REMOTE SENSING APPLICATIONS IN WATER RESOURCES DEVELOPMENT IN INDIA

A.K. CHAKRABORTI*

INTRODUCTION

Need for Remote Sensing Methods in Hydrology

Water resources planning is usually based on limited and often inadequate data. Existing hydrologic data base may not be oriented to newly arising water resources development requirements It is intuitive that when situations arise which were not considered in the planning of water management systems, it is possible that the systems can fail to meet their design purpose. A major limitation of the existing methods of hydrologic data collection is that these can not provide time-effective data necessary for taking prompt action especially when the area covered is extensive. Hydrologic data measurement points are sparse in most instances. But most important is. hydrologic processes are phenomena that vary rapidly in space and time. Measurements of these hydrologic processes have so far been accomplished primarily by in-situ point measurements. This has required either a high dense network of in-situ observations, or more frequently, and assumption of uniformity or aherence to appriori knowledge of the variability in space and time.

Remote sensing techniques can often acquire data that are available in no other way. or acquire data more quickly, or with more frequent temporal and more complete spatial sampling than other methods of data acquisition. The successive launchings of weather satellites and earth resources observation satellites since nineteen sixties and seventies by many nations including India have given a new dimension of information acquisition and processing through remote sensing techniques in water science. Thus a new potential tool, called 'Hydrologic Remote Sensing' or more popularly, 'Satellite Hydrology' is in the process of evaluation and utilisation over the past two decades. Manual of Remote Sensing. (Colwell, 1983) defines hydrologic remote sensing as 'the study of the Earth's water resources by the use of electromagnetic radiation that are either reflected or emitted from its surface in wavelengths ranging from 0.3 micrometres (um) to 3 metres'. Within this wavelength interval, most remote sensing instruments, that are available today, record spatial variations in electromagnetic radiation coming from the Earth's surface in different spectral bands.

Real strength of modern-day space technology applications in water resources assessment and management are:

**Head, Water Resources Division, Indian Institute of Remote Sensing, Dehradun*

i. Synoptic coverage over large geographic region/river basin with high ground resolution and mapping format.

.ii. Repetitive imaging/spatial data gathering capability, through orbital satellites, for time sequential hydrologic data for change detection and monitoring.

iii. Near real time data gathering, transmission and processing of hydrologic events and phenomena, e.g., flood, drought, snow-melt, reservoir regulation etc.

iv. Compatibility of hydrologic station-point data through proximity sensing (e.g., soil moisture, surface temperature, water quality, etc.) with remote sensing over spatial domains (reflectance, emittance etc.) of the same hydrologic features.

v. 3-dimensional model of the terrain through stereo viewing and interpretability of the photo/image.

vi. Computer compatibility of remote sensing data analysis and generation of thematic map, histogram, statistical correlations, area table, modelling.

vii. Increasing use of automated scene classification, automated cartography, digital terrain modelling, geographic information syste ı through computer-aided techniques.

Indian Scenario

Water resources development is essential for economic and social progress in our country. Rapid population growth in India has resulted in sharp rise in human requirements of water, necessiating expeditious development of the available water resources, and their proper management. The time is perhaps not too far when suitable technologies may have to be evolved for augementing water resources to cater to the needs of areas with inadequate supplies. National priorities of water resources development are increasingly addressed to harnessing water resources in water scarcity areas, cleaning pollution in major rivers, combating duel problems of flood and drought, hydro-power development, assured drinking water supply to urban and rural population and an ever increasing water role to support agricultural production in India. In tune to this priority sector of water resources in overall planning and development in India, some of the present concepts of water technology need to be updated with new tools now available to deal more effectively with the problem of socio-economic growth.

Remote sensing technique in water resources development is in evolving process in many application areas and in some cases in operational stage in India. Use of satellite data for water resources applications was started almost with the launch by USA of Earth Resources Technology Satellite (ERTS-1), later renamed LANDSAT-1 in July 1972. With increasing availability of data over India from a multitude of satellites since then (Table 1), application of this technology has received a good momentum. Spatial and temporal resolutions which were once a constraint for specific applications in water resources, have been narrowed down with currently available satellite coverage over India (Table 2). Department of space has an well-coordinated remote sensing application program, called, 'National Natural Resources Management System' (NNRMS) through which applications to water resources are channelised to achieve conceptualisation, experimentation, development and operationalisation in the country.

Table 1 : STATUS OF REMOTE SENSING SATELLITE DATA AVAILABILITY IN INDIA

Satellite		Launch Date	Termination Date	Data Acquisition in India
Landsat	-1 -2	23 July, 1972 22 Jan., 1975	January, 1978 July, 1983	Selected MSS data from L1 & L2 of atleast one time coverage over India were archived at NDC, NRSA, Hyderabad.
	-3	March, 1978	Sept., 1983	MSS and RBV data from L3 were routinely acquired and archieved at NDC since late 1979.
	-4	16 July, 1982	TM mal - functioned aftre launch	MSS data from L4 have been acquired and archieved at NDC regularly since L4 launch.
	-5	1 March, 1984	Functional	MSS and TM data from L5 are being acquired and archieved at NDC regularly since L5 launch.
SPOT	-1 -2	22 Feb., 1986 22 Jan., 1990	Functional Functional	SPOT Receiption Station (Hyderabad) acquired HRV data directly from early 1987 to Dec. 1990.
IRS	-1A -1B	17 March,1988 29 Aug., 1991	Functional Functional	Data reception,archieval,distribution distribution are done by NRSA Hyderabad.
INSAT	-1B -1D	30 Aug., 1983 12 June, 1990	Functional Functional	VHRR Data reception facility has been established at Satellite Meteorology Centre, IMD, Delhi.
NOAA	-6 -7 -8 -9 -10 -11	June, 1979 June, 1981 March,1983 Dec., 1984 Sept.,1986 Sept.,1988	Terminated Terminated Terminated Terminated Functional Functional	AVHRR data from NOAA-satellites are being selectively acquired, on request by users, and archieved at NDC, NRSA, Hyderabad since 1979.
ERS	-1	17 July,1991	Functional	ERS-1 Receiption station is established at Hyderabad to receive SAR data in image mode.

- LANDSAT, SPOT, IRS series of satellites are dedicated to earth resources and environmental applications,launched by the USA,France and India respectively.
- NOAA series of satellites are primarily designed for meteorological and oceanographic applications, launched by National Oceanographic and Atmospheric Administration (NOAA), USA, since 1960.
- INSAT (Indian National Satellite) satellite series provide national meteorological support services as one of its many functions.
- ERA-1 satellite is Launched by European Space Agency (ESA) with active & passive microwave payloads dedicated to land, ice and ocean observations.

Table 2 : CHARACTERISTICS OF REMOTE SENSING SATELLITE OF INTEREST TO INDIA

Satellite	Orbital Altitude (km)	Equatorial Crossing Time (hrs)	Repetitive Coverage (days)	Swath (km)	Sensor	Resolution (m)	Spectral Bands (um)
Landsat	-1	920	0930	18	185	MSS 80	0.5-0.6,0.6-0.7,0.7-0.8,
	-2				2x98	RBV 40	0.8-1.1,0.475-0.575
	-3						0.58-0.68, 0.69-0.83
Landsat	-4	705	0930	16	185	MSS 80	Same as in L1, 2&3
	-5				185	TM 30	0.45-0.52,0.52-0.60,
							0.63-0.69, 0.76-0.96,
							1.55-1.75, 2.08-2.35
						120	10.4-12.5
SPOT	-1	833	1030	26	60	HRV-MLA 20	0.50-0.59, 0.61-0.68,
	-2					-PLA 10	0.79-0.89, 0.50-0.90
IRS	-1A	904	1030	22	148	LISS-I 72.5	0.45-0.52, 0.52-0.59,
	-1B						0.62-0.68, 0.79-0.86
					2x74	LISS-II 36.25	same as LISS-I
INSAT	-1B	34,000 Geostationary	3 hourly	VHRR	2.75	0.55-0.75	
	-1D					DCS 11 km	10.50-12.50
NOAA	-10	860	0600,1800	2 times	2700 daily	AVHRR 1.1 km	0.58-0.68, 0.725-1.1, 3.55-3.93
	-11		0200,1400				10.5-11.5, 11.6-12.5
ERS	-1	785	1000	variable in phases 3,35,176	100	SAR 25	5.3 GHz, HH Polarisation

MSS : Multi-Spectral Scanner
RBV : Return Beam Vidicon Camera
TM : Thematic Mapper
HRV : High Resolution Visible Imager
MLA : Multispectral Linear Array
PLA : Panchromatic Linear Array
LISS : Linear Imaging Self-Scanning Sensor
VHRR : Very High Resolution Radiometer
DCS : Data Collection System
AVHRR : Advance Very High Resolution Radiometer
SAR : Synthetic Aperture Radar

Scope of this Review

Remote sensing technique is being increasingly used in many earth sciences, environment and engineering disciplines. Manual of Remote Sensing (Colwell, 1983) provides a comprehensive review on weather and climate, marine environment, water resources, agriculture, forest and range lands, geology, urban and rural development, engineering applications, archaeology-anthropology and cultural resources management. In water sciences, this technique is providing valuable information to water resources management situation. However, an well defined school of thought in several branches of satellite hydrology is yet to emerge. This is due to the fact that end-to-end experimentation in any of these branches has yet to take place. And, secondly with fast changes in space technology scenario and associated hardware and software availability, water resources researchers are more pre-occupied with absorption of these technologies than conceptualisation of this tools in water sciences. This situation is relevant in India as well as in developed countries around the world.

However, a bold attempt is made in this review to group works carried out in India in following branches of water sciences : i) Snow and glacier hydrology, ii) Limnology, iii) Flood hydrology, iv) River morphology. Water resources is an inter-disciplinary science in which concept and methodology of other allied sciences need to be incorporated. Remote sensing technique has more integrated these inter-disciplinary sciences than ever before.

Most of the works in India, reported in published literature, are field oriented applications in water resources. Mapping remains the main thrust in developing information system. Analytical/mathematical studies in evolving water resources management models are yet to take shape. This review thus concerns field oriented case studies in most instances.

REVIEW OF WORKS CARRIED OUT IN INDIA

Snow & Glacier Hydrology

Snow, a renewable water resource, represents one of the most complicated parameters to measure with. This is due to the heterogeneous character of the snow-cover in high terrain-relief region, altitudinal variation and presence of vegetation etc. and climatic control by snow storm, wind transport, solar elevation, diurnal temperature, and variation in energy exchanges. After the snow is deposited, the particle shapes are modified by a process known as metamorphism which reduces the area of the snow-flakes accompanied by an increase in the strength of bonds between grains. Introduction of water into snow cover, either in the form of rain or snow-melt, causes a rapid metamorphism.

In the case of snow, crystal size, temperature, liquid water content, density and thickness vary within a short distance and rapidly over time. Field measurements about snow in snow bound areas are hazardous and are not very practical proposition whereas remote sensing from orbital satellite platforms offer easy and time-cost effective means in inventory and monitoring of snow cover information. Spectral response of snow is very unique which are largely influenced by metamorphic processes of snow. Freshly fallen snow has a very high reflectance in the visible wavelength, but the reflectance decreases as the snow ages. Melting condition of snow, presence of impurities, increasing grain size, increase in density of snow, all contribute to decrease in snow reflectance. While sensors in visible and near infrared spectral ranges are useful for snow albedo and snow cover area measurements, thermal infrared is suitable to study conditions. Microwave measurement of snow-pack provides information on snow depth and thermal emission (measured as brightness temperature) with added advantage of all-weather, day-night and penetration-through-cloud imaging system.

Over 600,000 sq.km. area in the Himalayas is snow-bound during winter including the land of permanent snow. 19 major rivers of Ganga, Indus and Brahmaputra systems originate from these permanent ice masses. The impregnable heights, the inaccessibility of the area coupled with steep terrain, very high formation zones of snow and avalanche inhibit ground-base investigations (Rao, 1983). The assessment of snow cover, permanent snow and ice masses (glaciers) and the study of the factors controlling accumulation and melting processes of snow and ice are however of great practical importance to the water management of Himalayan river basins. Himalaya also abounds with glaciers and according to one estimate, Chenab river basin alone contains more than thousand glaciers. The total number of glaciers in the Himalaya may well be around 15,000 (Vohra et.al., 1981).

Snow-melt Runoff Forecasting

The importance of snow-melt forecast lies in providing river management boards, prior information about the snow-melt runoff. If the expected snow-melt runoff can be forecast well in time before the on-set of snow-melt season, it will be great value to water resource project managers to plan in advance optimum reservoir operation schedule for the best utilisation of scarce summer flows for power generation, irrigation and other multiple uses. Runoff contribution of all the Himalayan rivers can be grouped into three major primary sources: i) melting of seasonal snow cover between April to middle of June ii) melting of glaciers from June to middle of October iii) monsoon precipitation from July to middle of September.

Snow-melt runoff forecast requires several information of snow-pack properties: snow cover area (SCA), snow depth, snow water equivalent, snow wetness, snow albedo and the state (frozen or thawed) of the underlying soil. Based on our state-of-art knowledge about space-borne sensors using visible, reflective infrared, thermal infrared and microwave radiation and advantages these provided in repetitive coverage of most inaccessible mountainous regions, it is obvious that remote sensing promises as an effective potential tool for monitoring many of the snow-pack properties. Case studies are:

1. Preliminary work is reported about snow cover mapping in Beas river basin upto Pandoh (5164 sq.km) in western Himalaya using landsat MSS 4 band images dated 21st March, 1973 when the snow cover is at its maximum. Five snow classes: continuous snow cover, wet snow, ice, avalanche-prone areas, and snow-free areas are delineated on 1:250,000 scale by visual interpretation of image, whereas permanent ice and snow line is demarcated from topographic maps (Vohra et.al. 1981).

2. SCA parameter, derived from NOAA AVHRR visible band imageries (0.55-0.68 um, spatial resolution 1.1 km), has been successfully utilised at National Remote Sensing Agency to forecast seasonal snow-melt runoff (April-June) of Sutlej river basin (43,230 sq.km) at Bhakra reservoir since 1980 using regression relations between satellite derived SCA and observed snow-melt runoff of 1975-1978 period (Figure). Cut-off dates when maximum snow-cover condition occurred (any day during January-March) and the day snow-melt runoff begins (sometime during March end/Ist week of April) is very important in this forecast scheme, therefore, judicious selection and interpretation of daily available NOAA AVHRR imageries are advantageous. Difference between forecast, F, (made by NRSA during March end/Ist week of April) and observed flow, 0, (April-June period) monitored by the Bhakra Beas Management Board is of interesting reading: 1980 (-)6%, 1981 (+)5%, 1982 (-)6%, (+ for F>0, - for F<0). With each years addition of data, regression relation is revised and updated (Ramamoorthi, 1984).

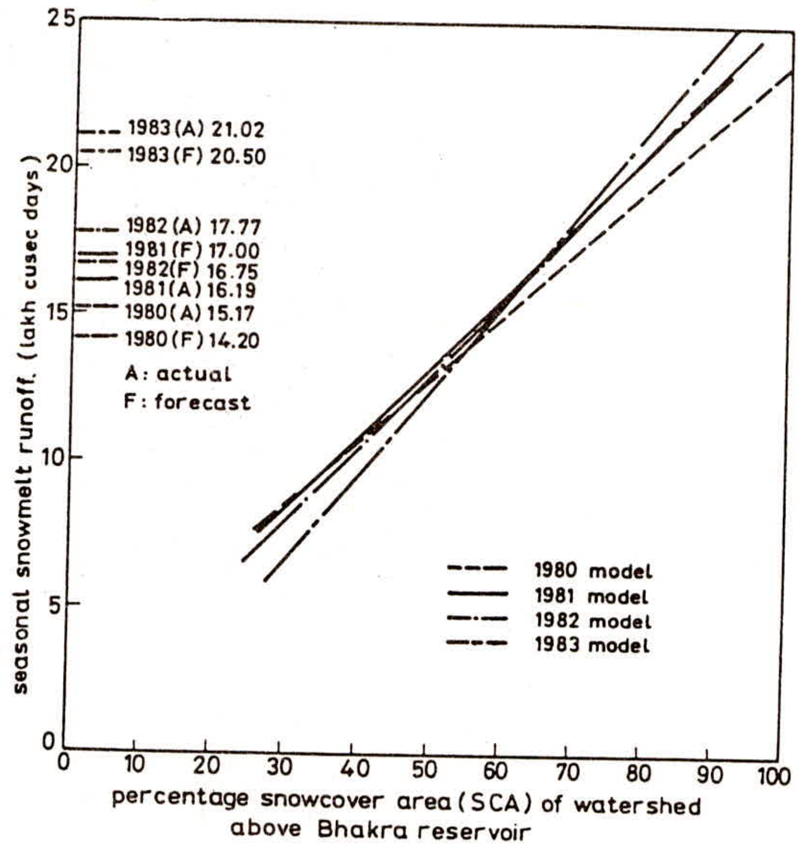

Fig. 1. Seasonal snowmelt runoff forcasting based on NOAA Satellite Image derived SCA of Sutlej River basin at Bhakra reservoir.

(Ramamoorthi, 1984).

Glacier Inventory

Systematic inventory of the Himalayan glaciers is necessary: i) for disaster monitoring and warning as a result formation and rupture of large terminal moraine causing catastrophic flood, and ii) for planning and operation of micro-hydroelectric projects which are supplied with substantial amount of glacier-melt runoff. Case studies are:

1. Satellite data in the form of IRS-1A and Landsat TM multi-date FCC images have been applied for preliminary investigation of glacier inventory in Sikkim and Himachal Pradesh. In order to undertake this task, satellite data are to be selected of season when the seasonal snow-cover is at minimum and glacier exposure is at maximum. This opportunity is available in November-December period in case if Sikkim Himalaya when cloud-free weather condition and minimum seasonal snow cover may coincide and in case of Western Himalaya, a period between middle of August to September is most suitable. Glacier inventory parameters, such as, location, areal extent, length, orientation, accumulation area, abalation/lake area are mapped on 1:250,000 scale (Himachal Pradesh) and on 1:50,000 scale (Sikkim) using image interpretation keys developed for this purpose and are measured using dot grid method. Preliminary findings indicate that in Sikkim Himalaya, based on TM image of 31 December 1987, total area under glacial cover is about 426 sq.km., that atleast 6 glacier lakes, with total areal extent of 5.9 sq.km. located in Tista river valley, appear to pose disaster potential. In Himachal Pradesh, a total of 125 glaciers with glaciated area covering 1896 sq.km. have been inventoried; glacier depths are inferred using geomorphological classification and areal extent of the glacier (both obtained using remote sensing techniques) based on a relationship developed by Muller (1970), water equivalent of glacier ice is estimated to be 165 cu.km. using specific gravity of glacier ice as 0.87. This estimate is 7 times more than the storage capacity of the Govind Sagar reservoir. Limitations in these investigations are: cloud cover in satellite scene in opportune glacier exposure period, cliff shadow, similar spectral reflectance of moraine covered glaciers and surrounding moraines with thick debris-cover around snout, minimal ground-truth information. These limitations might have resulted in error in estimation. Improvement in glacier inventory methodology is suggested by using i) middle IR and thermal IR data, ii) time sequential multi-date images iii) digital analysis techniques iv) reliable ground-truth information v) application validation programme. (Kulkarni, 1990a, 1990b).

2. A negative mass balance was observed for the Gangotri glacier for 1987-88 hydrologic year. This means for that year, total snow accumulation was less than ablation. This information was arrived at based upon analysis of IRS-1A LISS II FCC image of August 16, 1988. The estimate was made by using accumulation area ratio (AAR) method which is the ratio between the accumulation area to the total area of the glacier. The ARR value of 0.45 representing zero mean mass balance for the Himalayan glaciers, Gara and Gor Garang in Kinnaur district, Himachal Pradesh, when compared with observed value of 0.46 for Gangotri glacier on August 16, 1988 indicate that mass balance of this glacier for 1987-88 is negative since this value is likely to decrease further by

Table 3: Glacier characteristics and Mass Balance Parameters of the Gangotri Glacier (Kulkarni, 1989).

Location	:	30° 52'N 77° 07'E	Average height of accumulation area (1987-88)	:	5765 m
Max. glacier height	:	6230 m	Average height of ablation area (1987-88)	:	4610 m
Snout height	:	3920 m			
Transient snowline altitude on 16.8.88	:	5300 m	Accumulation area (1987-88)	:	63.32 sq.km.
			Ablation area (1987-88)	:	72.98 sq.km.
Mean elevation	:	5075 m	AAR (1987-88)	:	0.46
Orientation	:	N-W	Accumulation area (1986-87)	:	75.47 sq.km.
Glacier length	:	26.5 km			
Average gradient	:	87.2 m/km	Ablation area (1986-87)	:	60.83 sq.km.
Mean width	:	6.25 km	AAR (1986-87)	:	0.55

the middle of September. Cloud-free satellite data of September was not available for conclusive evidence. Various features of Gangotri glacier are delineated (Table 3). (Kulkarni, 1989).

LIMNOLOGY

Reservoir Water-Spread Mapping

Due to the strong contrast between water and surrounding surface afforded by satellite reflective infra-red observations, mapping and monitoring of surface water-spread of lakes and reservoirs can be obtained with very good degree of accuracy. In reflective infra-red region, incident radiation is absorbed by water whereas surrounding land and vegetation reflect. Because of this phenomenon, surface water appears black on reflective infrared images and digital mean values are lower than the surrounding land features.

1. Using Landsat MSS CCT data and supervised method of classification technique in Rakaskop reservoir, which supplies drinking water to Belgaum town in Karnataka State, surface water-spread is estimated which is found to be 4.95 percent less than the value obtained from the area-capacity curve of the reservoir (Srinivas and Marathe, 1983).

2. Study in Ukai reservoir using pre & post monsoon (March and November, 1975) Landsat MSS images and visual interpretation provided change in areal extent of water-spread in reservoir. Difference between pre and post monsoon change in reservoir water-spread was found to be quite appreciable (around 70 percent). (Nayak, 1983).

Suspended Sediments in Reservoir Water

Determination of suspended sediment concentration is important in understanding the rate of sedimentation in reservoirs, water quality for drinking water supply and management of aquatic flora and fauna. By conventional hydrographic survey, suspended sediment concentrations are sampled at point-locations. Of-late, orbital remote sensing method is found to be useful as complementary knowledge to in-situ sampling because of its capability for synoptic and repetitive coverage over the water body.

It is necessary to understand the principles of interaction of light and water as well as effects of atmospheric and limnological variables on remotely sensed signal for using satellite data for suspended sediment monitoring of water bodies. For this, laboratory experiment is conducted to establish relation between absolute percent reflectance as measured by Exotech spectro-radiometer compatible to Landsat MSS and corresponding known sediment concentrations in a specially designed laboratory sedimentation tank under known illumination conditions. Multiple linear regression equation between absolute percent reflectance and sediment concentration is found to be as follows:

$$y = 113.9\ B1 - 63.5\ B2 - 51.4\ B3 + 565\ B4 - 22.3$$

where,

y = value of suspended sediment concentration, mg/l.

B1, B2, B3, B4= corresponding percent reflectance in Exotech Radiometer bands.

with, standard error of estimate, e = 56.47 mg/l, coefficient of determination, R = 0.962.

The results indicate that diffused absolute reflectance of water volume increases with increase in sediment concentration and seperability between bands is higher at higher concentrations (Figure 2). Exotech band 2 provides significant response (peak of the curves) for suspended sediment concentrations (figure 3). (Jonna et.al. 1988).

Water Quality Monitoring

Remote sensing of water quality has certain advantages in identifying sources of water pollution, dispersion and dilution pattern in a water body. This is because physics of light and water interaction in presence or absence of pollutants is very unique both spectrally and temporally. However, all water pollutants can not be sensed and measured through this technique. Only those pollutants which affect the colour and intensity of reflected light in a water body can be sensed by remote sensing. For example, many dissolved chemicals have no specific spectral signature while many suspended particulate matters have distinct spectral signature. Thus, any pollutant that adds to the scattering and absorption in a water body has a potential for remote detection and measurement. The phenomenon that impart specific colour and brighteness to an image of water are the following : (i) pollution source characteristics (ii) atmospheric effects (iii) water surface reflectance (iv) water volume reflectance (v) bottom reflectance (vi) sensor characteristics. While qualitative nature of many water quality parameters like colour, turbidity, eutrophication, surface temperature can be obtained by analysing spectral response of water in visible, near infrared and thermal infrared of the electromagnetic spectrum, quantitative information requires statistical correlation of these spectral responses with in-situ water quality sampling. Case studies are:

1. In Husainsagar lake in Hyderabad city and in Godavari river near Rajamundry, industrial pollution and sewage have given rise to water hyacinth, hydrilla and filmentours algae. Water quality monitoring of these two water bodies was conducted using ground-truth instruments and airborne multi-spectral scanner data. Boat level radiometric experiments suggested good correlation between turbidity, dissolved solids, total suspended solids, chlorophyll, chlorides, conductivity and reflectance. Densitometric analysis of black & white diapositives indicates that pollution water can be discriminated from clear water. Scanner data was analysed digitally on an interactive image processing system to produce maps of pollution parameters. (Deekshatulu and Thiruvengadachari, 1981).

2. An example of regional models of water quality of inland tanks and lakes, through regression analysis between water spectral signatures measured by a Landsat MSS compatible Exotech radiometer and in-situ water quality parameters, is cited in four small to medium size storage reservoirs located in Bundelkhand region in central

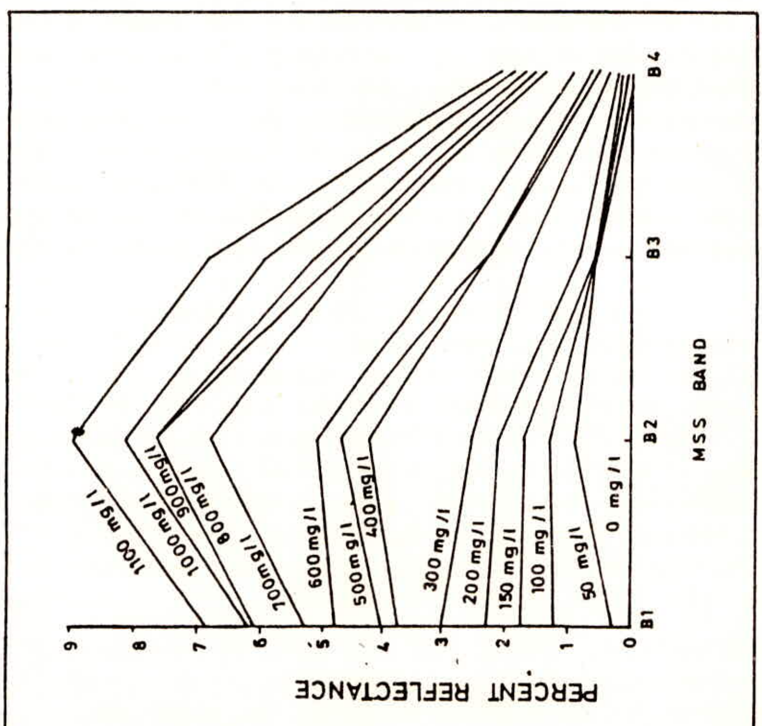

Fig. 2 : VARIATION OF REFLECTANCE IN MSS BAND FOR VARIOUS SEDIMENT CONCENTRATIONS
(Jonna et 1988)

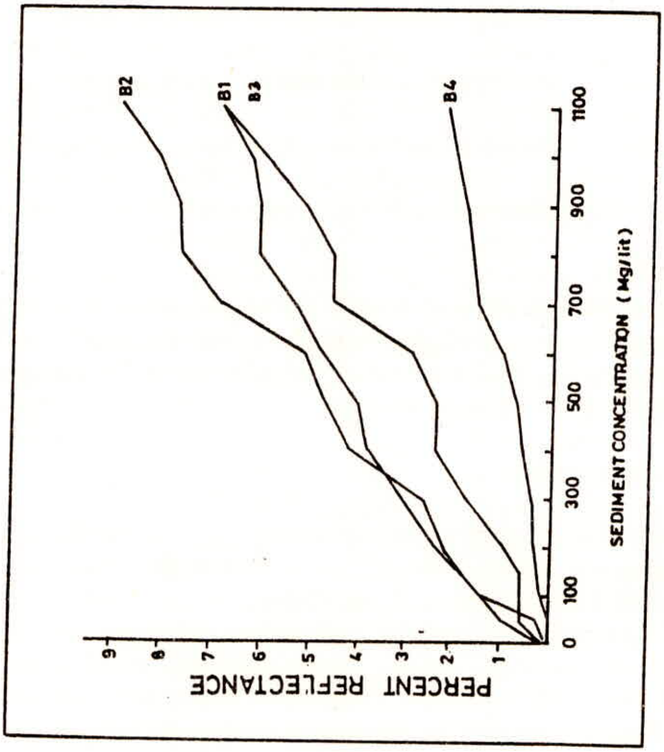

Fig. 3 VARIATION OF SPECTRAL REFLECTANCE WITH SEDIMENT CONCENTRATION IN MSS BANDS
(Jonna et. al. 1988)

India. Stepwise multiple linear regression analysis between water quality parameters (pH, conductivity, turbidity, Ca-Hardness, Chloride, total alkality, temperature, depth) and several functions of radiometer band reflectance values, namely, bands alone, bands and their ratios, and bands and their products are evaluated with respect to performance of the regression parameters (F= -test, correlation coefficient standards error of estimate). It is seen that the pairwise product of the reflectance in different bands is better correlated than the bands and their ratios. A possible explanation for this could be the higher order non-linear relation between the water quality parameters and the spectral bands (Rao et.al., 1981).

3. Water quality studies of Matatila reservoir in Uttar Pradesh, Dal and Wular lakes in Kashmir valley, and chilka lake in Orissa were conducted at Space Applications Centre, Ahmedabad. Characteristics vector analysis and regression analysis to quantify the relationship between 8 different concentrations (1 to 90 NTU) of turbidity levels and IRS-1A LISS II CCT data reveal that except for the periphery of the reservoir, the turbidity in the rest is <16 NTU. The periphery shows higher turbidity (16-40 NTU) due to shallow water and action of waves on the bottom sediments. In Wular lake, using multi-band Landsat images of May, 1977 and 1987 for turbidity studies and Landsat MSS FCC image (January to May) for aquatic vegetation mapping, 7 turbidity levels and distribution of aquatic vegetation (Trapa spp.) have been mapped using visual interpretation techniques. Maximum turbidity is observed at the confluence of Jhelum river and growth of aquatic vegetation is seen to be considerably high during May. A similar analysis is conducted using digital data, namely, band ratio, principal component (PC) analysis, chromaticity technique and supervised classifica-tion. FCC of PC 1 2 3 shows aquatic vegetation in lake clearly, in B3/B1, 3 levels of turbidity and 2 types of density of vegetation area clearly observed. 6 turbidity levels could be identified using chromaticity technique. A similar study is carried out in Chilka lake using Landsat MSS and TM B/W multi-band and multi-date images on 1:250,000 scale and digital data. Analysis of 1972-1988 time period Landsat images reveals decrease in the water-spread and increase in marshy area. Turbidity levels (6 to 8) delineated shows the following turbidity pattern: northern portion: very high turbidity (0.08 to 0.1 m SD), central portion : moderate (0.7 to 1.5 m SD), southern portion : low (>2m SD) (Tamilarasan, 1989).

Flood Hydrology

Floods are regular phenomenon in India during monsoon season. According to National Flood Commission 1980, total area susceptible to floods in the country is around 40 million hectares. National Water Policy 1987 recommends that, "While physical flood protection works like embankments and dykes will continue to be necessary, the emphasis should be on non-structural measures for the minimisation of losses, such as flood forecasting and warning and flood plain zoning, so as to reduce the recurring expenditure on flood relief"

Flood damage surveys are essential not only to assess the extent and severity of damage caused by the floods periodically in river valleys but also for economic evaluation of flood control measures. Moreover, timeliness of information is crucial for managing events like flood. Remote sensing admirably facilitates flood surveys by providing much needed information on flood inundated areas and flood damage assessment of the landuse affected by the flood. For flood hazard zoning. alongwith innundated area, information on flood plain landuse and soil and certain natural flood susceptibility indicators are helpful. Such information from multi-date satellite data on spatial and temporal domains can be derived in cost and time effective means.

Flood Inundation Mapping

Because of the unique recognition characteristics of near infrared spectral bands to map surface water, extent of the area inundated by flood can be obtained easily and uniquely from satellite observation. Both optical and digital data processing techniques are helpful for delineation of flooded area. However, problems encountered with satellite imaging is that (i) cloud free coverage of satellite scene during the monsoon season is most difficult to get, and, (ii) revisit period of the satellite many seem inadequate to map the peak flood situation. To resolve the first problem, active microwave sensors like Synthetic Aperture Radar (SAR) shall provide day-night and all weather imaging capability in near future which will solve terrain imaging penetrated through cloud cover during storm break/peak flood event. The second situation, however, is not a very serious problem, because, the receding flood waters leave identifiable residual effects on soil moisture, vegetation, etc. in the flood plain even days after the flood crest has passed (Chakkraborti, 1990).

In India, mapping flood affected area using satellite data is quite developed at-present.

1. Inundation area of record flood of Sahibi river during 5-6 August, 1977 in Haryana/ western part of Delhi was mapped on 1:250,000 scale using visual as well as digital analysis of Landsat MSS data of 18 August, 1977 (Ramamoorthi and Rao, 1983).

2. Similarly, flood inundation areas consequent to the devastating floods of September 1982 in Ganga, Yamuna, Ghagra, Rapti and Sai rivers affecting southern and eastern part of Uttar Pradesh were delineated using Landsat-3 MSS band 7 images of 20 September, 1982 (Chaturvedi and Mohan, 1983).

3. Experience gained in application of satellite remote sensing in flood mapping during the last two decades in India led the Standing Committee on Water Resources under NNRMS to come out with a monograph detailing procedure to be adopted in flood mapping studies. Regarding time and cost effectiveness using satellite data, time factor to prepare a flood inundation map using image interpretation technique at a Remote Sensing Work Centre in India will be around 10 days from the date of acquisition of satellite data. If IRS-1A/ Landsat TM imagery is used, cost of such mapping is expected to be of the order of 12 paisa per sq.km. (Central Water Commission, 1990).

Flood Damage Assessment

1. In 1988 flood season, near real-time flood mapping and assessment of crop damages due to floods in Ganga in Brahmaputra basins were carried out by the National

Remote Sensing Agency. Comparison of crop area damaged during 1988 Brahmaputra floods in Assam as estimated from satellite images and as per conventional flood damage reporting reveals that the former gives 33 percent less estimated crop damage acreage than the later one. (Ramamoorthi, 1989).

2. Flood affected areas and crop damaged in lower reach of kosi flood plain was monitored using multi date satellite data of 1988 with respect to rise in river flood level (Table 4). Their relationship was also presented (Figure 4) which was then utilised to anticipate flood affected area of 1989 flood season. Difference between anticipated (from Figure 4) and actual (from satellite imagery of 1989) was close to 8.3%.

Table 4 : Area Flooded and Crop Damage in Lower Reach of Kosi River Flood Plain (Ramamoorthi, 1989)

Satellite	Date	River Gauge Level at Baltara (metre)	Satellite Derived Flooded Area (Hectare)	Crop Area Hectares	Damage Value (Thousand Rupees)
Landsat 5 TM	17 July,'88	34.02	5480	2360	2830
Landsat 5 TM	02 Aug.'88	34.22	8310	3570	4290
IRS-1A	08 Aug.'88	34.42	10,940	4700	5640
IRS-1A	30 Aug.'88	35.55	26,280	11300	13560

Flood-Prone Area Zoning

Identification and mapping of flood-prone areas are necessary for proper landuse planning for flood-prone area zoning to keep flood damage to the minimum. Flood events of various magnitudes and recurrence intervals in the historic past might have left certain flood susceptibility indicators which are helpful in delineation of flood-prone areas. Factors to take into account broadly include meteorologic, physiographic, topographic, geomorphic, pedologic and landuse. Remote sensing data provide significant information in later three factors.

1. In a joint work carried out by the Space Application Centre, Ganga Flood Control Commission and Survey of India, preparation of flood-plain maps of middle Gangetic plains was carried out on 1:250,000 scale using available Landsat MSS infrared (0.8 - 1'.1 um) images of 1972-77 period. Flood plain features in these maps include : main river course, tributaries and main streams, inundated areas between getting flooded way and main river, inundated areas between flooded from stream spilling in upper reaches, poorly drained depression, well-drained depression, alluvial fan depression, permanently water congested areas, river levees, oxbow lakes, flood-plain boundary, water bodies, canals, sandy areas, forests. Image Interpretation keys and methodology to prepare

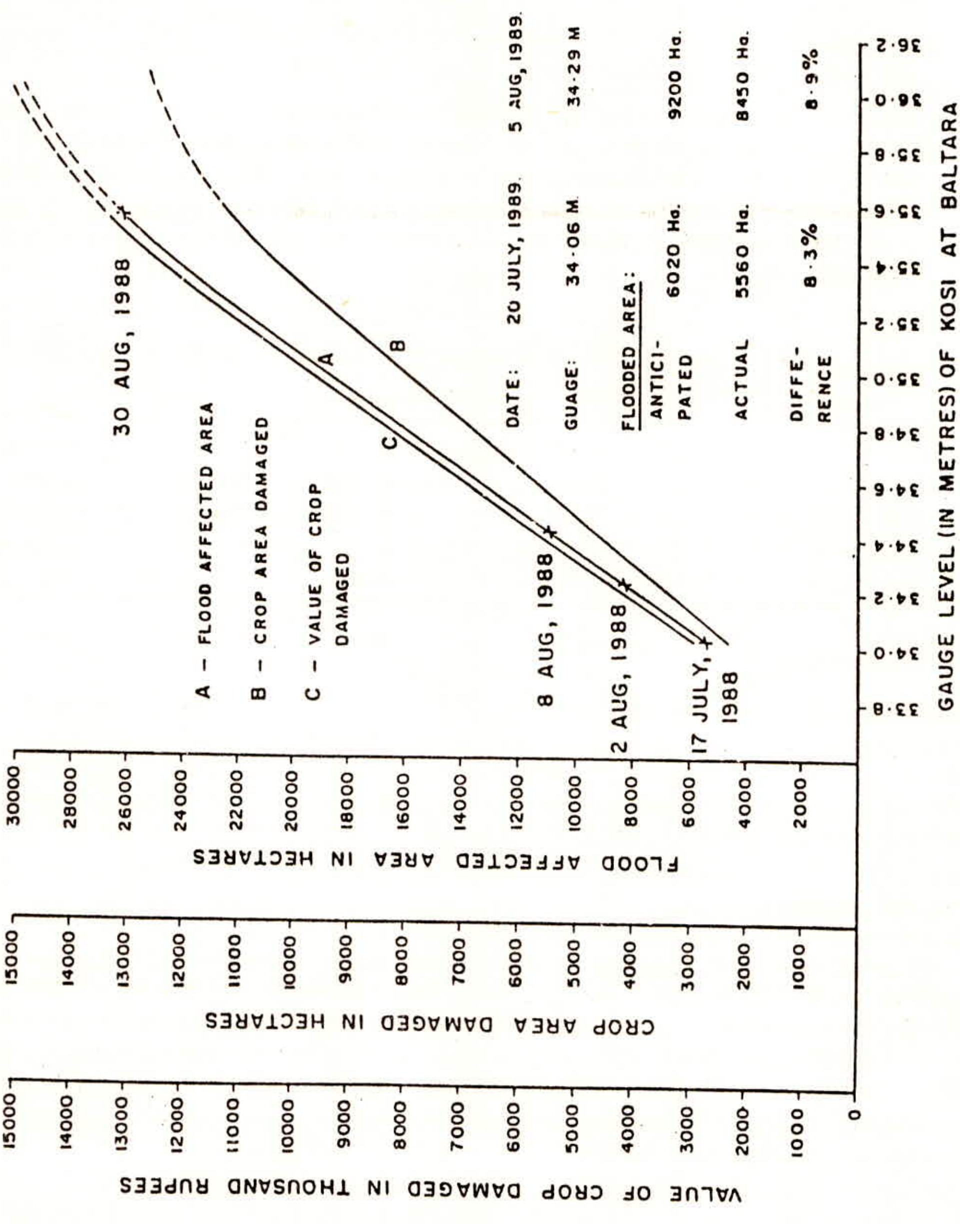

Figure 4 : Flood damage forecasting curves for the lower reach of Kosi Flood Plain.
(Ramamoorthi, 1989)

the maps were evolved. (Dhanju, 1984).

2 One of the important inputs to flood prone area planning is the landuse information of flood plain of the flood-prone river. For extraction of landuse, computer analysis of satellite digital data is often used and is advantageneous. A case study to cite is Lower Barak flood plain in Cachar district of Assam. Barak which causes flood every year, experienced an unprecedented flood in 1976. Historic frequency of flooding has created typical flood-specific landuse in the flood-plain. Landsat MSS digital data of 15 April 1978 have been analysed in the interactive image processing system to derive flood-plain landuse categories. These digitally derived landuse categories and their area estimates when arranged on the basis on geographic-physiographic stratifications provide basis for zoning flood-prone areas and flood-free areas (Table 5). Further refinement in methodology is suggested with detailed topographic contour information (< 0.5 metre) integrated with satellite derived flood-plain landuse information. (Chakraborti, 1985).

3. In a study of Mahanadi river basin down-stream of Hirakud dam using pre and post flood (1985) Landsat MSS FCC images, landuse/landcover information and flood-plain feature information, such as, river course, levees, inundated areas, abandoned channels, sediment deposits etc. are interpreted on a mapping scale of 1:250,000 (national Institute of Hydrology, 1987).

River Morphology

The major tributaries of the Ganga system, namely, Ghagra, Gandhak, Kosi are migratory in pattern and pose serious problem during flooding situation. The riverine system of Brahmaputra constitutes many channels of a most dynamic river changing and migrating in every flood season. Besides these, post-damming effect on the down-steam regime condition of river needs to be closely viewed for possible hydraulic control measures. River bank erosion caused by flood flows poses serious problems to river training works and hydraulic structures, destroys productive croplands and wildlife sanctuaries on the river margin.

Satellite and aerial remote sensing have been applied in India for mapping and studying of river situation. Hydrographic survey is time and costly proposition whereas river configuration mapping and monitoring river channel migration and bank-line changes can be very effectively carried out using remote sensing methods.

River Channel Migration

1. History of Kosi river course changes is an interesting study which still baffles hydraulic engineers in india. The river is said to have shifted its course laterally 112 km away from its original one within a period of 130 years. During its continuous shift, it had destroyed, by deposition of sand, vast tract of culturable land in north Bihar (estimated at 15,000 sq.km.), washed away number of villages and created large swamps in its flood plain. Since 1954, Kosi river has been embanked on both sides all along its 130 km length and controlled by a barrage. Yet the control of Kosi river becomes formidable. In a study of the Landsat MSS FCC image of March 1975, and using medium altitude airborne multi-spectral remote sensing, mapping of river configuration (Figure 5) was performed which provided information on river morphology, effectiveness of

BARAK RIVER FLOOD – PLAIN, CACHAR DISTRICT, ASSAM

TABLE 5. FLOOD-PRONE AREAS AND FLOOD-FREE AREAS BASED ON DIGITALLY DERIVED FLOOD-PLAIN LANDUSE CLASSIFICATION

Landuse Categories		Flood Prone Areas				Flood Free Areas				Total Area under Level I	
Level I	Level II	Riverine Land		Lowlying Country side		Upland		Hills			
		*	**	*	**	*	**	*	**	*	**
Agricultural Land	1. Post-harvest, mainly paddy field					13.49	938.98				
	2. Pre-harvest, seasonal crops	4.99	347.66								
	3. Pre-harvest, chance crops@			3.20	222.93					21.68	1509.57
Water/ Wet land/ Swamp	4. Water in oxbow lake, river	0.39	27.25	.							
	5. Water in inland lake			0.03	1.84						
	6. Turbid/shallow water in field depression			0.14	9.69						
	7. Marshy vegetation			0.09	6.26					0.65	45.04
Forest/Misc. vegetation	8. Misc. trees in rural habitations					33.55	2335.78				
	9. Dense forest/wooded areas							26.86	1869.89		
	10. Scrub/degraded forest							9.76	679.66		
	11. Plantation							1.26	87.95		
	12. Forest jhuming +							0.67	46.33	E 38.55	2683.83
Others	13. Cloud	1.83 *	127.69 **	Summary i. Floodprone Area						8.84 *	615.63 **
	14. Cloud shadow/ hill shadow	3.25	226.53	ii. Floodfree Area						85.59	5958.59
	15. Unclassified	0.49	34.16	iii. Others						5.57	388.38
				iv. Geographical Area Analysed						100.00	6962.61

(Ref. Chakraborti, 1985).

* Percent of Total ** Area in sq.km. E Excluding 8 of Level II.

@ depending on flooding situation in previous monsoon, Boro paddy as chance crop is grown

\+ forest clearing in hill slopes for shifting cultivation practised by tribal people

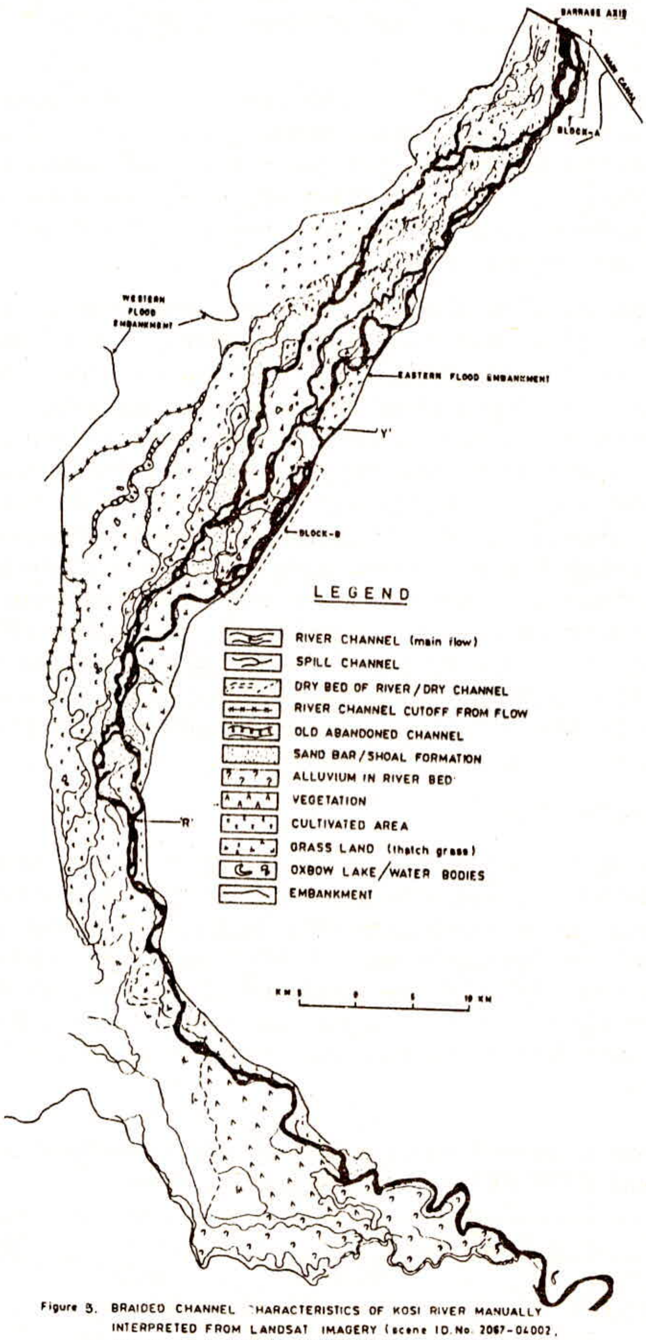

Figure 5. BRAIDED CHANNEL CHARACTERISTICS OF KOSI RIVER MANUALLY INTERPRETED FROM LANDSAT IMAGERY (scene ID. No. 2067-04002, date 30th March 1975). MAJOR FLOOD PLAIN FEATURES WITHIN THE FLOOD EMBANKMENTS ARE SHOWN. BLOCK 'A' SHOWS MAJOR DIVERSION OF FLOW TOWARDS EASTERN FLOOD EMBANKMENT. NOTICE, THE RIVER HAS DEVELOPED REGIME CONDITIONS WITH A SINGLE DEEP CHANNEL DOWNSTREAM OF POINT 'R'. BLOCK 'B' SHOWS HEAVY DRAINAGE CONGESTION AREA DUE TO DIVERSION OF FLOW THROUGH SPILL CHANNEL AT POINT 'Y'. (Chakraborti, 1980)

existing flood control structures, vulnerable reaches where strengthening of control works are needed and inputs necessary to revise layout of laboratory hydraulic model of the river (National Remote Sensing Agency, 1978; Chakraborti, 1980).

2. Flood control problem posed by Brahmaputra river has become a gigantic task for the planners and flood control managers in north-east India. Airborne multi-spectral scanner and photographic survey over Brahmaputra river system from Sadiya to Dhubri extending over 600 km. river stretch provided base line information on river configuration and flood-plain landuse of Brahmaputra valley (National Remote Sensing Agency, 1980-1981).

3. In the Indian arid zone of western Rajasthan, rivers are occassionally subject to flash floods. These flash floods appear suddenly and cause significant morphological changes, particularly in the form of channel widening, deepening, bank erosion and deposition by bank scour and slumping. Temporal changes in emphemeral river courses and associated flood plains of Luni river was identified and mapped using post-monsoon season of October 1986 Landsat TM FCC image on 1:50,000 scale and topographic maps of 1958 of the same scale (Singh et al. 1988). Boundaries of flood plains could be delineated on the basis of the flood plain indicators such as channel configuration, fluvial geomorphic characteristics and soil differences. Average width of river and flood-plain when compared with Landsat based estimation were found to be within 10% of the actual field estimation. Superimposition of maps of river courses and flood-plains prepared from both data sources revealed that over a period of 28 years, the river courses widened by 1.8 times and their areal extent increased due to 2-4 metre dissections of the flood plains (Table 6 and 7).

River Bank-Line Migration

Mighty Brahmaputra river erodes its banks at many reaches during every flood season. To arrive at quantitative evaluation of the river bank recession along Kaziranga national Park, an approach has been evolved by using satellite images and aerial photographs of 1984 and 1987 and topographic maps of 1915 and 1968 in a time series analysis using national highway NH-37 as the datum line. Results indicate that there has been a trend of increasing erosion (1.06 sq.km./year) between 1968-1984 time-frame than previous period of 1915-1968 with bank erosion of 0.40 sq.km./year. (Chakraborti and Das Gupta, 1989).

Table 6 : Extent of River Courses and Associated Flood-Plains as Computed from Landsat TM FCC Image (Singh et.al., 1988)

River	River Course		Flood Plain	
	Area (Km^2)	Average Width (m)	Area (Km^2)	Average Width (m)
Luni	68.27	555	324.95	2640
Mitri	15.53	222	118.78	1540

Table 7 : Temporal Changes in River Courses and Associated Flood-Plains (Singh et.al., 1988)

River	Area (Km^2)		Average Width (m)	
	1958	1986	1958	1986
Luni	38.10	68.27	310	555
Mitri	8.50	15.53	121	222

CONCLUDING REMARKS

1. In the context of critical need for judicious management of our limited water resources, basic hydrologic data and monitoring are required. Remote sensing has some advantages vis-a-vis conventional hydrologic methods to meet some of these requirements.

2. Works carried out in India (mainly field oriented) in several branches of hydrology using remote sensing techniques, with special emphasis on use of data directly acquired in India from several satellites including India's own satellite IRS-1A, have been outlined in this paper.

3. Greatest strength of hydrologic remote sensing is its ability to identify, measure, map, inventory, monitor, model, forecast, surveillance of hydrologic events and phenomena. While many of these are in research mode, remote sensing activities ahead of us held better promise for Space Hydrology.

4. While it may well be appreciated that not all elements of 'water cycle' are amenable to remote sensing, this technique can aid in some of the water resources development programmes, if judiciously applied and understood.

5. Building up of application-oriented case studies in this emerging technology is the need of the hour for the water resources planning agencies in the country to derive maximum benefit of hardware being put into space and the promise offered by Satellite Hydrology.

REFERENCES

Bhar, A.K. 'An Overview of Remote Sensing Applications to Sedimentation Studies'. Hydrology, vol.11, no.1, Jan-April, 1988, p.13-17.

Bhar, A.K., Ramasastri, K.S. 'Snow Cover Mapping and Snow-melt Runoff Estimation from Remotely Sensed Data. Jal Vigyan Sameeksha, vol.4, no.1, June 1989, p.65-73.

Central Water Commission, Govt. of India. 'Monograph on Application of Satellite Remote Sensing in Flood Mapping'. 1990, 44p.

Chakraborti, A.K. 'Quantitative Description of Upper Barak Drainage Basin & Stream Networks Derived From Landsat Imagery'. Proc. INDO-US Workshop on Remote Sensing of Water Resources, Hyderabad, April 1978, p.160-173.

Chakraborti, A.K., Roy, P.S. 'Influence of Drought on Ecosystem As Observed From landsat'. Proc. International Symposium on Hydrological Aspects of Droughts, New Delhi, December 1979, vol.1, p.47-66.

Chakraborti, A.K., Rao, K.R. 'Utilisation Potential of Surface Water Information Through Satellite Sensing'. Proc. XIX Congress of the International Association of Hydraulics Research. New Delhi, December 1980, vol.VI, p.20-27.

Chakraborti, A.K. 'Study of Kosi River Characteristics Using Airborne/Space Orbital Multispectral Scanner Data'. Advances in Space Exploration, Pergamon Press, 1980, vol.9, p.211-214.

Chakraborti, A.K., Seelan, S., Rao, K.R. 'Assessment & Management of Land and Water Resources in Drought Prone Areas From Satellite Derived Data'. Proc. International Symposium on Remote Sensing of Environment, Cairo, January 1982, vol.2, p.1003-1012.

Chakraborti, A.K. 'Digital Mapping of Flood-Plain Landuse'. Proc. Sixth Asian Conference on Remote Sensing, Hyderabad, November 1985, p.442-447.

Chakraborti, A.K. 'Urban Storm-water Runoff Modelling Using Remote Sensing technique'. IIRS Technical Report, 1989, 66 p.

Chakraborti, A.K., Das Gupta, I. 'Study of Bank Erosion of Brahmaputra River near Kaziranga National Park Using Remote Sensing Data'. Technical Note, 1989, 21 p.

Chakraborti, A.K. 'Flood Control Planning : A Role For Aero-Space Technology' Proc. 5th National Convention of Civil Engineers, Calcutta, January 1990, p. AKC 1-8.

Chandra, S., Sharma, K.P. 'Application of Remote Sensing to Hydrology'. Proc. Symposium on Hydrology of Rivers With Small & Medium Catchments. New Delhi, vol.2.

Chaturvedi, R.S., Mohan, R. 'Delineating Flood Affected Areas of South Uttar Pradesh Using Satellite Remote Sensing Technique'. Proc. National Symposium on Remote Sensing in Development and Management of Water Resources, Ahmedabad October 1983, p. 79-87.

Colwell, R.N. (ed). 'Manual of Remote Sensing'. American Society of Remote Sensing, 1983, vol.II.

Deekshatulu, B.L., Thiruvengadachari, S. 'Application of Remote Sensing Techniques for Water Quality Monitoring'. Final Project Report, National Remote Sensing Agency, Hyderabad, 1981, 261 p.

Dhanju, M.S. 'Studies of Kosi River Flood by Remote Sensing'. Hydrology Review, vol.2, no.4, 1976, p.43-48.

Dhanju, M.S. 'Ganga Flood-plain Mapping From Satellite Imagery'. Project Report, Space Application Centre, July 1984, 114 p.

Farnsworth, R.K., Barrectt, E.C., Dhanu, M.S. 'Application of Remote Sensing to Hydrology including Ground Water. Technical Document in Hydrology, UNESCO, 1984, 122p.

Jonna, S., Mohanty, P.K., Badrinath, K.V.S., Chakraborti, A.K. 'Spectral Characteristics of Sediment Laden Water'. Journal of Indian Society of Remote Sensing, vol.16, no.4, 1988, p.27-32.

Kulkarni, A.V. 'Application of Remote Sensing For Glacier Inventory & Mass Balance'. Proc. National Symposium on Engineering Applications of Remote Sensing and Recent Advances. Indore, Dec. 1989, p.26-30.

Kulkarni, A.V., Narain, A. 'Remote Sensing Based Glacier Inventory in the Sikkim State'. Scientific Note, SAC/RSA/RSAG-MWRD/SN/01/90, January 1990, 11p.

Kulkarni, A.V. 'Remote Sensing Based Glacier Inventory in the Himachal Pradesh'. Scientific Note, SAC/RSA/RSAG-MWRD/SN/04/90, June 1990, 22p.

Ministry of Water Resources, Govt. of India. 'National Water Policy' 1987.

Mohan, S., Mehta, N.S., Mehta, R.L., Patel, P., Bora, V.H., Sule, K.K., Purohit, S.P., Rai, S., Singh, H.P., Ramakrishna, Y. 'Multi-Frequency Microwave Measurements of Soil Moisture'. Proc. National Symposium on Remote Sensing For Agricultural Applications New Delhi, December 1990, p.357-363.

Muller, F. 'Inventory of Glaciers in the Mount Everest Region', in : Perennial Ice and Snow Masses : a guide for compilation and assemblage of data for World Inventory, Technical paper in Hydrology, USCO, no.1, p. 47-59.

National Institute of Hydrology. Landuse Mapping of Upper Yamuna Catchment Using Remotely Sensed Data. Case Study Report, CS-14, 1986-87, 41p.

National Institute of Hydrology. "Flood-Plain Mapping of River Mahanadi by Remote Sensing Application". Case Study Report, CS-20, 1986-87, 48p.

National Institute of Hydrology. 'Remote Sensing Applications for Sedimentation Studies in Reservoirs'. Technical Report, TR-57, 1987-88, 39p.

National Institute of Hydrology. 'Metamorphism and Remote Sensing Physics of Snow'. Technical Report, TN-40, 1988-89, 61p.

National Remote Sensing Agency. "Airborne Multispectral Scanner Survey of Kosi River, January 1978 and October 1978 Tasks". Project Reports, 1978.

National Remote Sensing Agency. "Airborne Multispectral Scanner and Photographic Survey of Brahmaputra River". Project Report, 1980-1981.

National Flood Commission, Ministry of Irrigation, Govt. of India. Guidelines and Instructions for the Implementation of the Recommendations of the National Flood Commission'. 1980.

Nayak, S.R.' Orbital Monitoring of Suspended Sediment in Water Bodies'. Proc. National Symposium on Remote Sensing in Development and Management of Water Resources, Ahmedabad, October 1983, p.134-147.

Palria, S., Thakore, S.S., Muley, M.V., Chakraborty, M., Tamilarasan, V., Kawosa, M.A. "Remote Sensing of Water Quality in the Dal and the Wular Lakes of Jammu and Kashmir, India". Proc. 39th Congress of International Astronautical Federation, Bangalore, October 1988, Paper No. IAF-88-147.

Ramamoorthi, A.S. 'Snow-melt Runoff Studies Using Remote Sensing Data' in : Remote Sensing. Indian Academy of Sciences, Bangalore, 1984, p.185-192.

Ramamoorthi, A.S. 'Flood Management : Application of Remote Sensing'. Proc. 40th Congress of International Astronautical Federation, Special Current Event Session, Malaga. Spain, 1989, p.9-30.

Rao, K.R., Krishnan, R., Chakraborti, A.K., Deekshatulu, B.L. 'Water Quality Models With Different Functions of Exotech Radiometer Band Values'. Proc. 7th International Symposium on Machine Processing of Remotely Sensed Data. LARS, Purdue University, USA, 1981, p.262-268.

Rao, K.S., Chandra, G., Rao, P.V.N. 'Study of Penetration Depth & Its Dependence on Frequency, Soil Moisture, Texture and Temperature in the Context of Microwave Remote Sensing'. Journal of Indian Society of Remote Sensing, vol.16, no.2, 1988, p.7-19.

Rao, N.M. 'Problem Areas in Snow Cover Monitoring and Avalanche Investigations'. Proc. National Symposium on Remote Sensing in Development and Management of Water Resources, Ahmedabad 1983, p.19-23.

Rao, U.R. 'Space & Flood Management'. Proc. 40th Congress of International Astronautical Federation, Special Current Event Session, Malaga, Spain, 1989, p.1-7.

Sharma, K.P., Seth, S.M., Acharya, B.N. 'Application of Remote Sensing Techniques for Hydrologic Investigations of Uttar Yamuna Catchment' Journal of Indian Society of Remote Sensing, vol.12, no.1, 1984, p.37-48.

Sharma, R., Sahai, B., Karale, R.L. 'Identification of Erosion Prone Areas in a Part of the Ukai Catchment'. Proc. Sixth Asian Conference on Remote Sensing, Hyderabad, November 1985, p.121-126.

Sigamani, P.N., Guruswamy, V., Sakthivadivel, R. 'A Case Study of Tank Inventory in Aranian-Korataliyar Basin of Tamil Nadu By Remote Sensing Techniques'. Proc. National Symposium on Remote Sensing in Development and Management of Water Resources, Ahmedabad, 1983, p.93-98.

Singh, A.N. 'Assessing Extent of Damage Caused by Flooding and Drought in Dominently Rice Cropland Area Using Landsat Data'. Proc. Eighth Asian Conference on Remote Sensing, Jakarta, October 1987.

Singh, S., Sharma, K.D., Singh, N., Bhohra, D.N. 'Temporal Change Detection in River Courses and Flood Plains in an Arid Environment Through Satellite Remote Sensing'. Journal of Indian Society of Remote Sensing, Vol.16, no.4, 1988, p.53-56.

Sriniwas, M.G., Marathe, G.T. 'A Case Study on Computer Aided Analysis For Reservoir Capacity Evaluation Using Landsat MSS Data'. Proc. national Symposium on Remote Sensing in Development and Management of Water Resources, Ahmedabad, October 1983, p.43-48.

Sriniwas, P. 'Use of Multidate Landsat Data in Evaluating the Surface Water Availability as an Indicator of Drought Condition'. Journal of Indian Society of Remote Sensing, vol.17, no.1, 1989, p.17-22.

Tamilarasan, V., Muley, M.V., Chakraborty, M., Palria, S., Singh, T.S., Murthy, T.V.R. 'Water Quality Monitoring Using Remote Sensing Techniques'. Proc. Appreciation Seminar on Remote Sensing of Environment, Ahmedabad, Feb.1989, p.139-163.

Thiruvengadachari, S., Rao, P.S., Rao, K.R. 'Surface Water Inventory Through Satellite Sensing'. Journal of the Water Resources Planning and Management Division, ASCE, July 1980, p.493-502.

Thiruvengadachari, S. 'Satellite Sensing of Irrigation Patterns in Semi-arid Areas : An Indian Case Study'. Photogrammetic Engg. and Remote Sensing, vol.47, no.10, October 1981, p.1493-1499.

Thiruvegadachari, S. 'Remote Sensing of Tank Irrigated Areas in Tamil Nadu State, India'. International Journal of Remote Sensing, Vol.4, No.3, 1983, p.545-554.

Thiruvengadachari, S. 'Remote Sensing Applictions in Drought Monitoring'. Jal Vigyan Sameeksha, Vol.4, No.1, June 1989, p1-29.

Viswanath, B.R., Ramamoorthi, V.Y. 'Flood Indundation Mapping Through Satellite Remote Sensing-Indian Experience'. Jal Vigyan Sameeksha, Vol.4, No.1, p. 30-35.

Vohra, C.P., Agarwal, N.K., Srivastava, G.S. 'Application of Remote Sensing Techniques in Snow and Ice Hydrology'. Journal of Photo-interpretation and Remote Sensing, Vol.9, No.1, 1981, p.49-57.