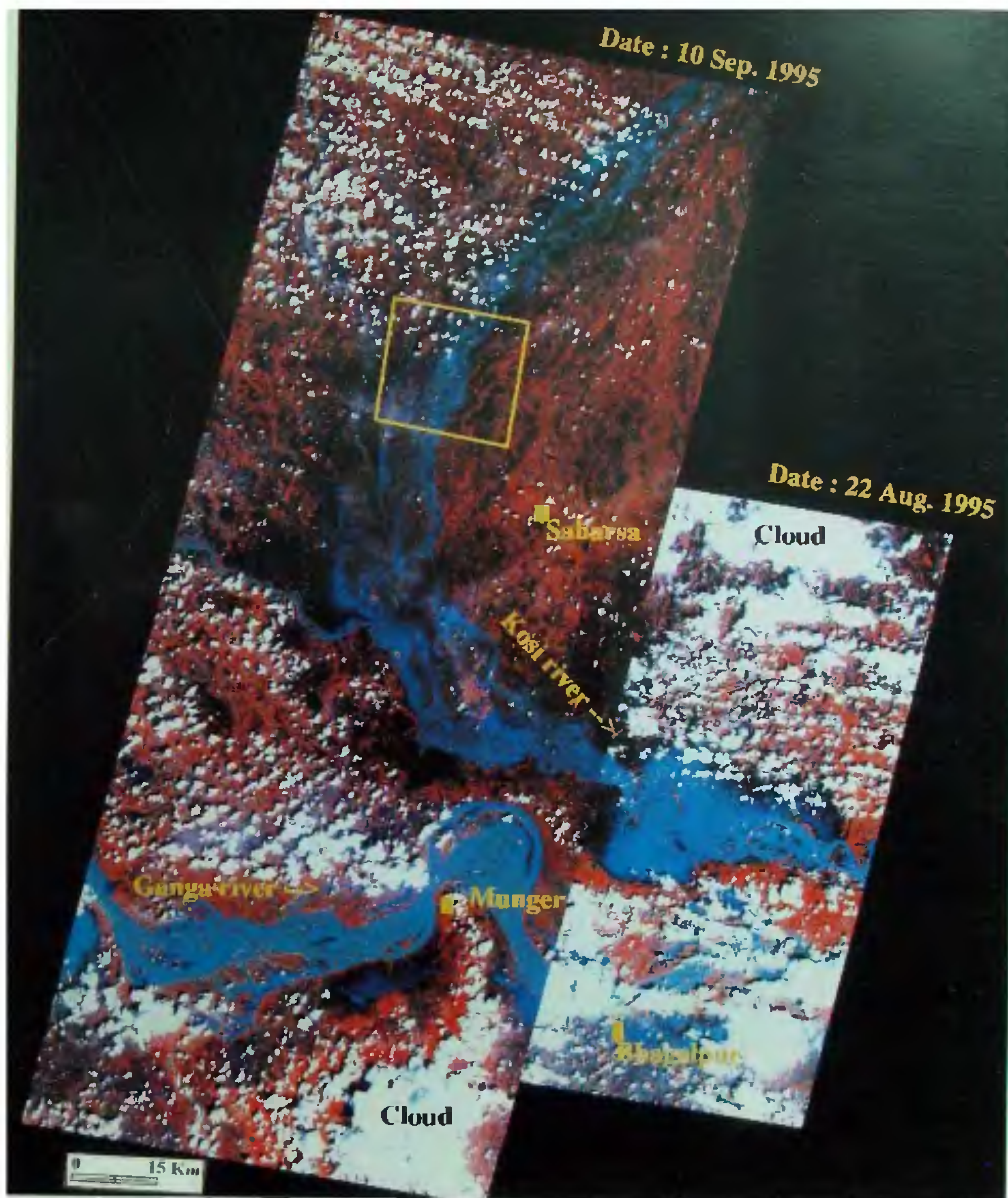
Figure 4. Simulated WiFS data covering Kosi river floods in 1995.

The fine spatial resolution of 23.5 m of LISS-III sensor makes it ideal for use in monitoring the status of flood control works. Figure 5 shows part of Kosi river as well as its embankments and spurs along the river which are clearly identifiable. It is seen that even a spur of 50 m in length can be identified on LISS-III data. A comparison of LISS-III data with LISS-II data indicates that spurs which could not be identified in the latter are clearly visible in the former. Flood plain features could be better mapped on LISS-III data. Such details

are expected to be even better in PAN data of 5.8 m resolution. These high resolution data can be utilized to generate up-to-date national inventory of flood control works and their status.

It is thus evident that while the basinwise synoptic coverage and the temporal dynamics will be provided by WiFS, the details of critical flood-affected areas would come from LISS-III and PAN sensors. The suite of these sensors on board IRS-1C is expected to enhance effective flood management in the flood-prone areas of the country.

Figure 5. LISS-III data of part of Kosi river showing river morphology, flood control embankments and spurs.

Forecasting of snowmelt run-off

NOAA AVHRR data currently have limitations in estimating snow cover areal extent in medium sized Himalayan basins of 5000–15000 km^2 size, in view of its coarse spatial resolution. It also does not capture snow cover information in smaller hydrologic units such as elevation zones and aspect zones in large basins like Sutlej (50,000 km^2) as well as in transition zones and patchy snow cover areas, which are critical for short term modelling of snowmelt run-off. It is in this context that the WiFS data is going to significantly contribute to snow studies in Himalayan basins.

This preliminary evaluation addresses the issues of saturation radiance, dynamic range and spatial resolution of WiFS data to satisfy the above important requirements.

The study has been conducted in the Tibetan portion of Sutlej basin.

The low radiometric resolution of 7 bit quantization of WiFS does not seem to limit precise delineation of snowcover areas. WiFS data of 24 January 1996 and AVHRR data of 29 January 1996 have been compared. AVHRR of 24 January 1996 was cloud covered and, hence, could not be used. The dynamic response of bands 3 and 4 of WiFS and of corresponding bands of 1 and 2 of AVHRR is given in Table 1. Since WiFS is designed for greater sensitivity to vegetation and other non bright objects compared to AVHRR, more than 80% of the snow covered area in the sunlit portion is seen to be saturated, while snow in shadows has a good dynamic range. This means that while different snow types such as fresh snow and dirty snow, having different

albedos, cannot be discriminated in WiFS due to high saturation, snow/nonsnow-discrimination is very good. The high sensitivity of band 4 in WiFS compared to band 3 may have significance in regard to surface wetness and grain size. However, this extrapolation from the earlier studies of TM data (Dozier 1991) needs further investigation.

Figure 6 shows the classification results with WiFS data for the three categories of snow, transition and non-snow. The transition zone which could not be earlier captured in the AVHRR data can now be accurately mapped due to the WiFS 188 m spatial resolution and

Table 1. Dynamic response of snow in WiFS and NOAA data

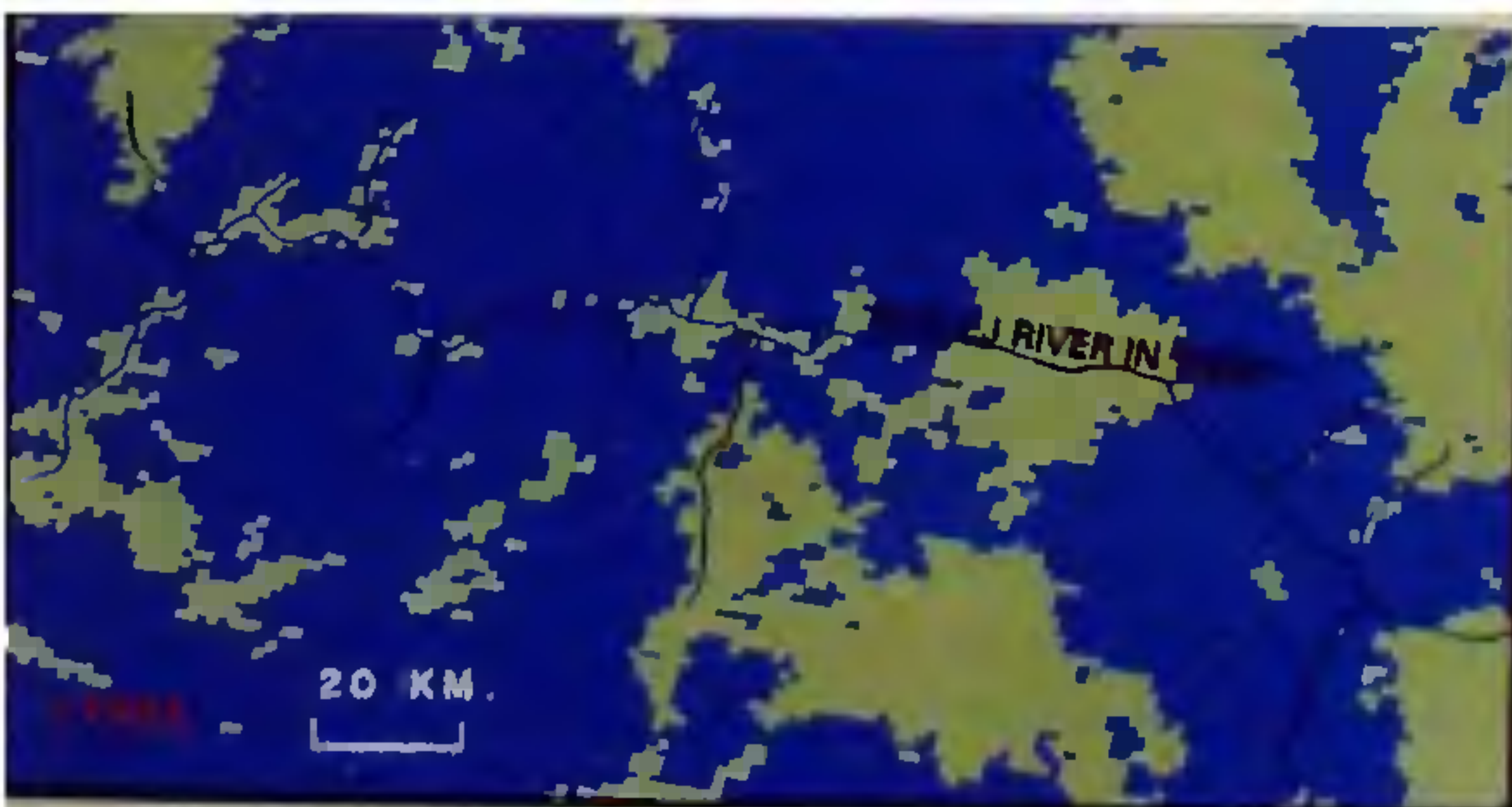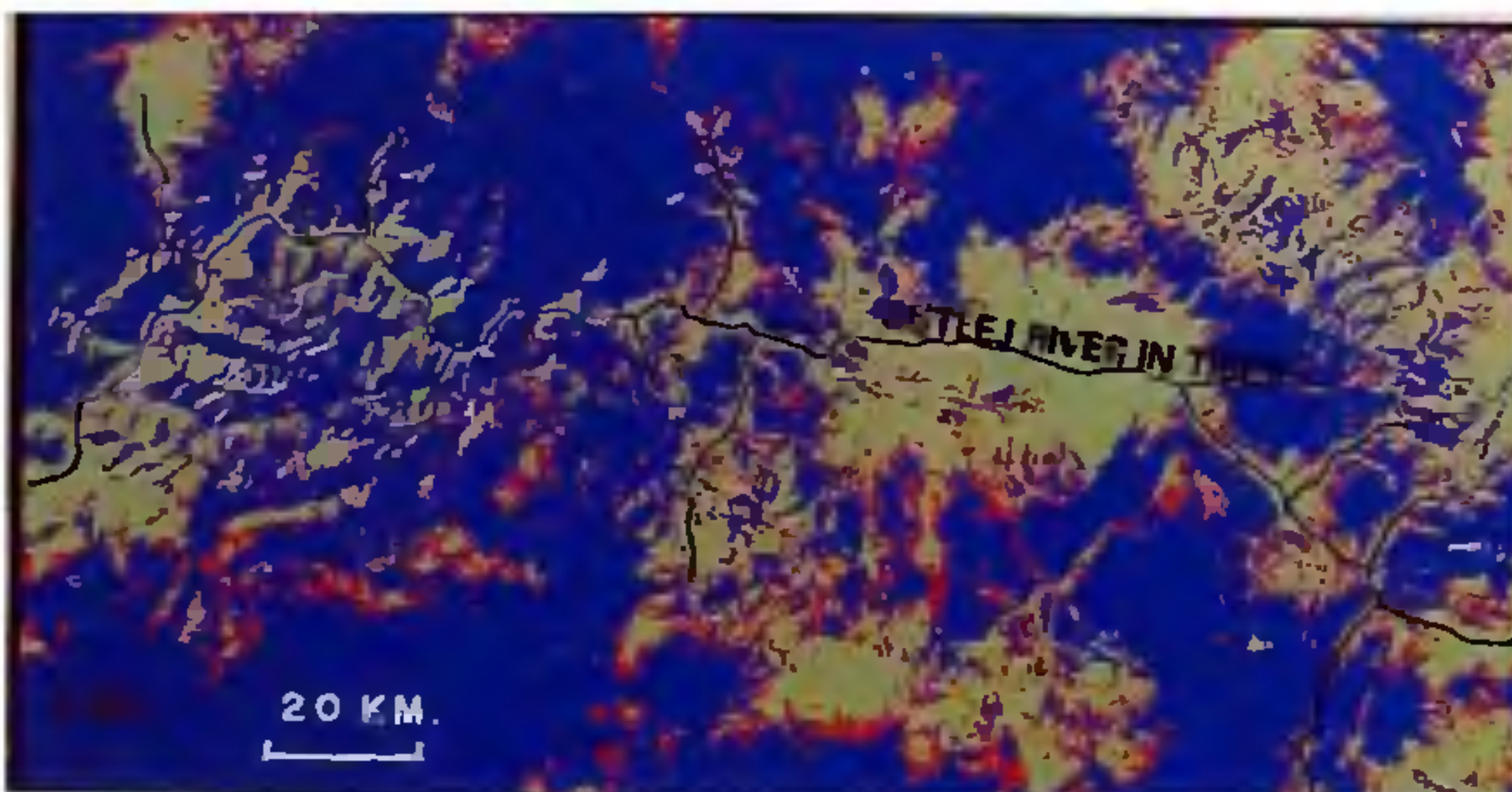| Class	Band 3			Band 4		
	Mini-mum	Maxi-mum	Range	Mini-mum	Maxi-mum	Range
WiFS of 24 January 1996 (7-bit rescaled to 8-bit)						
Snow in sun	233	255	22	162	255	93
Snow in shadow	148	253	105	104	213	109
Transition snow	213	232	19	153	161	8
AVHRR of 29 January 1996 (10-bit)						
Snow in sun	335	675	340	310	605	295
Snow in shadow	277	410	133	247	369	122

Figure 6. Classified snow cover map from WiFS and AVHRR data (blue is snow, red is transition snow and light green indicates nonsnow).

better sensitivity to non-bright objects. The AVHRR data seem to fail even when the transition zone extends to larger patches, as a result of poorer spatial resolution and radiometry. The mapping of transition zone is very important in short term snowmelt forecasting.

Short term forecasting in large basins such as Sutlej requires a spatial modelling approach involving smaller hydrologic units. Table 2 shows the snow cover statistics in 6 elevation zones of the study area from WiFS and AVHRR data. The percentage snow-covered area for the entire study region is 70.3 in WiFS (treating transition by 50% weightage) and 69 in AVHRR data, thus the latter in spite of its coarse resolution would still provide an acceptable basinwise statistics in seasonal runoff models[3]. However, short term forecast involves areal estimates for elevation zones and consideration of snow-melt process modelling separately for transition and full snow areas, which call for WiFS data.

The different overpass times of WiFS in the morning and AVHRR in the afternoon could have significant impact on snow application in Himalayan basins. The morning pass of WiFS can result in lower probability of cloud cover compared to AVHRR data. The WiFS coverage of Sutlej in Tibet on 24 January 1996 was relatively cloud-free but AVHRR of afternoon pass on the same day was extensively cloud-covered. Figure 8 also shows how coastal Andhra Pradesh was cloud-covered in NOAA AVHRR data but cloud-free on WiFS data.

Since most of the shadow areas including obliquely-illuminated slopes in WiFS are well-illuminated in afternoon AVHRR pass, a combined analysis of WiFS and AVHRR can prove very useful in illuminating most of the shadows. This can be clearly seen in Figure 7. WiFS coverage with Sun and sensor in opposite directions can provide useful information in the shadow areas because of forward scattering.

The LISS-III with high spatial resolution has the capability for mapping snowcover in very small basins up to 100 km[2], with SWIR band having proven capability for discriminating snow from cloud. The PAN data will provide unique opportunity to study avalanche-run sites,

Table 2. Classification of snow-covered area on WiFS and AVHRR data

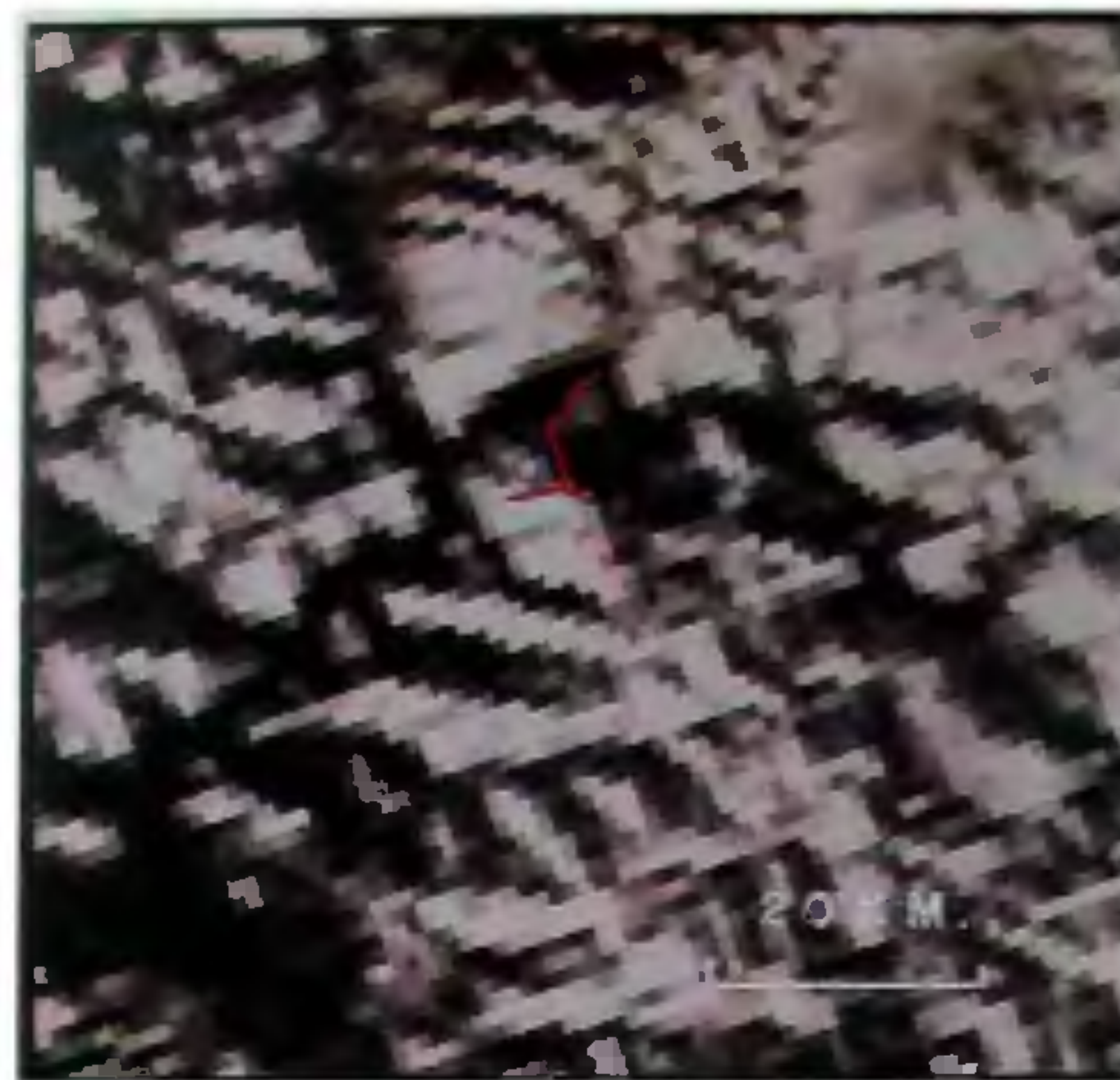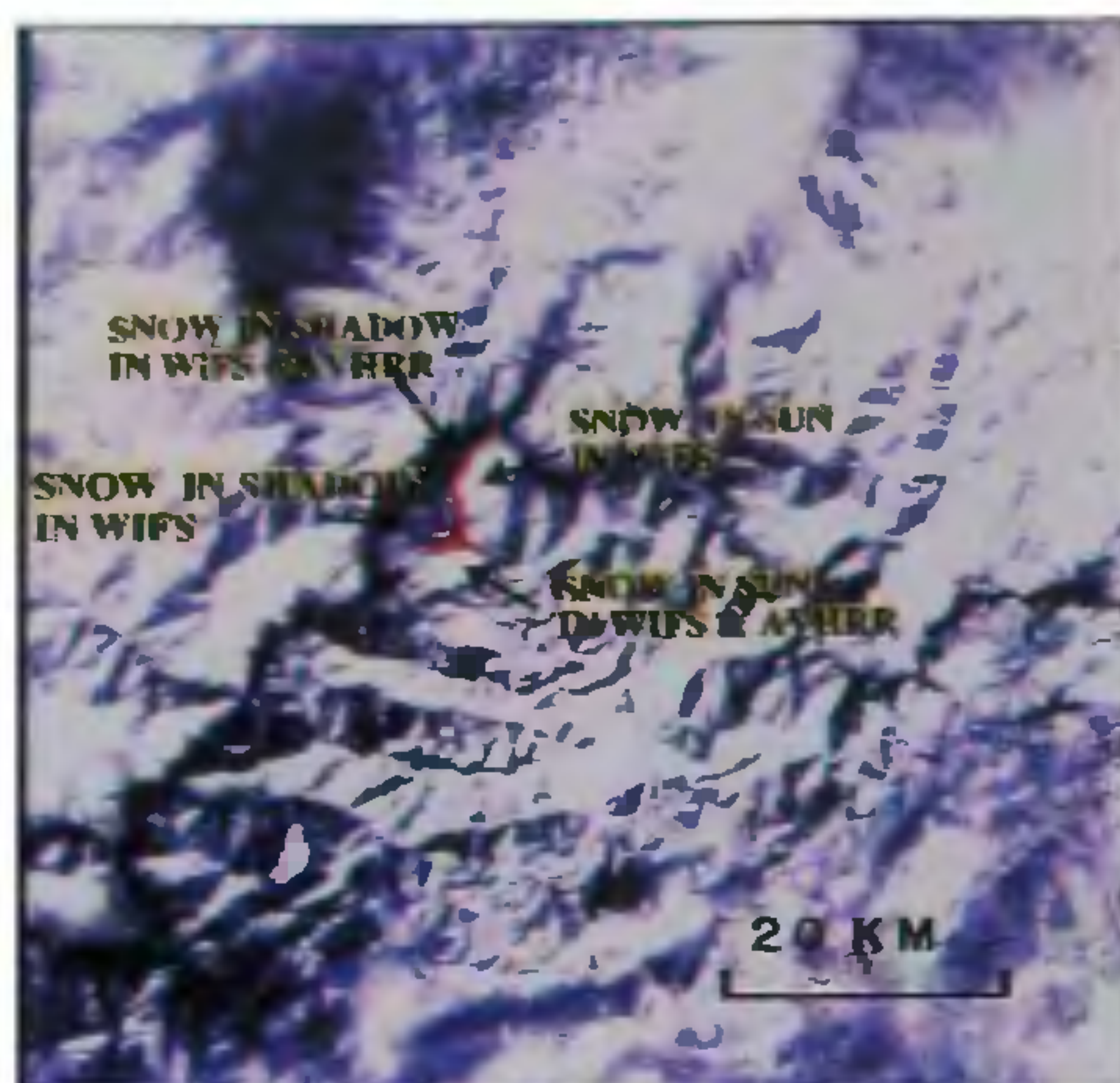| Zone	Elevation zone area (km²)	WiFS			AVHRR	
		Snow (%)	Transition snow (%)	Non-snow (%)	Snow (%)	Non-snow (%)
1	1.7	0	10.2	89.8	0	100
2	230.8	8.7	5.9	85.4	0	100
3	2,335.9	28.0	21.7	50.3	40.2	59.8
4	9,036.0	57.5	22.1	20.4	62.2	37.8
5	8,852.0	72.4	14.9	12.7	81.8	18.2
6	1,210.0	86.8	8.1	5.1	95.1	4.9
Total	21,667.0	61.5	18.2	20.3	69.0	31.0

Figure 7. WiFS (left) and corresponding AVHRR (right) imagery showing the effect of acquisition time on shadows in snow-bound Himalayas.

mapping avalanche-hazard zones and development of high resolution DTMs. The utility in avalanche studies however is to be further evaluated from the point of view of saturation radiance as also spatial resolution.

Drought assessment

Agricultural production in India, in spite of significant technological advances, continues to be affected by periodic droughts due to monsoon aberrations. The National Agricultural Drought Assessment and Monitoring System (NADAMS) at NRSA is currently providing crop and seasonal condition reports at district and sub-district levels through the kharif season in 11 agriculturally important and drought-vulnerable states of India[4]. The system uses National Oceanic and Atmospheric Administration (NOAA) satellite's Advanced Very High Resolution Radiometer (AVHRR)-based Normalized Difference Vegetation Index (NDVI) data in view of its large swath (about 2700 km) and daily coverage.

Though NADAMS is able to provide regional drought assessment, locale-specific information cannot be generated in view of coarse resolution of NOAA satellite data. In a recently held meeting, the user agencies have assigned high priority for providing more detailed drought assessment for smaller areal units and for specific themes. It is in this context that the WiFS data have been evaluated for its potential for detailed drought monitoring.

The evaluation addresses the WiFS potential to generate more detailed drought assessment at district/ tahsil/mandal/block level, NDVI sensitivity to vegetation dynamics and effect of morning coverage of WiFS in regard to cloud cover in comparison to NOAA AVHRR afternoon overpass.

The standard WiFS digital product over Andhra Pradesh (path 101/row 61) acquired on 25 January 1996 has been evaluated in comparison to afternoon pass of NOAA AVHRR data of 24 January 1996 with similar look angle.

Since the standard WiFS data had been acquired with gain 3 and later converted into 8 bit, the conversion of digital count into radiance was based on the following prelaunch calibration coefficients.

$$R3 = DN3 \ (31.76/255), \tag{1}$$

$$R4 = DN4 \ (29.84/255), \tag{2}$$

where R3, R4 is the radiance, in $mw \, cm^{-2}$-str-micron for the corresponding digital counts of (DN3, DN4) band 3 and band 4.

The master image of India and adjacent countries, generated from the Survey of India (SOI) maps in 1 : 2.5 million scale with pixel resolution 1100 M, was resampled to 188 m. The geometric correction was carried out by ground coregistering control points through appropriate transformation model.

The NOAA AVHRR data of 24 January 1996 was processed for north–south orientation and earth curvature correction. Since the AVHRR data are from NOAA-14 satellite, the corresponding pre-launch calibration coefficients for the first two bands channel 1 (0.58–0.68 micron) and channel 2 (0.78–1.1 micron) were applied for converting 10 bit (1024 grey levels) AVHRR data into per cent albedo with the following equation.

$$R1 = 0.1081 \quad DN1 - 3.8648, \tag{3}$$

$$R2 = 0.1090 \quad DN2 - 3.6749. \tag{4}$$

Figure 8. False colour composite of WiFS and AVHRR of Andhra Pradesh.

where R1, R2 are the per cent albedo for the corresponding digital count DN1, DN2 respectively for channel 1 and channel 2 of AVHRR data. The geometric correction was carried out in reference to SOI map-based master image, and the image portion of Andhra Pradesh was selected and resampled to 188 m resolution.

The radiometrically calibrated data of B3 and B4 of WiFS were used to calculate NDVI image with similar look up table as that of NOAA-based NDVI for comparison. The NDVI equation used for both WiFS and AVHRR is as follows:

$$NDVI = 222.5 - 350 \ \frac{near \ infrared - red}{near \ infrared + red} , \qquad (5)$$

where NDVI is the 8 bit normalized difference vegetation index, near infrared is the calibrated B4 of WiFS and calibrated channel 2 of AVHRR and red is the calibrated B3 of WiFS and calibrated channel 1 of AVHRR data. In case of NOAA, instead of single date, time composited weekly vegetation index ending with 24 January 1996 was selected to minimise off-nadir and cloud effect. Statistics was generated from individual bands and VI of WiFS and NOAA over selected district (Adilabad and Kodavallur Mandal of Nellore District) and over various land cover classes. The false colour composite of AVHRR (channel 2, channel 1, channel 1 as RGB) and WiFS (B4, B3, B3 as RGB) of Andhra Pradesh is given in Figure 8.

The cloud-free WiFS coverage over the coastal districts of Andhra Pradesh indicates high probability of cloud-free coverage from WiFS (morning pass) compared to NOAA data (afternoon pass) particularly in the coastal regions.
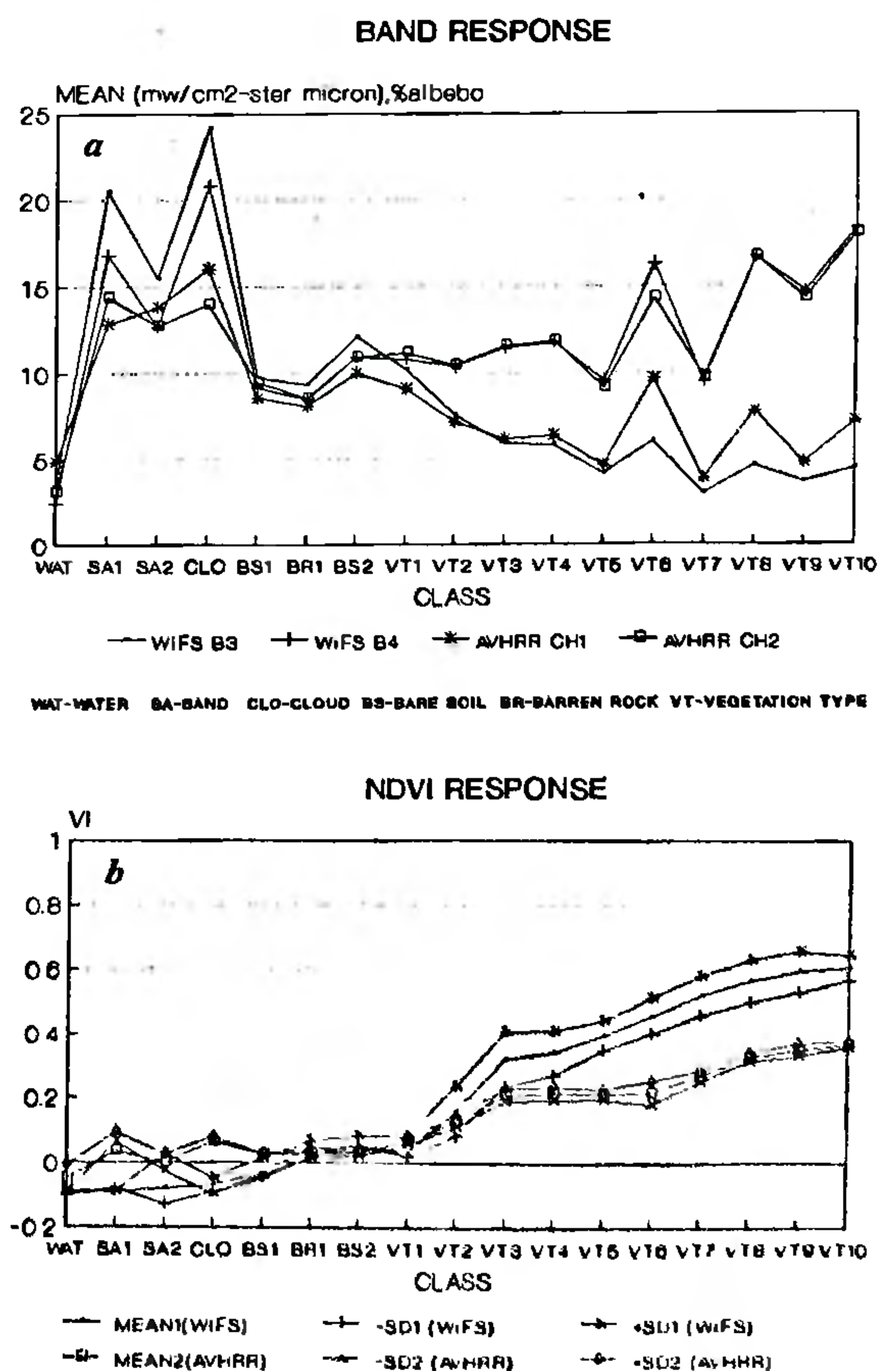

Figure 9 a and b. Comparison of dynamic response of vegetation cover in WiFS and AVHRR.
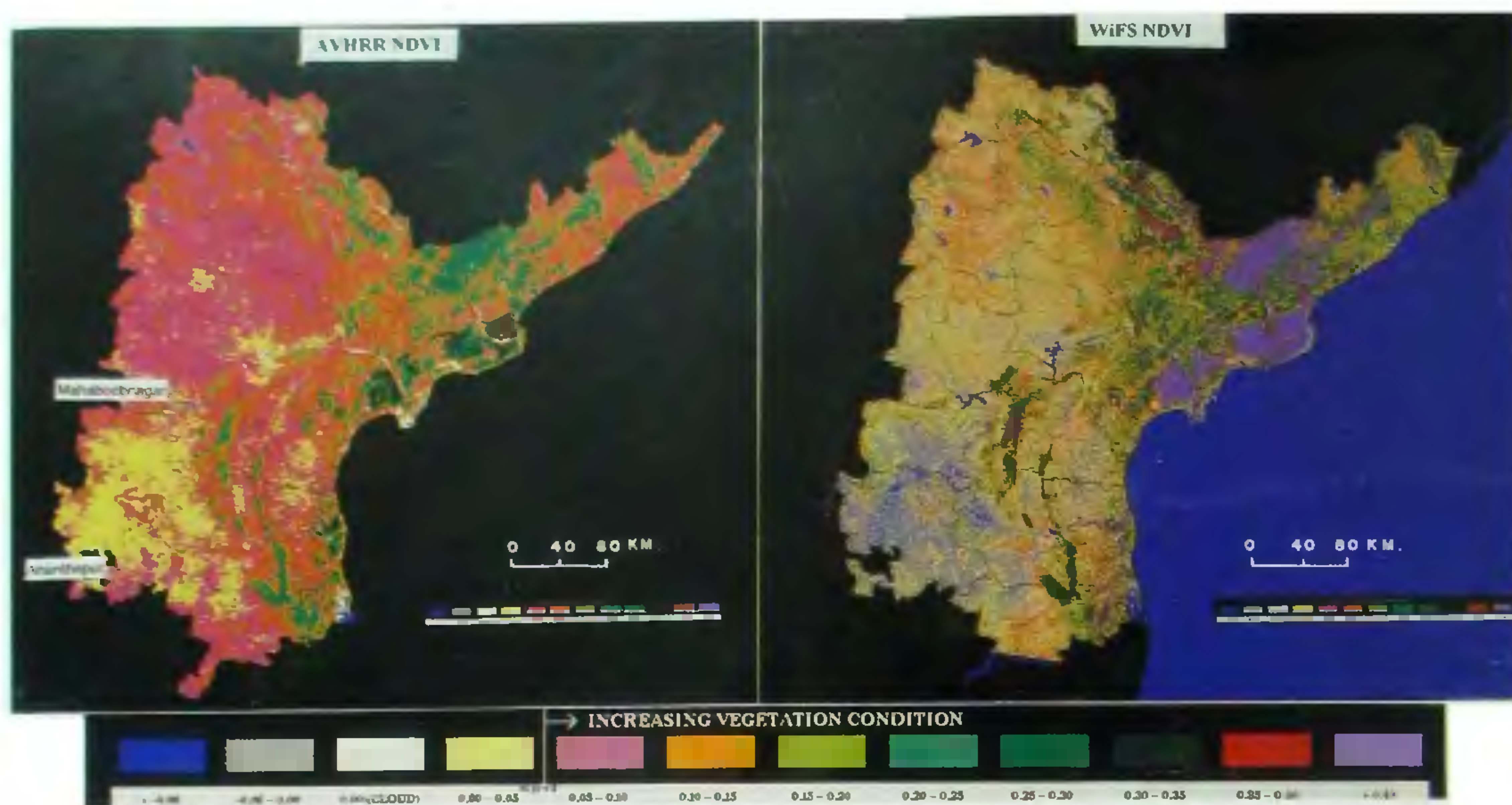
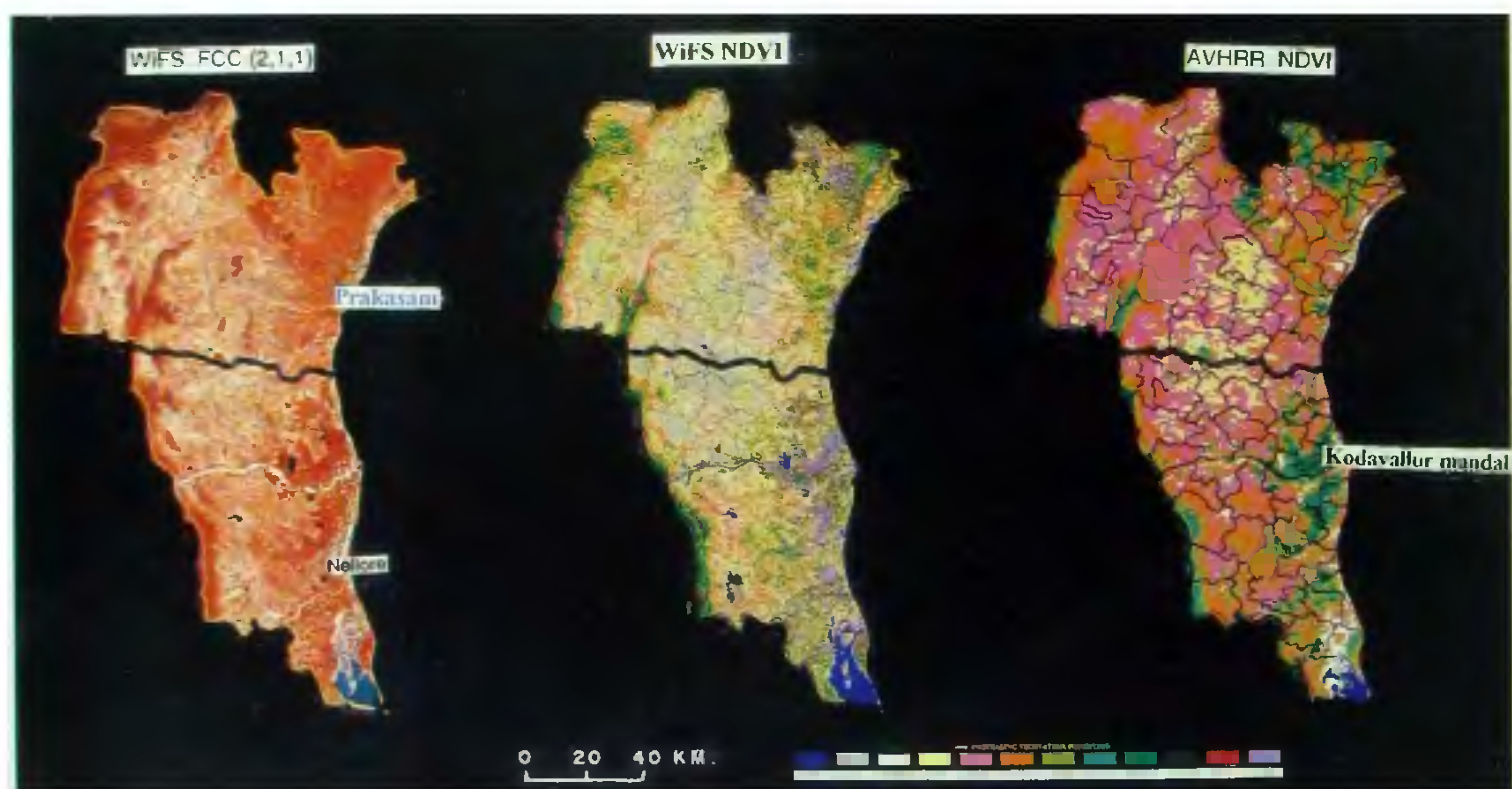Figure 10. NDVI imagery of Andhra Pradesh from AVHRR and WiFS.

Figure 11. Comparison of vegetation index at mandal level in coastal districts of Nellore and Prakasam in Andhra Pradesh.

In spite of its 188 m spatial resolution, waterspread in surface waterbodies can be delineated clearly by WiFS data. While only three irrigation reservoirs could be identified on NOAA data of drought-prone Mahaboobnagar district, most of the minor irrigation tanks can be mapped in WiFS data, indicating the possibility of hydrological drought assessment in addition to improved agricultural drought assessment. Better spatial resolution in WiFS also helps in improved bare soil/vegetation discrimination.

Figure 9 a shows the dynamic range of comparable WiFS and NOAA bands for various landcover/use

categories including different vegetation types. Clearly, the dynamic response of WiFS for all the land cover categories, particularly over vegetation cover, is very high compared to AVHRR data. This is remarkable considering the 7 bit quantization of WiFS compared to 10 bit quantization of AVHRR data, indicating that WiFS is well tuned for vegetation monitoring.

The high dynamic response of WiFS for vegetation monitoring reflects in better NDVI sensitivity for vegetation monitoring (Figure 9 b). The large NDVI range for different vegetation types, compared to the relatively low response in AVHRR, indicates that it would be an effective tool for monitoring the vegetation status and dynamics. Figure 10 shows the comparison of NDVI image generated from WiFS and the time composited NOAA data with the same colour lookup table for different NDVI ranges. The increased vegetation sensitivity of WiFS is seen in longer NDVI range and more number of NDVI classes. The significant increase in NDVI at the bare soil/vegetation transition is also indicative of improved capability for monitoring low vegetation status in the early stages of agricultural season.

A comparison of NDVI statistics at district and mandal levels indicates that similar district statistics are obtained from both WiFS and AVHRR. However, WiFS provides high NDVI value at mandal level compared to AVHRR. Figure 11 shows the NDVI images from WiFS and

AVHRR generated over Prakasam and Nellore districts with overlay of mandal boundaries.

WiFS thus seems to be very effective for monitoring the status of vegetation cover and its dynamics and thus would be a very valuable supplement to AVHRR in objective and reliable monitoring of drought conditions.

Conclusions

This preliminary evaluation of IRS-1C sensors has high-lighted exciting potential for improved water management through its repetitive coverage of dynamic changes and the capability to generate locale-specific details. These initial results will be followed by more comprehensive investigations into its utility in various aspects of sustainable water resources development, leading to its integration in national programmes.

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3. Paul, P. R., Ramana Rao, Ch. L. V. and Siva Sankar, E., International Symposium on Snow and its Manifestations, India, 1994.
4. Thiruvengadachari, S., 39th IAF Congress, Special Publication on Space and Drought Management, ISRO-44-89, Bangalore, India, 1988.