CS(AR)-23/96-97

FLOOD PLAIN MAPPING OF PHULBARI AREA USING SATELLITE DATA (ASSAM/MEGHALAYA)

NATIONAL INSTITUTE OF HYDROLOGY
JALVIGYAN BHAWAN
ROORKEE - 247 667
1996-97

CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

ABSTRACT

Flood is a natural calamity in which most parts of the North Eastern States are ravaged. Management of the problem in these disastrous flood affected areas often requires flood plain mapping for protection and resource development. This has mostly being done on the basis of ground based survey which is time consuming as well as often hazardous.

Remote sensing methods especially with the advent of satellite era, provide excellent periodic information in real time for these areas. In fact, data obtained from satellite has now become the only reliable means for mapping the problem areas.

Phulbari, one of such problem areas in Assam & Meghalaya within flood plain of the mighty Brahmaputra has been undergoing continuous erosion by the recurrent floods. To conceive protection scheme for Phulbari, flood plain mapping has long been warranted. The report attempts to map the flood plain of the area with the remote sensing data for which IRS-1A & 1B, 1:50000 False Colour Composite have been used. Analysis has been carried out from the delineation of pre & post monsoon periods of 1988, 1992, and 1996. Survey of India toposheet (1961) has been compared with the latest satellite data for the study of bankline migration of the Brahmaputra at Phulbari area. Extensive site visit was made for ground truth verification and interpretations from imageries were supplemented.

1.0 INTRODUCTION :

Flood plain is an area adjoining a main river course, stream or other water course which gets flooded during periods of high water when stream flow exceeds the carrying capacity of normal channel. During the process of river bed deformation, it results from bank erosion and deposition of sediments transported by the stream.

Natural floodplains provide a temporary storage for attenuating floods significantly. These generally are excellent areas for aquacultural, agricultural and forestry production, pleasing settings for homes, and ready made transportation corridors that make them attractive for intense human activities. Due to increasing human encroachments, capacity of flood plains to store water temporarily gets reduced resulting increased flood peaks on downstream and necessitating costly protection works.

Before taking up any protection works detailed maps depicting extent of floodplains and water features are required. Also, to assure the effectiveness of existing flood protection works investigations are to be carried out at regular intervals. Such studies help in detecting possible changes in the terrain condition, land cover etc. due to developmental activities in the flood plains and to conceive suitable steps to deal with the problems.

In India, an area of about 40 million hectares is prone to floods, out of which 30 million could be protected economically according to National Flood Commission,1985. The area affected annually on an average is 7.4 million hectares. The loss when covered in terms of money is Rs.640 crores. Major flood problem in India is mostly in the Brahmaputra and its tributaries and other rivers like the Barak in Assam. North East of India experiences heavy rainfall which causes frequent overflowing of the rivers, erosion of the river banks and inundation of towns and agricultural lands. Phulbari area in west Garo Hills of Meghalaya is one of the problem areas severely affected by large scale erosion. Here the river

Jinjiram with its frequent changing course outfalls into the Brahmaputra on its south bank between Fakirganj and South Salmara of Dhubri District of Assam. Under the guidance of CWC, the Irrigation Dept.,Govt of Meghalaya has undertaken a erosion control project in the area.

To supplement the field survey already carried out for the project, flood plain mapping from satellite imageries for different periods have been made. It has been further updated with ground truth verification.

The conventional approaches to collect such information have been ground based surveys which are both uneconomical and time consuming. Remote sensing data is used with advantage over conventional methods because of its capability to provide broad synoptic coverage which helped in studying the integrated effects of various aspects of the ecosystem. It is now possible to correlate the cause effects of changes which are being monitored and plan for sustainable preventive measures.

2.0 REVIEW :

2.1 Features of Flood Plain :

Mapping of flood plains of a river system is based on the identification of various features connected with floodplains. These features are river course, drainage pattern, alluvial fans, oxbow lakes, marsh areas and back swamps, point bar deposits, river levees and flood plain deposits.

2.1.1 River Course

Three distinct patterns of river course are identified viz; (i) braided stream (ii) straight stream and (iii) meandering stream. A braided stream can be defined as one which flows in two or more channels around alluvial islands. Braided pattern develops after local deposition of coarser material which can not be transported under local condition existing in the reach. Straight reach is rarely found in streams for a long stretch. Rivers flowing through alluvial material follow a zigzag path. This phenomenon is known as meandering. These streams follow a more or less sinusoidal path.

2.1.2 Drainage Pattern

The drainage pattern may be defined as the arrangement of surface flow channels covering an area, in complete details of their density, orientation, uniformity etc. The surface drainage pattern is probably the most consistently reliable indicator of ground conditions available.

2.1.3 Alluvial Fans

When there is a reduction either in the discharge or in the slope of an equilibrium stream, the stream can not transport the material carried by it and the excess materials will be deposited. These deposits depending upon the mode of deposition are called as alluvial fans.

2.1.4 Oxbow Lakes

As meanders grow, a narrow neck of land is often cut through from two sides, thus causing the stream to straighten its course. The ends of the meander that have been cut off are then likely to be chocked with sediments. Water from the main stream seeps in to this meander and forms what is commonly known as Oxbow Lake.

2.1.5 Marshy Areas and Backswamps

Low lying areas that get inundated during floods turn in to marshes when floods recede. Sediments of marshes consists of organic clays. Burrows and plant roots are also its features. Backswamps are developed behind the levees when these are overtopped by flood waters.

2.1.6 Point Bar Deposits

Bed forms having lengths of the same o der as the channel width or greater and heights comparable to the mean depth of flow are known as bars. A bar occurring on the inside of the bed in an alluvial channel is called a point bar.

2.1.7 Flood Plain Deposits

During floods, river water rises above the banks and as it moves away from the main current, its velocity is reduced. As a result a large part of the sediment load of the stream gets deposited as the bank line is passed. These deposits are called flood plain deposits.

2.1.8 River Levees

River levees are formed by deposition of sediments when flood waters overtop the river bank. The velocity is reduced causing deposition of much of the suspended sediments near the channel. The maximum height of a levee indicates the water level reached during the highest flood.

2.2 Techniques of Flood Plain Mapping

The techniques of flood plain mapping can be classified in two categories. They are:

i) Conventional Technique and

ii) Remote Sensing Technique

2.2.1 Flood Plain Mapping by Conventional Technique

A variety of methods are available for mapping of floodplains by conventional technique. The appropriateness of a particular technique can be presumably be judged by the extent to which the flood plain information satisfies the objective of the user. Methods of mapping areas subjected to flood can be grouped as : physiography, pedology, vegetation, regional flood of selected frequency, flood profile and back water curves.

<u>Physiographic Mapping:</u> The concept of physiographic mapping of flood prone areas is based on the correlation of specific topographic features with flood discharge of known frequency. Thus the flood plain, often the lowest topographic bench near a river, has been found to lie at an elevation that is overtopped generally once in every 1 to 2 years. Where successive levels of stepped topography exist, these river terraces or deposits on them may be correlated with particular flood events. Once such a correlation is established large areas of a valley may be mapped with the knowledge that specific topographic levels can be associated with floods of known frequency and elevation. The method will not ofcourse permit distinction of local variations of topography due to scour and erosion.

<u>Soil Mapping</u>: Mapping of flood areas by correlation of soil type, stratification of deposits, or drainage characteristics with known flood levels requires the same

kind of established relationships as those required for flood zone mapping based on topographic form. In the field soil characteristics are often associated with topographic features and hence one might be used to strengthen the other.

Vegetation Mapping: Many observers have noted an association of vegetation with presumed flood levels. Specific assemblages of plants may sometimes may correlated with specific water levels. Studies have established between susceptibility of species of damage and flood deposition and duration of inundation. Such physiological evidence and the distinct age differences in the flood plain trees produced by destructive floods suggest the possibility of designating maximum flood heights or minimum land elevations subject to flood from associations between flooding and vegetation.

Regional Flood Mapping: Experience shows that in a given physiographic or hydrologic region, flood heights of chosen frequencies may be mapped on a regional basis from records at selected localities. The method is based on observations at stations in the region of the heights above the channel bed attained by floods of different magnitudes. By relating flood heights of different return periods to parameters such as drainage area and mean annual flood discharge, curves can be drawn that permit flood heights to be determined at ungauged sites of known drainage area within the region.

Flood Profile and Back-Water Curve: In this method flood lines are delineated by defining flood profile from high water marks or detailed hydraulic computations. To achieve a high degree of accuracy detailed topographic information is required for the purpose which may be obtained either by engineering ground surveys or aerial photography combined with ground control.

2.2.2 Flood Plain Mapping Through Remote Sensing Technique

For flood plain mapping two types of information are of primary concern: i)Timely information of character and extent of flooding and ii)Accurate flood plain delineation.

Conventional ground based methods are well established but often time consuming and hazardous to be undertaken before the recession of flood. Hydrologists as well as water resources planners and decision makers often felt handicapped in absence of timely data about flooding extent and other related data till the advent of remote sensing techniques to acquire such data.

To meet the need of quick and reliable information, modern technique of remote sensing can be used to map the extent of flood plains, to monitor floods in progress and also to predict the occurrence of floods. As in the case of most remote sensing applications, the best use of satellite capabilities is achieved in the context of well designed multifaceted observing system which makes the best scientific and economic use of available data. The optimum mix of satellite, aircraft and surface data is situation specific. It will depend upon the size of the basin being considered, the availability and relative costs of various types of data and the analysis of such data. Remote sensing has been gaining wide spread application in most important fields of Hydrology, environment, agriculture, flood, meteorology etc. due to its repetitive and real time data collection abilities.

Two basic approaches for flood plain delineation by remotely sensed data are available. The dynamic method records floods as they actually occur or soon after the high waters have receded. It takes the advantage of the fact that visible evidence of inundation in the near infra-red region of the spectrum remains for upto two or more weeks after the flood. This is significantly reduced near infrared reflectivity in the flood areas caused by the presence of increased surface soil moisture, moisture stressed vegetation and isolated pockets of standing water.

Real Time Flood Plain Mapping by NRSA: Real time data on flood indicating its extent was prepared by NRSA and can be procured at any time. With only time required for mapping, the outline of the flood plain can be drawn. NRSA prepares such maps on requisition. On cloud covered days it is difficult to procure remote sensing data which makes browsing essential before ordering for the data. On time browsing facilities are not available at the state remote sensing application centres, however from 1998 July taped information shall be provided by NRSA through INTERNET. Preparation of real time flood maps will then be much easier.

The second method referred to as the static approach, utilizes the fact that flood plains can be recognized with remote sensing because of permanent or long term features caused by historical floods. These indicators (**Table-2.1**) have been enumerated by Rango and Anderson.

TABLE:2.1 LANDSAT FLOODPLAIN INDICATORS

Sl.No.	Description
1.	Upland physiography.
2.	Watershed characteristic such as shape, drainage, density etc.
3.	Degree of abandonment of natural levees.
4.	Occurrence of stable sand dunes on river terraces.
5.	channel configuration and fluvial geomorphic characteristics.
6.	Backswamp areas.
7.	Soil-moisture availability.
8.	Soil differences.
9.	Vegetation differences.
10.	Landuse boundaries.
11.	Agricultural development.
12.	Flood alleviation measures on the floodplain.

In remote sensing two types of platforms- Aircraft and satellite are most commonly used for earth observations. The data obtained from these platforms are termed as aerial photos and imageries respectively.

2.3 Flood Plain Mapping Using Aerial Photos

Aerial photography is found to give satisfactory results especially when it is possible to obtain a series of successive photographs during the flooding and recession period. However the interpretation becomes difficult in the areas where bodies are covered by bushes and forest. In a wide and poorly forested flood-plain, water edges can be easily identified. Stereoscopic viewing is helpful in areas in which interpretation based on tonal variations is difficult. Black and white infrared film is superior to the black and white panchromatic film. The addition of colour aids interpretation in both the visual and near infrared wave lengths Where heavy vegetation is encountered colour infrared film appears to be the best available film for inundation mapping(Hoyer et al,1978).

Airborne multispectral scanner data has also been used for flood plain mapping by many researchers. Using aircraft multispectral data and using natural indicators such as vegetation types, soil types, moisture differences and geological variations, accuracy of the flood plain delineation was improved in pristine areas and reduce the costly field surveys. Remote sensing delineations of flood plains using aircraft data have proven successful because of capability of detection of various natural and artificial indicators. Airborne surveying of floodplains requires favorable coincidence of the inundation level needed for flooding and suitable weather for taking photographs. These difficulties considerably limit the use of aerial photographs for studying flood-plain inundation over long river reaches.

2.4 Flood Plain Mapping Using Satellite Data

The things have improved radically after the onset of satellite era, especially after the launching of Landsat series from 1972. Because of the unique and distinctive property of water to absorb energy at reflected infrared, it becomes very convenient to use reflected or near infrared data obtained from Landsat to map flood inundation. It may be observed that water as a significant lower reflectance than terrestrial features throughout the near infrared(0.7- 12 um) portion of the electromagnetic spectrum.

Because of this, surface water appears black on reflective infrared images except for cases of high turbidity. The aerial spread of water bodies is relatively easily and accurately delineated from near infrared data. Measurements of area covered by a water spread is function of the pixel size. Suitability of different spectral bands for flood plain mapping is given in **Table: 2.2.**

TABLE 2.2: SUITABILITY OF DIFFERENT SPECTRAL BANDS FOR FLOOD INUNDATION MAPPING

SPECTRAL BAND	APPEARANCE OF FLOODED AREA	SUITABILITY OF FLOOD MAPPING
Blue (0.4 to 0.456 um)	Lighter	Fair
Green (0.48 to 0.57 um)	Lighter to Darker	Very poor
MSS-5,Red	Lighter to Darker	Poor
MSS-7,IR	Darker	Good
Colour IR Composite (Green,Red & IR Bands)	Mottled red,grading to green,blue or gray.	Very Good
Blue and IR false coloured as blue and red respectively	More blue to purple	Excellent

2.5 Visual Method of Analyzing Remote Sensing Data

Aerial photos and imageries represent the permanent record of terrain information at the time of exposure. Different terrain features reflect different amount of electro-magnetic energy due to variation in their chemical composition and physical condition. This variation in amount of reflected energy, which is recorded on imagery, forms the basis of its identification. The process of extracting qualitative information from the imagery is termed as image interpretation. There are eight elements in image interpretation which help in identifying the features of the object of interest. These are:i)shape, ii)size, iii)pattern, iv)shadow, v)tone, vi)texture, vii)site and ix)association.

i)Shape: This is an important single factor in recognizing objects from their images. Shape relates to the general form, configuration or outline of an individual object. A railway can be distinguished from a road because of its shape consists of long straight tangents and gentle curves when compared to the curved shape of highway.

ii)Size: Size of an object is an usable clue to identify it. By measuring an unknown object in an imagery the interpreter can eliminate from consideration groups of possible classification.

iii)Pattern: Pattern relates to spatial arrangement of objects. The repetition of certain general forms or relation ships is characteristic of many objects both natural and manmade and gives objects a pattern which aids the interpreter in recognizing them.

iv)Shadow: Shadows are of important to interpreters in two opposing respects. The outline of a shadow affords a profile view of objects within shadows reflect little light and are difficult to interpret.

v)Tone: Tone refers to colour or relative shades of the imagery. It is related to reflectance of light from the objects. Water which absorbs nearly all incident light appears black where as cement concrete highway reflects a high percentage of light tone without tonal differences, shapes, patterns and textures of objects can not be distinguished.

vi)Texture: Texture is created by tonal reflection in groups of objects that are often too small to be identified as individual objects. It gives a visual impression of roughness or smoothness. The texture of an image may be coarse, medium or fine. Enlarge scale photographs for example broad leaf tree species can be distinguished from small leaf species on the basis of coarser texture.

vii)Association: The location of objects with respect to terrain features and othe. objects is often helpful. The open flat dark vegetation is easily identified as swamp or marsh in vegetated area once it is known that the area of study lies near the sea coast.

2.6 Colour Photography

Both Panchromatic (B&W) and colour photography can be used effectively to conduct photographic interpretation. There are special applications where colour photography can be very valuable. These include geological mapping, geochemical, geobotanical studies, forestry studies, detailed landuse studies where difference in growth patterns of the time of exposure are of significance. In certain river, harbor and coastal studies colour photo is much in use.

The strong contrast between water and surrounding surfaces in Landsat band 7 MSS imagery is of much use for delineation of surface waterbodies. Surface water features have a very dark tone in this band. However, some times if black soils are metwith, it would pose difficulty in delineating the water bodies as both have almost the same reflectance. In such cases band 5 imagery can be referred to a False Colour Composite (FCC) which is of best use in such interpretation difficulties.

2.7 Thematic Mapper (TM) vs Multi-Spectral Scanning (MSS) Data for Flood Studies :

The Thematic mapper (TM) data has a high spatial resolution and regarding mapping of surface water resources, it results in improved surface water detection capability both in terms of location and water spread fluctuations. The finer resolution implies a smaller percentage of boundary pixels for the same water spread area compared to MSS, leading to improved area calculations. The increase from 4 bands in MSS to 7 bands in TM sensor, theoretically doesn't add to improved surface water mapping and monitoring,using visual interpretation techniques, since band 4 of TM analogs to band 7 of MSS is one of the best for this activity.

In general the black and white images from near infrared wave lengths provided best visual interpretation capabilities. FCC products provide additional information on surface water quality which are not easily obtainable from black and white imagery. Studies have shown that TM band combinations 3 4 5 & 3 4 7 are better than 2 3 4 combination, for visual delineation of water features. Digital mapping has indicated that band 7, in combination with MSS analogs bands provides better results. Surface water mapping is possible upto 1:50,000 scale using currently available TM data enlargements.

In the case of flood studies, embankments, spurs and other control works are more clearly discernible on TM imagery as compared to MSS imagery because of the finer resolution of TM data. Because of more number of TM bands, better differentiation between wet/moist, dry areas, standing water damage scares, sand cast areas etc. is possible. Among the FCC band combination 4 5 7 combination is very useful especially for differentiating sandcast areas from other inundated areas. Moist areas are enhanced although different classes within the standing water are not identifiable. While TM FCC with band combination 2 3 4 is comparable with Landsat MSS FCC except for higher contrast in the former, TM FCC with band combination 3 4 5 is more useful to delineate dry and wet crops. TM FCC 3 4 5 is also useful to delineate command areas under tanks and inundated areas under crops. General flood inundation mapping can be done at 1:250,000 scale but finer details like breaches in embankments and detailed river configuration studies are possible at 1:50,000 scale. It is also possible to distinguish more number of classes of damaged groups and partially damaged crops by digital analysis.

One of the distinct advantage of Landsat TM data is improvement in the boundary delineation of different strata of inundation due to increase in resolution. The individual bands bring out certain unique aspects of vegetation cover as manifestation of physiological and phrenological variations.

Considering the spectral separability between land water and vegetation is more pronounced in the visible to middle reflected region of the electro-magnetic spectrum, the different multispectral band combinations of Landsat TM increase the scope for identification of more number of land cover classes. Digital techniques are more useful for differentiating between overlapping classes like forest cover and plantation, plantation and crops etc. where interpretation cannot discriminate.

2.8 Flood Plain Analysis Using Digital Data :

Use of digital data enables an automatic classifier to be developed. There are two basic approaches that use pixel by pixel analysis to map water bodies.

This method is fast and easy to set on computer but it may result in serious misclassification if there are area adjacent to the flooded area that have similar low reflectances. The second approach is to develop a classifier from training set data. This approach is to minimize the misclassification by taking advantage of reflectance data from more than one spectral band. In addition, this approach may be the only reliable way to differentiate sediment -laden water from adjacent land.

Digital mapping has indicated that band 7, in combination with MSS analogs bands provides better results. Digital techniques are more useful for differentiating between overlapping classes like forest cover and plantation, plantation and crops etc. where interpretation cannot discriminate.

2.9 Remote Sensing Satellites:

The satellites in the space are capable of providing stable platform with distortion free images covering a larger area under uniform illumination condition to facilitate easy recognition of major features of the earth surface. Since satellites orbit around the earth/with the rotation of the earth, it has added advantage that it is possible to obtain repetitive coverage at periodic intervals under different seasonal and illumination condition. Based on the purpose and objectives, the satellites are classified into:

1.Weather satellites/meteorological satellites (Metsat)
TIROS-1/NIMBUS, NOAA, INSAT-1D

2.Remote sensing satellites - IRS, LANDSAT, SPOT, ERS3.

3.Marine resources satellites - SEASAT, MOS

4.Specific purpose oriented satellites - RADARSAT, SPY
satellites

Another type of classification which is common with the satellites system is based on their orbital characteristics viz. Polar orbiting satellites and Geostationary satellites. Polar orbiting satellites circle around the earth from north to south and the orbit is near polar. Most of the Remote sensing satellites are of this nature which facilitates easy scanning of the earth surface at periodic intervals. Example: IRS, LANDSAT, SPOT, NOAA, etc. The Geostationary Satellites are positioned in the space in such a way that the satellite orbit is synchronized with the speed of the earth resulting in continuous observations of the same spot of the earth. Example: INSAT -1D, GOES.

2.9.1 Indian Remote Sensing Satellite (IRS):

In India, Department of Space is engaged in space research activities during the past decades. One of the off shoot of space activities is the design, development and management of Remote Sensing satellites. The first Indian experimental satellite for remote sensing, designed and developed by Department of Space was BHASKARA-I, launched from Soviet Cosmodrome in 1979. The second satellite, named BHASKAR-II was launched in 1981. These satellites were placed at an altitude of 525 km with circular orbiting characteristics carrying sensors composed of two television cameras and three microwave radio meters. Parallely, ROHINI series of satellites designed and fabricated by the Department of Space were also launched during 1981 and 1983. The experience gained with the launching of experimental satellites such as BHASKARA and ROHINI gave enough confidence to design and develop Indian Remote Sensing satellites (IRS). The IRS-1A which is a representative of the first series of remote sensing satellites for resources survey and monitoring was launched on March 17, 1988. This satellite is sun-synchronous, polar orbiting at an altitude of about 900 km. with a repetitive cycle of 22 days with equatorial crossing time of 10:00 AM. This satellite is expected to carry a payload consisting of one low resolution (72.5 m) and two medium resolution (36.25 m) LINEAR IMAGE SELF SCANNING cameras utilizing solid state linear arrays operating with a "PUSH BROOM" scan mode. The multispectral data in the IRS-1A system is collecting data in four different spectral regions ranging from 0.42 m to 0.86 m. The spectral bands chosen in IRS-A are closer to those of the first four bands of thematic mapper in Landsat-5 and also those provided in the French remote sensing satellite, Spot. Second Indian remote sensing satellite IRS-1B was launched in August, 1991 since the life of IRS-1A was to expire in 1991 though it is still working. So IRS-1B was launched as a complimentary to IRS-1A both having similarity in various spectral and orbital characteristics. For acquisition, storage, retrieval, evaluation, dissemination and training for utilization of IRS data, NRSA has been identified to play the key role.

Encouraged by the past experience Department Of Space took up the ambitious challenge of developing next generation satellite namely IRS-1C with improved sensor and coverage capabilities to meet the growing needs. The popularity of satellite based remote sensing has created a need for providing data with better resolution, coverage and revisit. IRS-1C was conceived to meet these demands. Two satellites IRS-1C and IRS-1D with similar payloads each with a life mission of three years were also planned. Principle components of the mission are a three axis stabilized polar sun synchronous satellite with three sensors, ground system for in-orbit satellite control and the main objective of the mission is to develop new areas of user applications to take full advantage of the enhanced resolution and capability of IRS-1C/1D sensors. The pay load platform accommodates the Panchromatic camera (PAN), Linear Imaging and Self Scanning Sensor-III (LISS-III) and Wide Field Sensor (WiFS) cameras. In addition it accommodates Earth sensors and Star sensors.

IRS-P2 is also placed in sun-synchronous orbit at an altitude of about 817 Km on October 15,1994 by PSLV-D2 from Shriharikota with a ground tracing velocity of 6.67 Km/s. The 804 kg satellite carries two cameras LISS-IIA and LISS-IIB, providing images in four spectral bands similar to IRS-1A/1B without LISS-1 sensor. IRS-P2 sensors are configured on board with two CCDs(Charge Couple Device) placed in the focal plane of a single optics of each band thus resulting in only one electro-optic module. This provides the working capability of LISS-II of IRS-1A/1B with reduced volume and weight.

2.10 Case Studies:

Remotely sensed data for flood plain mapping have been used in India by various investigators. Using satellite data (Landsat 1 and 2) taken during 1972 and 1975. Dhanju (1976) studied the shifting meandering and flooding of Kosi river. From the imagery taken in the flooding period he was able to map the inundated areas flood boundaries and other associated features. Chakraborty (1979) has observed that courses of interlacing channels of the river can be easily delineated through band 7 imagery alone. Band 5 analysis of airborne multispectral Scanner data was found to be useful in obtaining detailed information regarding flood protection works. Further applications of remote sensing methods on Ganga flood plain mapping indicate the usefulness of satellite data for delineation of the features like inundated areas, backswamps, oxbow lakes, river levees etc.

Usually, aerial photographs of 1:30,000 to 1:60,000 are used. Some of the important recent studies dealing with flood mapping with aerial photographs or with data collected with airborne surveys are mentioned. Bhattacharya and Mankhand(1979) have delineated geomorphic units in the flood plains of Ganga-Gomti in Azamgarh and Ghazipur districts in Uttar Pradesh. Chopra(1980) had delineated an abandoned meander belt close to the Ranganadi river in district Lakhimpur, Assam. Such recognitions are important as these indicate the channel migration pattern and susceptibility to floods.

At the instance of Ministry of Water Resources, Govt. of India part of the Ganga in the vicinity of Farakka Barrage was surveyed in May 1981. Aerial Photomosaics and river configuration maps were prepared and supplied to Farakka project to take timely flood protection and anti erosion measures and to under take model study at CWPRS. In order to provide data products to Ganga Flood Control Commission scanner and photographic survey of Gandak river below international border to its confluence with Ganga was undertaken in December 1982. This survey showed that the reach of Gandak which was surveyed has undergone considerable changes from what has been shown in the toposheets of

1970.

National Remote Sensing Agency arranged a number of aerial flights both with modular multispectral scanner and aerial photography over flood prone rivers in the country (Ramamoorthi, 1983). At the instance of Central Water Commission, an aerial photography and scanning of certain reaches of the Brahmaputra river was undertaken in August, 1978. The Brahmaputra is normally at its highest stage in August. Aerial photographs and scanner visicorder photo outputs covering the Brahmaputra river and adjoining area near Jogighopa-Goalpara reach including the photo mosaic were prepared. Computer analysis of digital data of four different channels were also done. The thematic photo outputs provided significant hydrologic information about the flood plain features, submerged areas and situation of river when it was in high stage. The survey was repeated in November , December, 1978 for a stretch of 600 Km from Sadiya to Dhubri. This survey was done to provide information to the Brahmaputra Flood Control Commission for effective flood control planning.

Dhanju (1976) made visual interpretation of Kosi River Flood Plain with landsat imagery. Areas under inundation by floods during August/September 1975 were delineated by Dhanju using Oct 1975 Landsat Imagery. In October some areas were still under water due to low gradient and poor drainage.

Dhanju delineated flood plain features of the Ganga basin lying between the latitudes of 25^{o} N to 27^{o} N and longitudes 83 ^{o} E to 85 ^{o} E by visual interpretation of Landsat Imagery. Interestingly this study inferred that frequent inundation of Ganga Kosi Area might result in Kosi joining the Ganga above Bhagalapur bend instead of its present point at Kursela, distance between them being about 50 Km. This forecast may or may not materialize but it demonstrates the potentialities of such studies.

Multi stage remote sensing data has been used to study the flooded coastal areas of Andhra Pradesh during Nov. 1977 by Narain and Patel. Landsat imagery was used at the stage-1 and the aerial imagery at stage-2. Diazo colour composite and black and white paper prints were used for delineations employing visual interpretation. This study has lead to formulate an operational approach for quick assessment of damage caused by flood. It has been estimated that such a study would cost Rs.45/- per Sq.Km.

Study of Ramamoorthi and Subba Rao (1983) is among the few where both digital and visual interpretation techniques were employed in flood plain mapping. In this study, dealing with the Sahibi river flood in Delhi Harayana in Aug. 1977, outputs were produced based on improved contrasts between water/wet surfaces and surrounding dry area. Band rotation and contrast stretching were resorted to. Colour thematic outputs showing the pre flood and post flood conditions of the flood affected areas were prepared in 1:250,000 scale. However, it is worthy to note that there is not much difference between the aerial extent of the flooded areas delineated from satellite data and from photographic survey.

Chaturvedi (1983) delineated the flood inundated areas in parts of Southern and eastern Uttar Pradesh during the peak floods of September, 1982 on the basis of sharp tonal contrast between the water spread and the adjacent areas. It was also possible to delineate areas from where the water had just receded. The impounding of pre-existing dry lakes and ponds was particularly noticeable in the vicinity of flooded rivers. Notwithstanding the limitations on account of cloud cover and resolution of present day satellites, it was still possible to make accurate assessment of flood affected areas.

Sharma et al. (1985) visually analyzed the band 7 infra-red landsat for mapping flood plains and allied features in the Ganges between Allahabad to Chapra (Bihar). The features were identified in the 1:250,000 scale enlargement of band 7 imagery. The aerial extent of the flood plain area in the study region was also computed which came out to be 3800 Sq.Km. It has been observed in the imagery that flood plain of river Ganga increases immensely at downstream of Varanasi and reaches its maximum at chapra. The river Gomti which meets with river Ganga about 40 Km. downstream of Varanasi is itself famous for its devastating floods in the study regions.

3.0 STUDY AREA :

3.1 Location:

The study area is geographically located between 25°50'and 26°0' of northern latitude and 90°0' and 90°15' of eastern longitude. It is situated in West Garo Hills of Meghalaya and Dhubri district of Assam and at a distance of 250 km from Guwahati. Location of study area and its IRS imagery index is shown in **Fig 3.1 & 3.2.**

.3.2 Rainfall:

Average annual rainfall in the Jinjiram sub-basin is about 3324.70 mm. November to February are the dry months of the year. Spring rains are frequently high which are about 26% of the annual rainfall. June to August are the wettest months of the year and rainfall during this period is about 62% of the total annual rainfall. Rainfall and related data regarding the Jinjiram river and the basin collected from CWC, Phulbari at the time of ground truth verification are as follows:

Maximum daily rainfall	- 511.140 mm
Minimum daily rainfall	- 0.254 mm
Total monthly rainfall (Max.)	- 818.730 mm (September 1995)
Total monthly rainfall (Mini.)	- 8.13 mm (January 1996)
Maximum water level	- 29.50 m (July 1995)
Minimum waterlevel	- 23.12 m (February 1996)
Maximum discharge	- 3864.40 m^3/sec (July 1996)
Minimum discharge	- 4.86 m^3/sec (March1996)

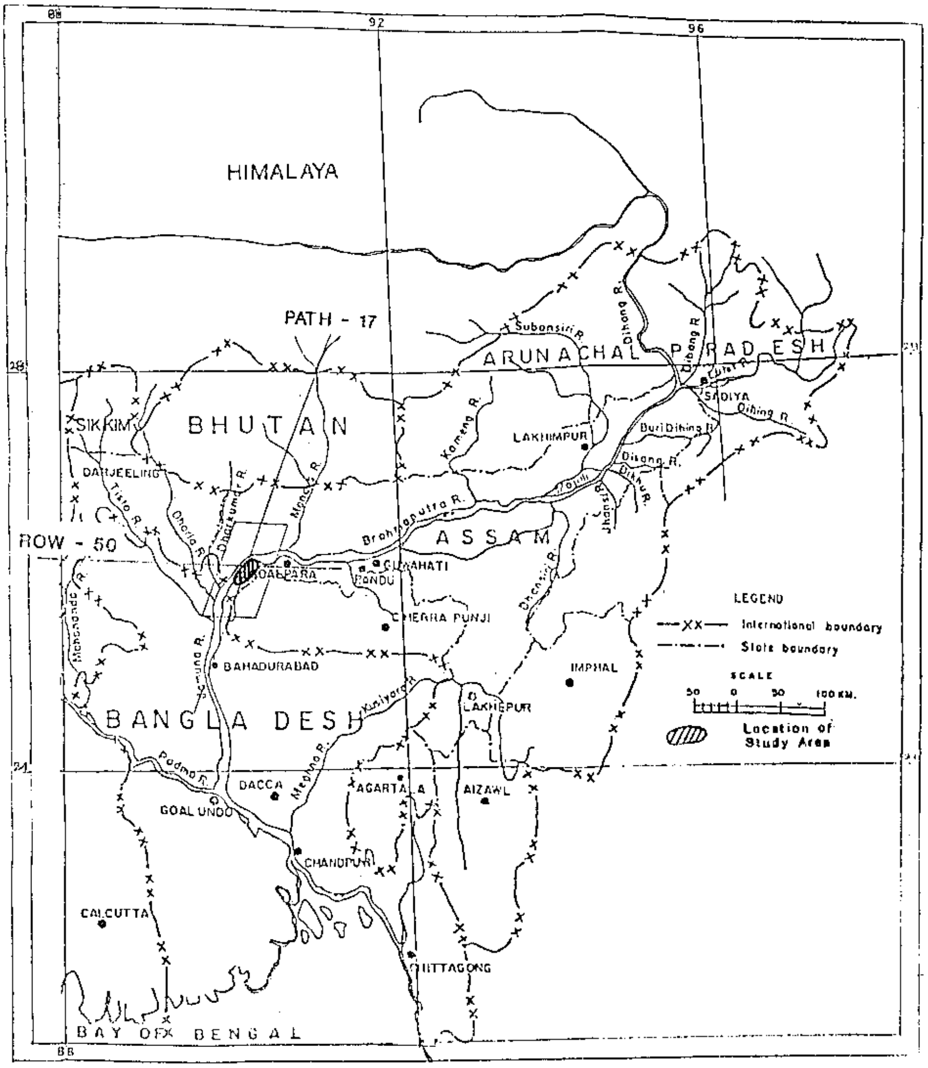


Fig. B.1. LOCATION OF STUDY AREA ON BRAHMAPUTRA AND IT'S IRS IMAGERY INDEX

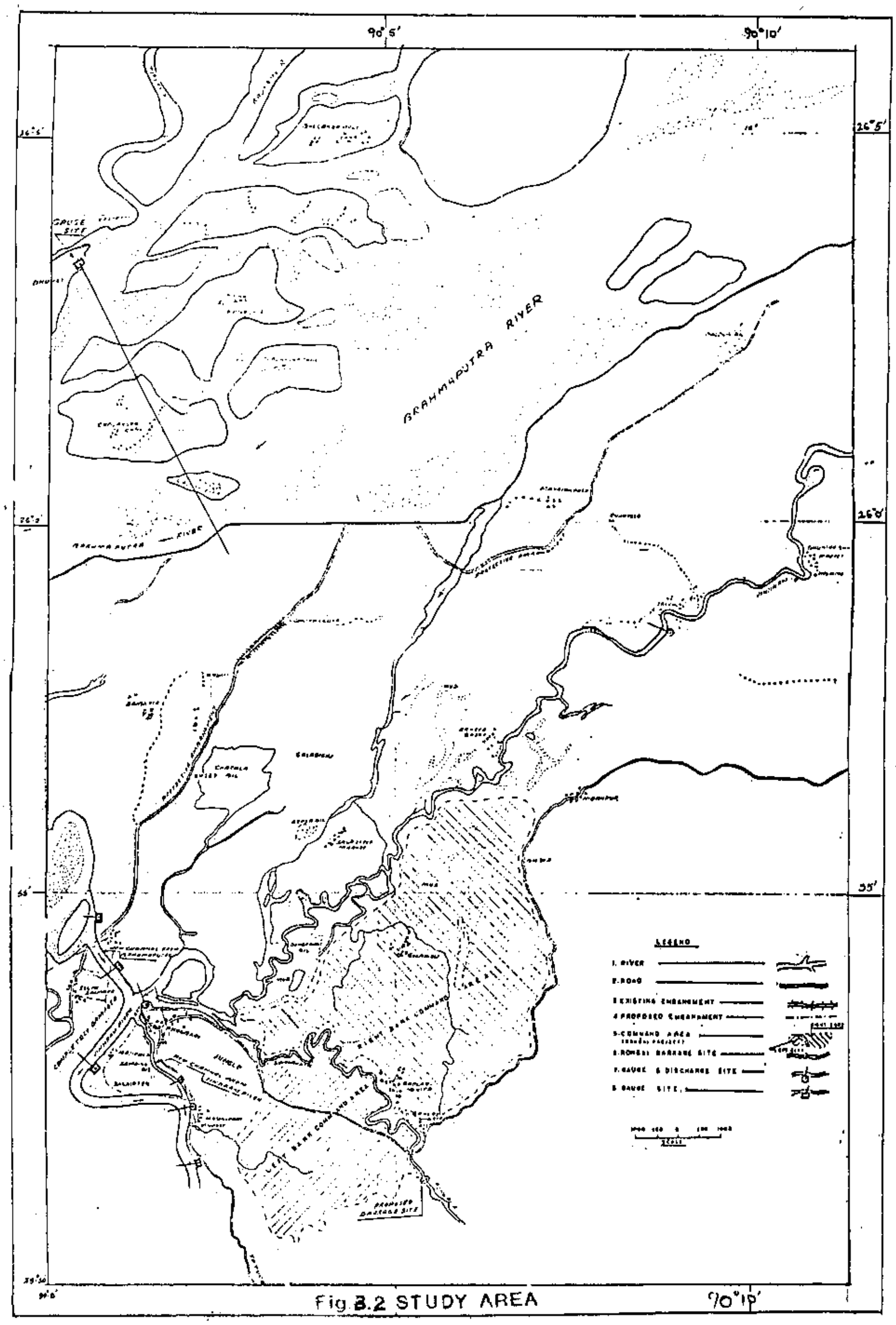


Fig.3.2 STUDY AREA

3.3 Temperature and Humidity:

It is seen that in the sub-basin annual average temperature ranges between 29.5°C and 19.7°C. The temperature starts rising from the beginning of March and reaches maximum in July and August. Maximum & minimum temperatures are 29.5°C and 19.7°C.

Relative humidity observations indicate high moisture content in this region for which the weather is very oppressive. Relative humidity in the rainy season (May to September) is between 72% to 85%. February to April are relatively dry with relative humidity ranging between 50% to 75%.

3.4 Agriculture:

Paddy and Jute are the main crops being cultivated in this sub-basin. In plains paddy is the main agriculture crop. Most common variety of paddy is Sali, Ahu etc. and other products are pulses, potatoes, maize, wheat, sugarcane and bananas. In the portion of Garo hills district paddy is the main product other than orange, banana and cotton.

3.5 Forests:

Above 60% of the sub-basin is covered with thick to mild forests. It is very thick in the hilly areas of the state of Meghalaya where numerous wild animals like elephant, tiger, jackals and deer are found abundantly. Forests are covered with very valuable timbers like Sal, Chegun, Gamari etc. Some people have taken forestry as their main occupation. Afforestation is taking place in the plain areas of the basin for environmental reasons besides protecting the soil from erosion due to heavy rainfall. Forestry is mainly carried out by the Social Forestry.

3.6 Soil characteristics:

Eventhough detailed soil survey in the Jinjiram sub-basin has not been under taken, soil of the sub-basin may be classified as New Alluvial, Old Alluvial and Red Loam. New alluvial type of soil is predominant in the plains while red loam & old alluvial soils are seen in the hilly areas of the Jinjiram sub-basin. It is necessary to under take soil survey to ascertain broadly the soil characteristics to ascertain soil groups and finally to arrive at a scientific cropping pattern.

3.7 Population :

Based on the figures of 1991 census the plain areas have high population density while the hilly areas are thinly populated. The density of the basin was 300 persons per sq.km. in 1981 and 467 persons per sq.km in 1991. These are very high with respect to overall average population of Assam 254 and 284 per sq.km in the respective census years. Percentage growth of population of the basin between the census years 1971 and 1991 is estimated to be above 50%.

3.8 Statement of the Problem :

The Phulbari area where the river Jinjiram outfalls into the mighty Brahmaputra has been subjected to severe erosion and floods since long past. The area at present is cris-crossed by number of new channels/spill channels changing its courses frequently and in the process eroding away new areas on one side and creating sand chars on the other. Protection of the Phulbari township has been the major concern of the people and the Government. The problem has been examined in details in Chapter the 'Analysis & Results'.

4.0 METHODOLOGY :

In the present study visual interpretation technique of satellite imageries was employed to delineate flood plains and inundated areas at Phulbari. Imageries from Indian Remote Sensing Satellites (IRS) were obtained from NRSA, Hyderabad. Comparison of pre-flood and post-flood data helped in better identification of the flood plain features. In visual interpretation, tone & texture variation forms the basis of identification of flood plain and inundated areas. Flood plain maps prepared from imageries were found to have slight geometric distortions and were corrected by optical projection techniques with reference to the base map prepared from survey of India topographic maps.

Flood plain maps prepared for the years 1988, 1989, 1995, and 1996 were studied for detecting various changes that has occurred in the study area. Ground truth verification was conducted with the help of CWC, Silchar Division. Toposheets, field survey maps and other available reference materials also used. Sites were visited and occurrence of features verified wherever more transperancy was felt for during interpretation of imageries.

4.1 Satellite Data :

The false colour composite (FCC) of IRS, LISS-II data generated on two different scales were used for delineation. Details of IRS data product used are given in **Table: 4.1.**

TABLE NO.4.1: DETAILS OF IRS DATA PRODUCT USED

Sl.No.	Name of the Satellite	Date	Scale	Data type	Path & Row
1.	IRS - IA	23.11.88	1:50,000	FCC	17 - 50
2.	IRS - IA	04.04.89	1:50,000	FCC	17 - 50
3.	IRS - IB	17.12.92	1:500,000	Film Positive	17 - 50
4.	IRS - IB	30.11.95	1:50,000	FCC	17 - 50
5.	IRS - IB	04.02.96	1:50,000	FCC	17 - 50

4.2 Toposheets :

The study area has been delineated from 78 K/1 (1:50,000) survey of India toposheet (Year 1961).

5.0 ANALYSIS AND RESULTS :

Flood plain of Brahmaputra and its tributary Jinjiram extends up to the foot of Garo Hills at Phulbari Area where elevation rises due to starting of hills after an extent of flood plain (**Fig.5.1**). The minimum and maximum distance between Brahmaputra and the flood plain is 2 k.m and 11 k.m at Phulbari and Pushkarnipara respectively. Unlike other parts of the country's riverine areas, features of low lying flood plains of the Brahmaputra are extensively visible during the post monsoon period.

Initially Jinjiram river was flowing through Majipara. Later on, a new channel (**Fig.5.2**) started flowing along its course through Mochhumati. The process of formation of new channel has taken place between 1988 and 1992. In the process, it has occupied a considerable portion of human habitation of Phulbari township and village Mochhumati was completely engulfed by erosion. Phulbari town and its surrounding areas which lie between the old and new channel of Jinjiram totally remain under submerged condition for a period of minimum two months after the flood and thus creating enormous hardship to the inhabitants of the area. The same condition prevails for nearly 70% of the study area.

The Brahmaputra is joined by Jinjiram river (**Fig.5.2**) at two points during the period 1990 to 1992. The first one was by washing away the towns Sabaltari, Bororbatari and destroying the horn shape of the Jinjiram river. The second was through an old alluvial channel which was active long back ago and to pass through south Salmara. In the processes of Jinjiram merging into the Brahamaputra, a fertile land of 4.0 sq.km has been occupied and the horn shape of the river which was present at the North of Phulbari town started disappearing during this period.

The following interpretation (**Fig.5.3**) has been carried out with the help of S.O.I. maps compared with the imageries:

1. Shifting of river banks during 1970-96 was studied. It reveals that the Brahmaputra has extended its bankline to a distance of 2.4 k.m at Phulbari by washing away the town South Salmara. At Dhulamara, Surjamoni and Pholimari it shifted a distance of 3.5 k.m, 7.0 k.m, and 7.5 k.m respectively. In this period the Brahmaputra has eaten away vast fertile land which includes two big towns Fakirkanj, Gulaberiaga and nearly fifty villages that were existing in the study area.

2. It is seen that (**Fig.5.3**) 1988 bankline was extended to a maximum distance of 1.2 km. towards south from the 1989 bank line. This was due to high flood (85600 m^3/sec) occurred in 1988.

3. The Brahmaputra water carries huge amount of suspended soil. In due course of time alluvial deposits take place in the low lying areas where water stagnates for a considerable period. Alluvial deposits that occurred in large area in and around Pholimori, show that these areas were under submerged condition for a long period after the flood. It is seen that from 1992 to 1996 area under submerged condition extended to a considerable portion than the period 1988 to 1992. In this process the bow shaped portion of river Jinjiram at Pholimori has been covered under sand which induced Jinjiram to divert its flow a distance of 1.25 k.m away from the former.

4. It is seen that the Brahmaputra river bank line has been shifted by about 1.2 km. & 1 km. in five years at Namashala and Pholimari area respectively. This necessitated bank protection measures in this reach.

5. Villages Paikarpara, Jamadarpara, Nutanbasti, Sasalya, and Tharangajhar has been identified as flood risk places.

6. Comparison of post monsoon seasons of 1988 (**Fig.5.1**) and 1995 (**Fig.5.5**) revels that 21%, 8%, 35% and 75%, 8%, 10% of the study area is under severely, moderately and partially inundated condition respectively. The alarming rate of increase in severely inundated condition is due to the fact that the Brahmaputra has occupied more land surface by extensively migrating its bankline which

inturn caused drainage congestion. In the pre-monsoon season (Fig.5.4) nearly 70% and 15% of the area was under fallow and vegetation condition. Flood inundation during post monsoon period of 1992 is mapped as in Fig.5.5.

7. It is seen that 20 k.m. length of embankment existing along the Brahmaputra was rooted out in 1988 due to the high flood occurred during the period.

8. At the time of ground truth verification (Fig.5.6) it is seen that PWD, Meghalaya has initiated construction of embankment across new channel and along the down stream of Jinjiram to protect Phulbari from high flood. Location of deflectors has been proposed in such a way that incoming water from the upstream of Jinjiram join its course with the Brahmaputra. A stream from the Brahmaputra passes towards south and joins with Jinjiram named as channel-1. Another stream from little down stream of the Brahmaputra and perpendicular to the channel-1 digged its way into Jinjiram which is termed as channel 2 by the PWD officials for cartographical purpose and its identification. Development of these channels which are of the size of large rivers has further complicated the problem.

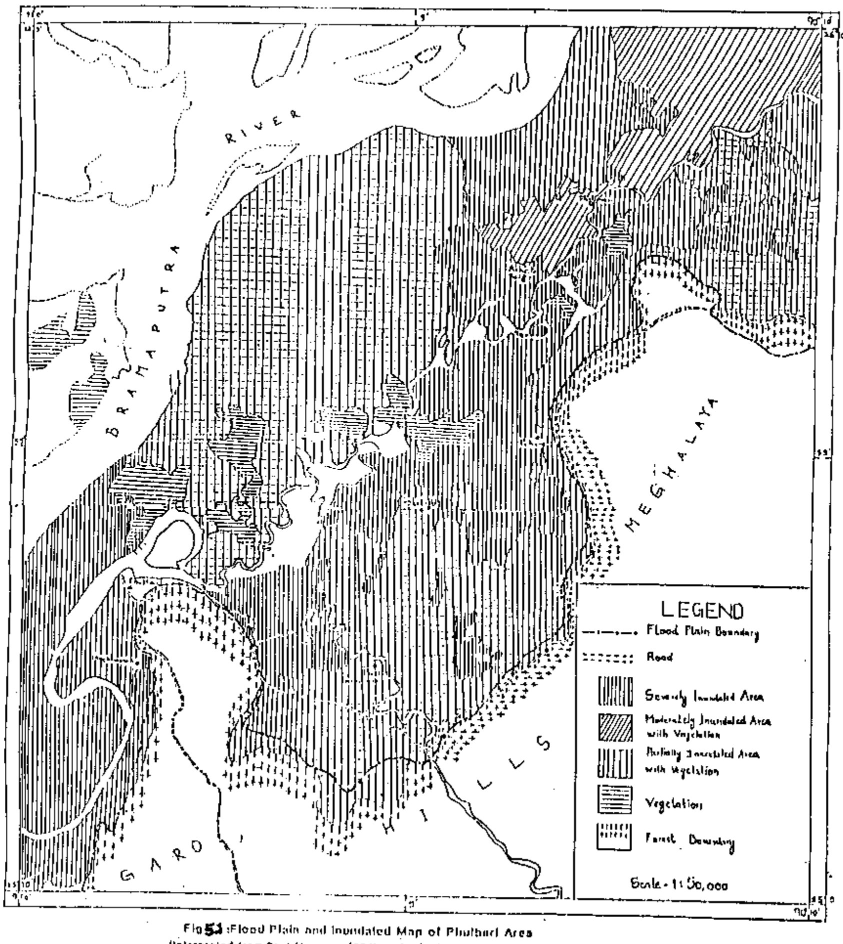
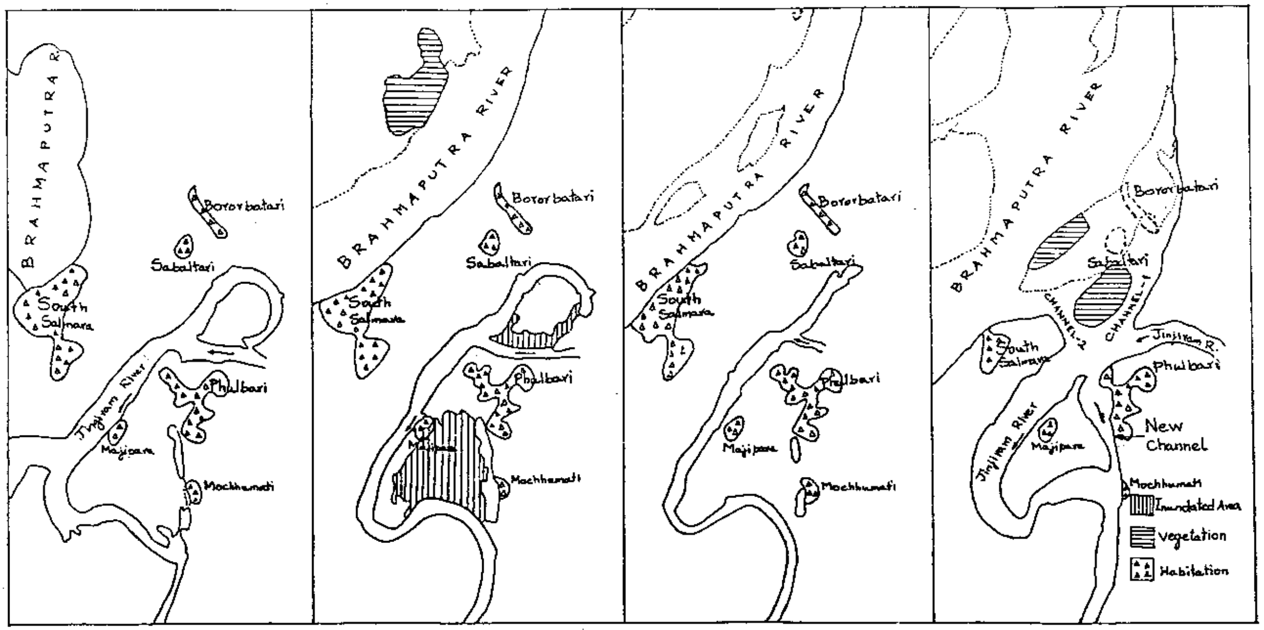


Fig 5.1 :Flood Plain and Inundated Map of Phulbari Area
(Interpreted from Post Monsoon (23 Nov. 1990) IRS-IA Satellite Imagery)



Flow of the Rivers from S.O.I Toposheet-1970.

Post-Monsoon (23.11.88) flow of the Rivers from IRS-1A data.

Pre-Monsoon (04.04.89) flow of the Rivers from IRS-1A data.

Post-Monsoon (17.12.92) and Recent flow (04.02.96) of the Rivers from IRS-1B data.

Fig. 7.2 Different Stages of River Jinjiram and Brahmaputra at Phulbari Area.

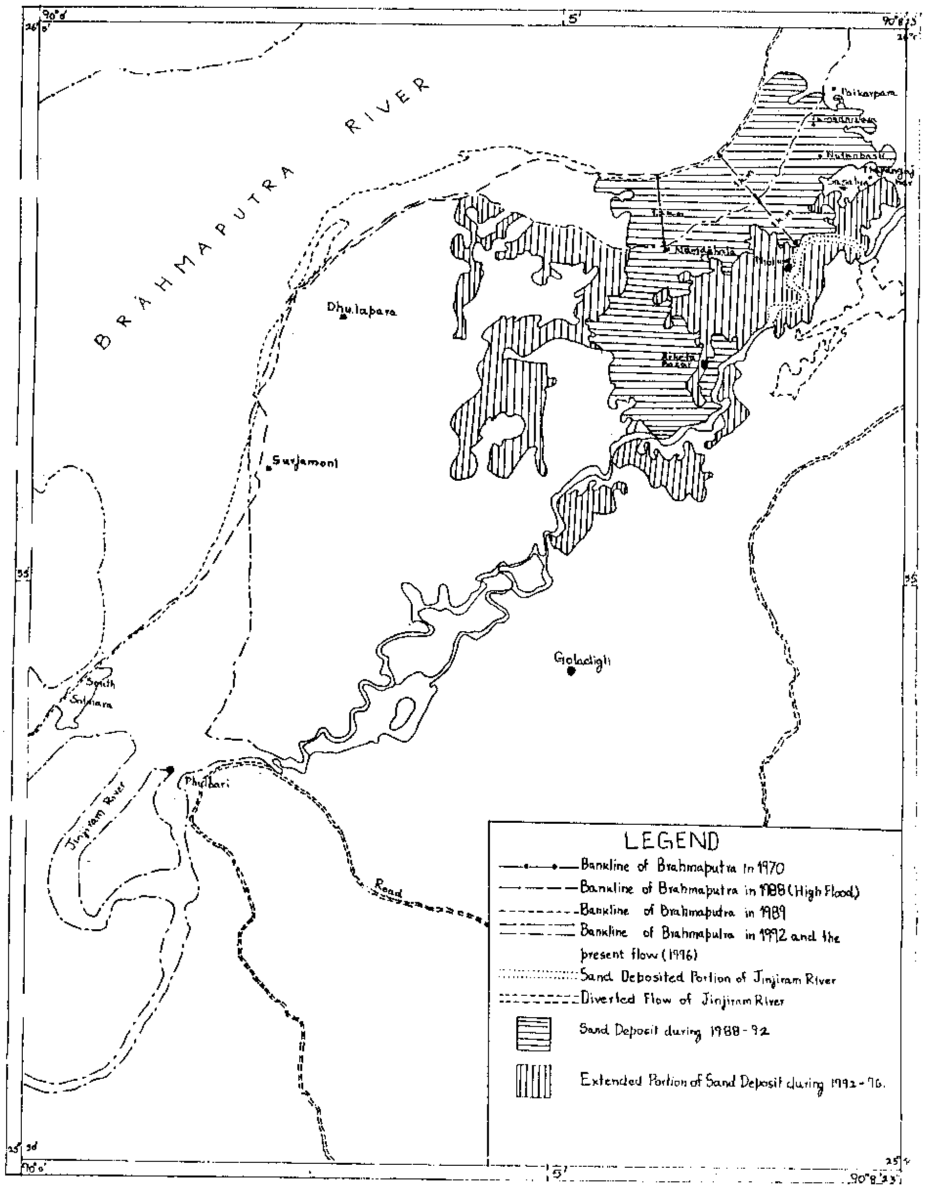


Fig 5.3 Bankline Migration of River Brahmaputra in the Study Area.

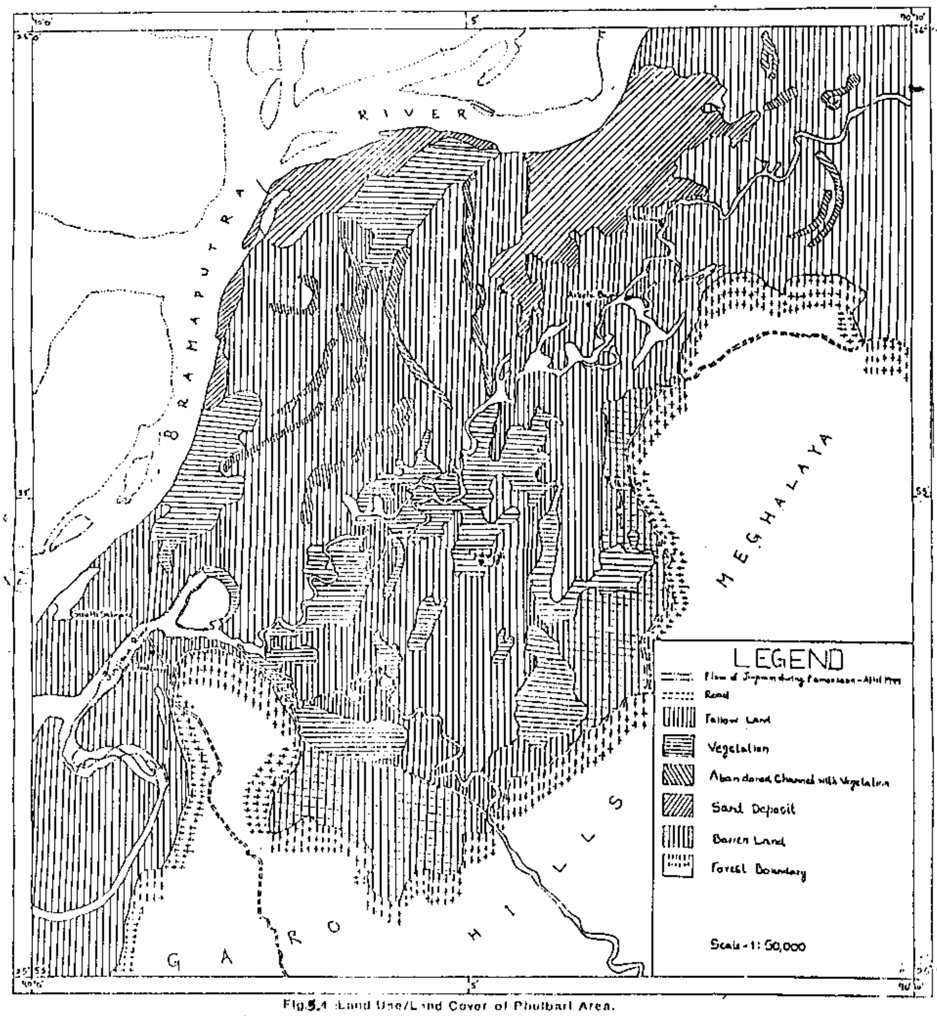


Fig.5.4 :Land Use/Land Cover of Phulbari Area.
(Interprated from Pre Monsoon (04.Apr.1990)IRS-IA Satellite Imagery)

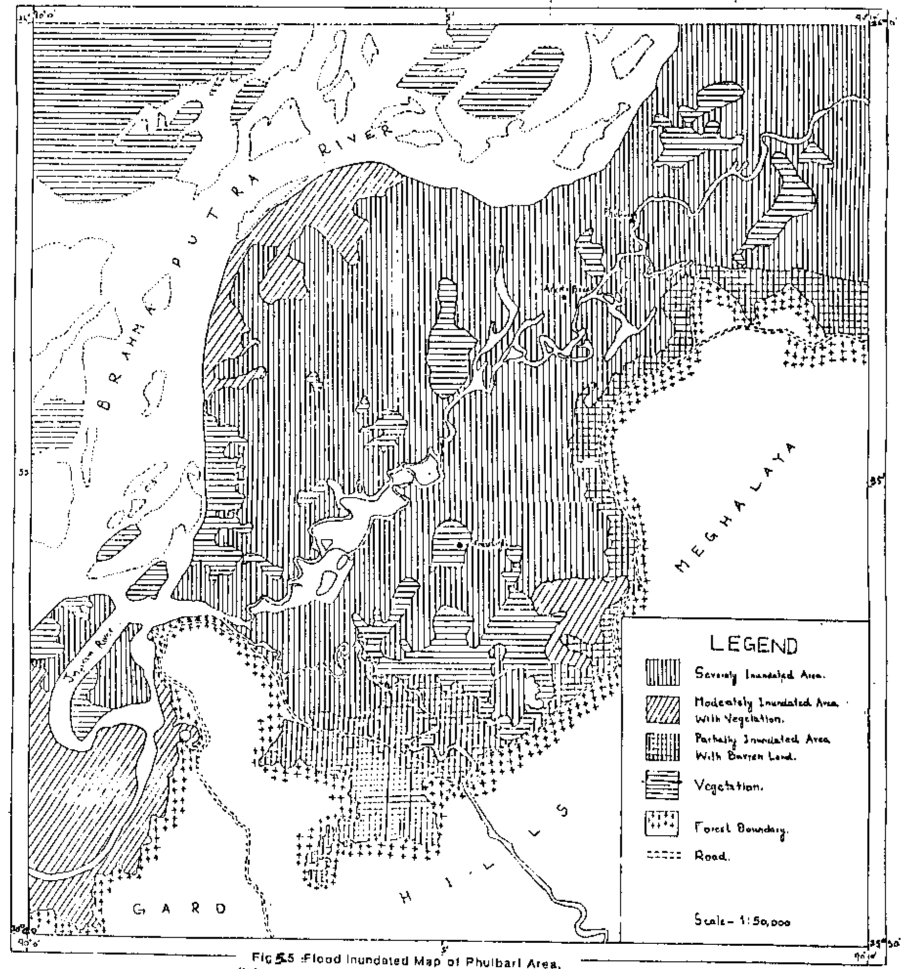


Fig 5.5 :Flood Inundated Map of Phulbari Area.
(Interpreted from Post Monsoon (17.Dec.1992) and Recent (04.Apr.1995) IRS-1B Satellite Imagery)

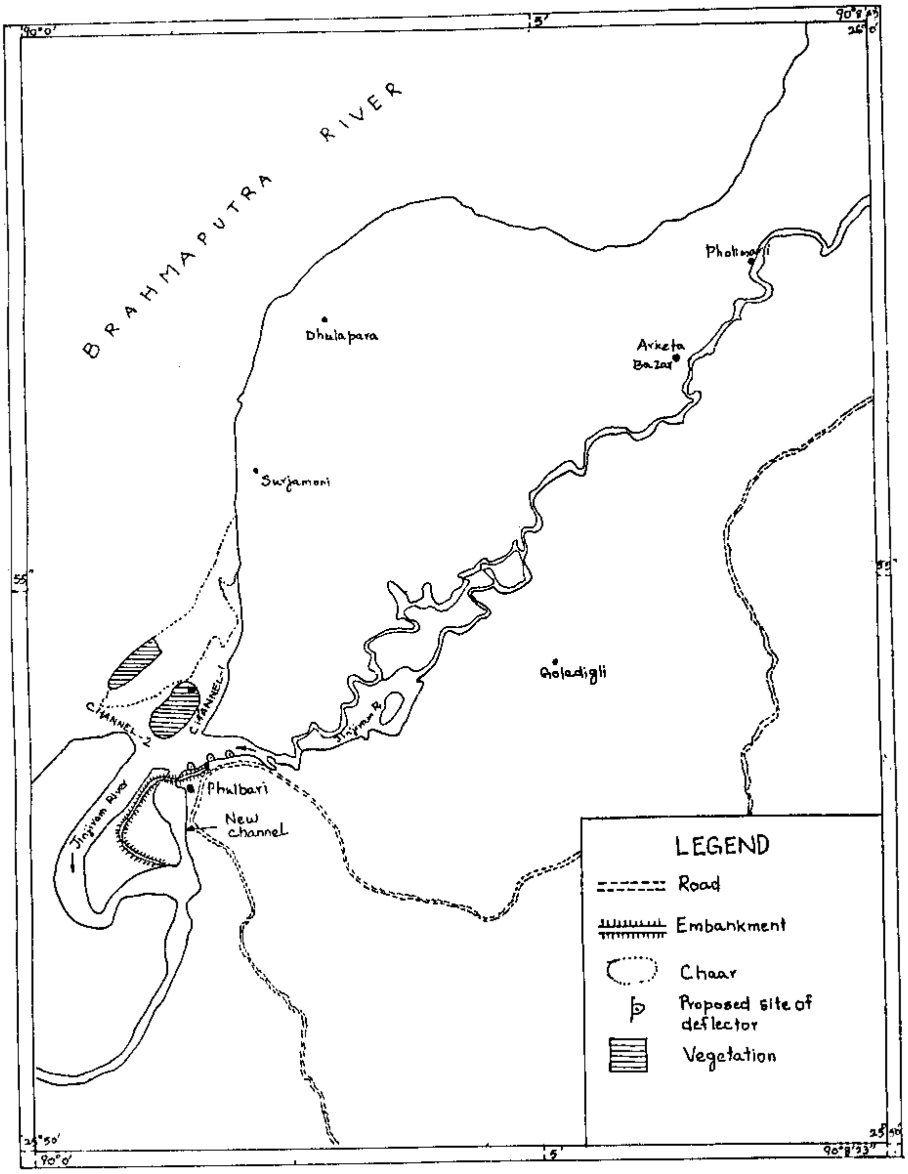


Fig.5.6 Details Collected From Ground Truth Verification

6.0 RECOMMENDATIONS :

1. The bankline studies for a mighty river like the Brahmaputra is very difficult. It can be carried out by continuously updating the changes occurred with the help of the new techniques of remote sensing using Multidate multitemporal satellite imagery.

2. Using satellite imagery numerous riverine islands, locally known as "Chars" can be located and the deflection of river flow due to these chars can be visualized . This helps in planning and effective positioning of river training measures such as spurs, bank revetments, pitched islands, surface and bottom panels etc.

3. Satellite images and other remote sensing data may be analyzed yearly before and after monsoon season for monitoring the fluvo-morphological changes.

4. To arrest bank erosion effective anti-erosion measures may be undertaken with the help of mathematical modeling studies with data input from remote sensing techniques, specially for areas having steep slopes.

5. Future studies can be made to correlate river turbidity and erosion potential in affected areas using satellite data.

6. Afforestation and soil conservation measures may be taken up in priority basis in the areas for which a trend is established by remote sensing techniques.

7. Permanent solution for protection of the area is however lies only in moderating the flood peaks of the Brahmaputra by construction of series of storage reservoir projects. Cascade system of reservoirs as practiced in river Danube may be cost effective for which sites are to be thoroughly investigated.

8. The ongoing protection measures taken up by the Govt. of Meghalaya for a small stretch should be a good example and experience to be extended further. However, the area being inter-state Govt of Assam may also join hands for a comprehensive protection planning.

9. Watershed management measures however are regional propositions and are effective if carried out at upper reaches of Brahmaputra. This may call for inter state collaboration much more effectively than at present.

9.0 REFERENCES

1. Abidon A.A. (1976) Satellita Survey of Particulate Distribution Pattterns in Lake Kainji,Remote Sensing Environment, vol. 5, pp 109-123.

2. Agarwal, C.S. and A.K.Mishra (1987):"Visual Interpretation of FCC Satellite Data for Channal Migration and Water Logging Conditions, Along Ghaghra & Terhi Rivers in Part of Disst. Gonda and Baharaich, U.P.;Photonirvachac Vol. 15, No.1, pp 19-28.

3. Ahmed Lanti, thesis for Master of Engineering, A.I.T., Bangkok, 1983.

4. Allord G.J and Scarpace F.L (1979) "Improving Stream Flow Estimates through use of Landsat", Satellite Hydrology, 5th Annual William T.Pecora Memmorial Symp. on Remo.Sen., Ameri. Water Reso.Asso., Minneapolis, pp 284-291.

5. Balakrishnan p,(1986), ISRO report NNRMS TR-67-86,Bangalore.

6. Barret E.C.,and Curtis L.F., (1982),Introduction to Environmental Remote Sensing, Chapman and Hall, New York.

7. Brakke T.W. and Kanemosu E.T. (1981), Insolation Estimation from sattellite Measurements of Reflected Radiation, Remote Sensing Envin., Vol. 11, pp 157-167.

8. Berg, C.P., D.R. wiesnet, M. Matson (1979), "Assessing the Red River of the North Flooding from NOAA Satellite Data", Satellite Hydrology, pp 309-315.

9. Bisaria M.S., (1986),"Review of Flood Damages in the Country Proce. of Workshop on flod damage Assessment, Delhi.

10. Burgess L.O (1967),Inter.Confe.Water for Peace 1(4),867-881.

11. Central Board of Irrigation & Power- Workshop on flood damage assessment-procedings-NewDelhi,1986.

12. Chakraborty A.K. (1979), "Study of Kosi River characteristics using Airborn/space Orbital Multispectral Scanner Data", Symposium on the Conribution of Space Observations to Water Resources Studies and Management of these Resources,COSPER, Bangalore, pp 211-214.

13. Chaturvedi R.S. and Mohan R.(1983), National Symposium on Remote Sensing Developement and Management of Water Resources, Inter. Remote Sensing, DehraDun, pp 79-87.

14. Choudhary A.M., Study of floods in Bangladesh and India with the help of meterological satellites,1980.

15. Das S. and R.Lee (1988),"A non-traditional methodology for flood stage-damage calculation", Water Resources Bulletin,

Journal of AWRA, Vol. 24.

16. Davis D.W. (1979),"Comprehensive flood plain studies using spatial data management techniques",Technical paper No.47 HEC, California.

17. Deutsch, M. and F. Ruggels (1974), "Optional Data Processing and Applications of the ERTS-1 Imagery Convering the 1973 Mississipi River Vally Floods",Water Resources Bulletin, vol. 10, No. 5.

18. Deutsch, M. and F,H.Ruggles (1978), "Hydrologic Applications of Landsat Imagery Used in the Study of the 1973 Indus River Flood, Pakistan, Water Resources Bulletin, Vol 14, No. 2, pp 261-273.

19. Dhanju M.S., (1976), "Studies of Kosi River Flood Plains by Remote Sensing", Hydrology Review, Vol.2. No. 4, pp 43-48.

20. Dhanju M.S., "Flood plain mapping of Gangetic basin using Landsat imagery", Symposium on the Contribution of Space Observation to Water Resources Studies and Management of these Resources",COSPER,Bangalore, pp 215-218.

21. El-Jabi N. and J. Rousselle (1983),"Flood Plain Management Stage or Discharge",Journal of Hyrology, ASCE,Vol 64,No.3.

22. El-Jabi N. and J. Rousselle (1987)," A Flood Damage Model for Flood Plain Studies", Water Resources Bulletin, Journal of AWRA, Vol. 23.

23. Egman E.T. and Gurney R.J. (1991) Remote Sensing In Hydrolo gy, Chapma and Hall, New York.

24. France M.J. and Hedges P.D. (1986) A Hydrological Comparision of Landsat TM, Landsat MSS, Black and White Aerial Photography Symp. of Remote Sensing for Resorces Development and Environmental Management, Enschede, The Netherlands pp 717-720.

25. Fransworth R.K.,Barrett E.C., and Dhanju M.S. (1984) Application of Remote Sensing to Hydrology including Ground Water UNESCO IHP Project A 1.5, pp 122.

26. Ganga Flood Control Commission (1986),:Classification of Flood Damages, Proc. Workshop on Flood Damage Assessment, NewDelhi.

27. Gautier C., Diak G. and Massie S. (1980) "A Simple Model to estimate incident solar radiation at the surface from GOES Satellite Data", J.Appl.Meteorol., Vol. 19, pp 1005-1011.

28. GHO (1982) Glossary of Hydrological Terminalogy with definitions, Berne.

29. Grade R.J. and Ranga Raju K.G., Mechanics of sediment transport and Alluvial stream problems, McGraw Hill Book Company.

30. Haralick R.M.,Wang S.and Shapiro L.G. (1985) "Extration of Drainage Network by Using a Consistant Labelling Technique Remote Sensing Envirn., Vol. 18, pp 163-175.

31. Hatifield J.L.(1983),Advances in Irrigation, Vol. 2, Acadamic Press, New York.

32. Heilman J.L. and Moor D.G. (1981) Satellite Hydrology, Amer. Water Resor. Associ., pp 446-454.

33. Herbst P.H.,Berdenkamp D.B. (1966) Journal Hydrology,Vol.3, pp 264-272.

34. Jackson R.D.(1981) Int.Geosci. Rem. Sensing Symposium, Washigton D.C., pp 463-474.

35. Jackson T.J. (1980) Journal of Irrigaton and Drainage division, ASCE (IR2) pp 81-92.

36. Jhonson R.W. (1980) Remote Sensing Environment, Vol.9, No.3, pp 197-209.

37. Kalubarme M.H.,Sahai B, and Bapat M.V (1983) "Remote Sensing of waterlogged and Salt affected soils in Mahi Command area" Proc. of Nat. Symp. on Remote Sensing in Development and Management of Water Resources,Ahmedabad, pp 182-190.

38. Khorram S. (1981) International Journal of Remote Sensing, Vol. 2, No.2, pp 145-153.

39. Khorram S. (1985) Photogrametry and Remote Sensing, Vol.51, No. 1, pp 53-62.

40. Kurus J., M.Deutsch, P.L. Hanson (1979) "Flood Applications of Satellite Imagery", Satellite Hydrology, American Water Resources Association, pp 292-301.

41. Linsely R.K.,Kohler M.A.(1982) Hydrology for Engineers, McGraw hill Book Co., NewDelhi.

42. NRSA.,Remote Sensing of channel changes of Brahmaputra River, Hyrabad, 1984.

43. Meyer W.and Welch R.I. (1975) Manual of Remote Sensing, American Society of Photogrametry, Virginia.

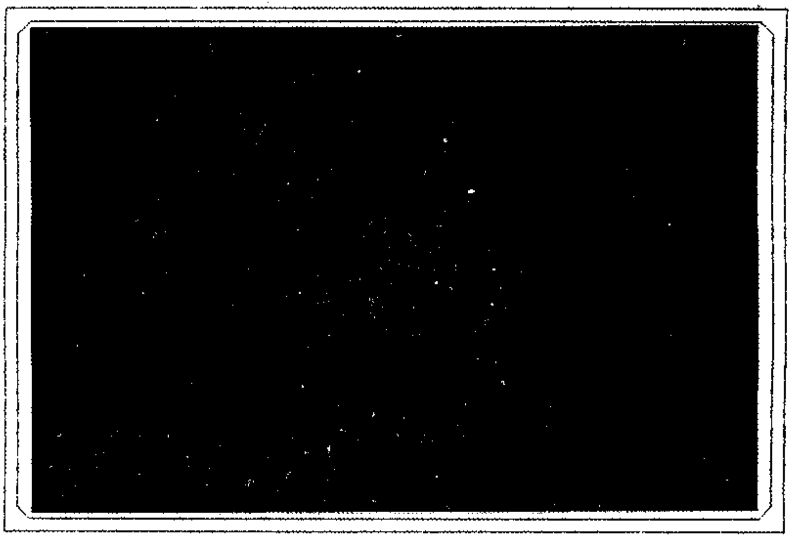


Plate - 1. Partial view of Channel-1 and erosion at South Salmara.

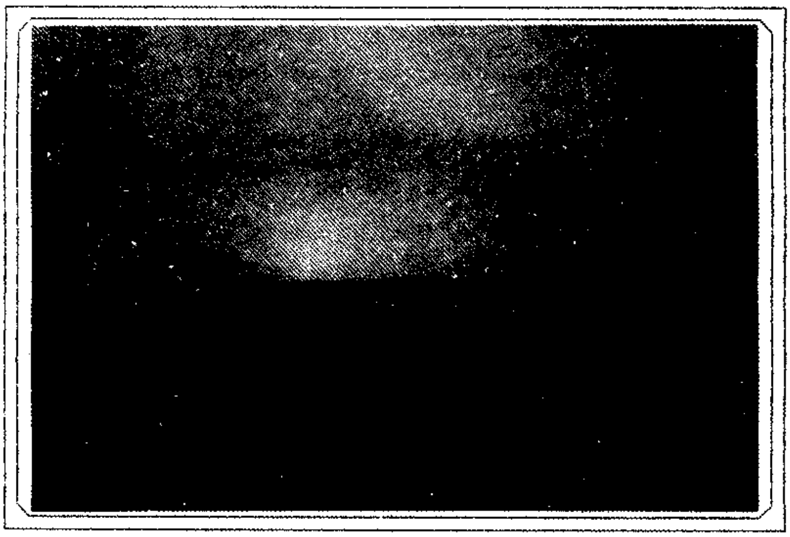


Plate - 2. Conflunce of old and new channel at Phulbari.

Plate - 3. Bankline protection (construction of embankment) at Phulbari, Meghalaya.

Plate - 4. Scientists and Engineers in discussion while ground truth verification.

Director : Dr.S M Seth

Coordinator : Dr.K K S Bhatia, Sc'F'

STUDY GROUP

V S Jeyakanthan, Sc'B'
B C Patwary, Sc'E'

ASSISTANCE

Satpal Singh, S.R.A.
T R Hansh, R.A.