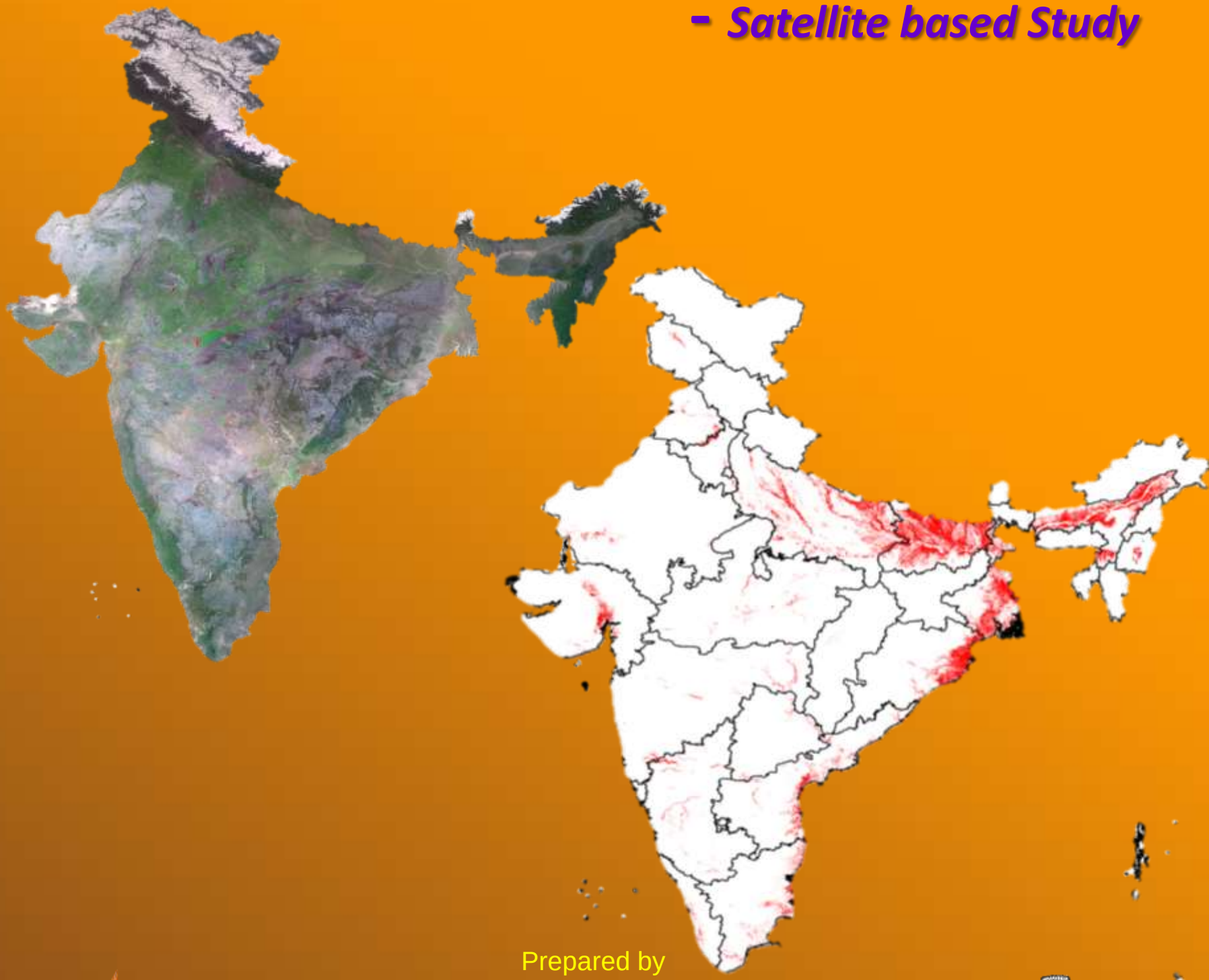
Version -1 (1998-2022)

Flood Affected Area Atlas of India

- *Satellite based Study*



Prepared by

National Remote Sensing Centre (NRSC)
Indian Space Research Organisation (ISRO)
Department of Space, Government of India

सत्यमेव जयते

In Association with

National Disaster Management Authority
Ministry of Home Affairs, Government of India

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March 2023

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15.	**Abstract:** Flood affected area maps are one of the very important non-structural measures of flood damage mitigation. These maps are useful in planning and regulating developmental activities in flood plains and carrying out relief and rescue operations, construction of relief, rescue. Satellites provide synoptic observations of the natural disasters at regular intervals that help in disaster risk reduction in the country. Over a period of time, National Remote Sensing Centre (NRSC), ISRO has created a repository of large data pertaining to the floods & cyclones in different areas of the Country. These historical flood maps, generated by NRSC/ISRO, are useful for identification of flood affected areas. Using these historical maps, Flood Affected Area Atlas of India – a satellite based analysis is prepared. District / State wise flood affected area statistics were presented along with the State Maps and India Map in the Atlas. This atlas will be useful in preparing disaster management action plans at state level and in disaster risk reduction in the country.			

आज़ादी का अमृत महोत्सव

अजय भल्ला, भा.प्र.से.
AJAY BHALLA, IAS

सत्यमेव जयते

G20 भारत 2023 INDIA
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गृह सचिव
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FOREWORD

The frequent and devastating floods in India have caused immense damage to lives and property. The need for accurate and timely flood warning systems and mitigation measures has become increasingly urgent. In this context, the 'Satellite Based All India Flood Affected Area Atlas' prepared by National Remote Sensing Centre (NRSC), ISRO is a timely and valuable contribution to the disaster management community in India.

2. This atlas prepared using satellite imagery and GIS technology to provide a comprehensive and up-to-date mapping of flood-prone areas , will serve as an indispensable tool for disaster management authorities to plan and implement effective flood response and recovery efforts. I hope that this endeavor of NRSC will serve as a stepping stone towards a more disaster resilient India.

3. It is my expectation that stakeholders will use the information provided in the atlas for prudent decision-making, particularly in the areas of planning, development, and disaster management. I hope this information shall be utilised for decision-making at all levels of government, including local, state, and national authorities, as well as the private sector and civil society organizations.

4. I would like to thank NRSC, ISRO for its unwavering commitment to using its expertise and technology to support sustainable development and disaster management efforts in India. The 'Satellite Derived Flood Zonation Atlas for India' is a remarkable achievement and will be a valuable tool for the disaster management community for years to come.

Place: New Delhi
Dated: 07.03. 2023

(Ajay Bhalla) 7/3/23

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FOREWORD

India faces flood disaster almost every year, in varying degrees of magnitude, resulting loss of precious lives; economic burden etc. Satellite Remote Sensing data provides information on flood inundation due to riverine and cyclonic floods, and are used for delineating the flood affected areas.

Under the Disaster Management Support Programme (DMSP) of Indian Space Research Organisation (ISRO), National Remote Sensing Centre (NRSC) has been monitoring and mapping major floods in the country using multi-mission satellite data, for more than two decades. The derived information is provided to MHA, NDMA, and State Disaster Management Departments, for supporting effective disaster management & disaster risk reduction measures.

Use of flood affected area maps are one of the very important non-structural methods of flood damage mitigation. These maps are useful in planning and regulating developmental activities in flood plains, constructions of relief; rehabilitation and health centres, etc. Using the satellite datasets spanning across 1998 to 2022, NRSC has prepared the ‘Flood Affected Area Atlas of India’.

‘Flood Affected Area Atlas of India’ is a testimony of ISRO’s commitment on supporting Prime Minister’s ten-point agenda on Disaster Risk Reduction. It is also a significant milestone in ISRO’s continuous efforts towards enabling space based inputs for disaster mitigation. It reflects the organization's vision to leverage advanced technologies for disaster management and it will be a valuable tool for the disaster management community in India.

I am sure that the ‘Flood Affected Area Atlas of India’ will be an important input for preparing disaster management plans by state DMS Organisations. It will play a vital role in reducing the impact of floods on communities and the environment. It will help the Indian disaster management community to build a resilient society, that is better prepared to respond to, and to recover from adverse effects of floods.

I congratulate and compliment the entire team of NRSC, Hyderabad and National Disaster Management Authority (NDMA) for bringing out this unique atlas.

March 3, 2023

(सोमनाथ. एस/ Somanath. S)

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MESSAGE

With the goal to create a safe and disaster resilient India through an integrated dynamic and technology-driven approach for disaster risk management, National Disaster Management Authority has commenced various programmes to induct science and technology in the country to achive the Prime Minister's 10 point agenda for disaster risk reduction in the country. One such important initiative is to develop upgraded hazard profiles of various natural hazards (for their subsequent use in vulnerability and risk assessment work). Flood is one of the most frequent disasters that affect our economy very badly. Information of the flood profile at a reasonably large scale is not available for planning necessary mitigation measures by concerned State Government.

The initiatives of National Remote Sensing Centre (NRSC), India Space Research Organization (ISRO) to utilize space- based technology for disaster management are commendable. NDMA entrusted NRSC/ISRO for preparing the flood affected area atlas of India using satellite data on priority. It is being carried out by utilizing the historic satellite imageries of about two decades period from the archives of the National Remote Sensing Centre, Department of Space, and these maps are duly validated by the actual observation data of flood inundation areas by the concerned states.

I am sure that the Flood Affected Area Atlas prepared by National Remote Sensing Centre, ISRO would provide the much needed information for effective and better planning for floods and taking necessary mitigation measures in the country.

Dated: 06/03/2023

(Kamal Kishore)

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PREFACE

Floods have been a persistent problem in India, causing widespread damage to life, property and communities. Despite efforts to mitigate their impact, floods continue to pose a major challenge to the country, and there is an urgent need for accurate and up-to-date information on flood-prone areas. This is where the 'Satellite Derived Flood Affected Area Atlas for India' comes in as a groundbreaking publication that provides a comprehensive and scientifically robust assessment of flood-prone areas in India.

National Remote Sensing Centre (NRSC) as the single window delivery mechanism has been providing near-real time products and services using satellite remote sensing and aerial data to support during various phases of disasters under ISRO's Disaster Management Support Programme (DMSP). For more than two decades, NRSC has been preparing flood inundation maps and performing damage assessments due to flood and cyclone events using Multi-mission, Multi-Sensor (Indian Remote Sensing) IRS and Foreign Satellite Data,. These near-real time operational activities has enabled the creation of reliable and long term database on flood affected area and associated risks.

The atlas is in line with the principles of the Sendai Framework for Disaster Risk Reduction, which emphasizes the importance of scientifically robust risk assessments in disaster management. Furthermore, the atlas is a step forward towards realization of Sustainable Development Goals (SDGs), that will help to promote sustainable communities through the reduction of flood impacts. The importance of this atlas cannot be overemphasized, especially in a country like India which is highly vulnerable to natural disasters.

To ensure effective acceptance of the information, the hazard maps prepared using satellite remote sensing data has been ratified with ground truth by the respective state disaster management authorities.

I am sure the atlas will be an important resource for the government, non-government organizations, and academic institutions working in the area of disaster management and flood risk reduction. It will also be useful for researchers, and policy makers in understanding the complexities of floods and the need for effective and sustainable measures to mitigate their impacts.

Dated . March 01, 2023

(PRAKASH CHAUHAN)

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Acknowledgment

The project team would like to place on record our deep sense of gratitude to Shri S.Somanath, Secretary, Department of Space and Chairman, ISRO for showing keen interest in Disaster Management Support Programme and for extensive support, guidance in DMS activities of NRSC.

The project team sincerely thank Sri Kamal Kishore, Member Secretary, National Disaster Management Authority (NDMA) for his support and encouragement in preparing the Flood Affected Area Atlas of India.

The project team expresses deep sense of gratitude to Dr. Prakash Chauhan, Director, NRSC for his constant encouragement, guidance and for providing necessary support in bringing out this atlas.

The project team conveys earnest thanks to Shri. Shantanu Bhatawdekar, Scientific Secretary, ISRO for providing guidance in disaster management support activities at NRSC.

Sincere gratitude is expressed to Dr. V. V Rao, Associate Director, NRSC and Dr. K. Vinod Kumar, DD RSA for their constant support and guidance in executing this task. The project team sincerely thank Dr John Mathew, Associate Programme Director, DMSP, EDPO, ISRO for his support and cooperation.

Senior officials of National Disaster Management Authority are acknowledged for their interactions, guidance and continuous support. Project team acknowledges the support and guidance extended by Sri S. K. Jindal, JS-DM, Ministry of Home Affairs.

Thanks are due to officials of State Governments, DMS Organisations for ground validation in highly flood prone states.

Concerned officers of Central Water Commission and India Meteorological Department are acknowledged for providing inputs during near real time flood mapping.

Sincere acknowledgements are due to Dr. V. Bhanumurthy, former Associate Director, Dr. P.V. N. Rao, former Deputy Director, Sri G S Rao, Sri C M Bhatt for their contribution during their tenure. The team also thank everyone who contributed directly or indirectly in preparing the atlas.

EXECUTIVE SUMMARY

Flood affected area maps are one of the very important non-structural methods of flood damage mitigation. These maps are useful in planning and regulating developmental activities in flood plains, construction of relief, rescue, and health centres. Satellites provide synoptic observations of the natural disasters at regular intervals that help in disaster risk reduction in the country. Over a period of time, National Remote Sensing Centre (NRSC), ISRO has created a repository of large data pertaining to the floods & cyclones in different areas of the Country. These historical flood maps, generated by NRSC/ISRO, are useful for identification of flood affected areas. At the behest of the National Disaster Management Authority (NDMA), NRSC/ISRO has prepared the Flood Affected Area Atlas for India using the available historical satellite datasets spanning over 25 years (1998 to 2022).

Indian Remote Sensing (IRS) satellite and foreign satellite datasets (optical and microwave) during this period were acquired covering different flood magnitudes in India and used in generating the flood affected area maps after its thorough analysis. Water levels of various gauge stations during the period 1998 to 2022 has been obtained from Central Water Commission and used for the preparation of flood affected area atlas of India. These state level flood maps are validated by the state disaster management organizations of major flood-prone states.

District / State wise flood affected area statistics were presented along with the State Maps and India Map in the Atlas. Digital spatial maps are hosted on National Database for Emergency Management (NDEM) geoportal of ISRO. The Atlas would be useful as a resource of information for policy makers, planners and civil society groups and find its value towards flood risk evaluation, sustainable development and flood mitigation efforts in India. This atlas will be useful in preparing disaster management action plans at state level and in disaster risk reduction in the country.

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1. Introduction

Flood is a recurrent natural disaster in India that affects various parts of the country every year. Very often, India has experienced several devastating floods that have resulted in a loss of life and caused significant damage to infrastructure, loss of crops, and livelihood. According to the National Disaster Management Authority (NDMA), over 40 Mha ha of land in India is prone to flooding (www.ndma.gov.in). According to the Ministry of Jal Shakti (MoJS) reported that the recent estimate on flood prone area in the country is 49.15 Mha, out of which Assam, Bihar, Odisha, Uttar Pradesh and West Bengal are largely affected (PIB, Aug 2022). Flood disaster affect people and the impact of floods cannot be completely prevented, while measures can be taken to mitigate the impact and ensure that people are prepared to deal with the consequences of the flood hazards. This requires a multi-stakeholder approach that involves government organizations, civil society, and individuals while in coordination and planning through disaster management support organizations.

The Indian government have taken measures to improve disaster management, early warning systems, and flood control infrastructure that include the construction of dams, embankments, and other flood control structures specifically to mitigate the impact of floods through different State & Central disaster management support organizations . In this context, it is necessary to prepare a flood-affected area atlas to understand about long-term impact scenario of the flood at sub-district, district, state, regional and national levels by using information available from multi-institutions and their support. Thus, the preparation of a Flood Affected Area Atlas is an important activity that can help the policy makers to plan for the mitigation of flood impacts at national level, there by improves the quality of social lives at disaggregated administration levels .

NRSC, ISRO has been mapping and monitoring spatial flood inundation across the country in near real-time using multi-date satellite / sensor data, and maps are being disseminated to disaster management support management organizations at State / Central level. These digital archives of the temporal spatial inundation maps helped to estimate the cumulative flood affected area, thus the archives of the spatial inundation maps generated by NRSC during the last 25 years help to assess the cumulative flood affected area at national level. Present study focuses on the analysis of long-term flood inundation maps and consolidation, preparation of Flood Affected Area Atlas at country level which represents the overall scenario and also the identification of hotspots. Satellite remote sensing is only a feasible technology for capturing the long-term scenario of major flood events and realizing spatial flood inundation mapping. These maps can help in flood preparedness, disaster management, and decision-making for future land use planning. Additionally, remote sensing can also be used to monitor and assess the damages caused by floods, which is critical in post-disaster management and recovery. Therefore, remote sensing technology plays an important role in the preparation of flood atlases.

1.1. Causes for Flood Occurrence and Impact

India is prone to floods due to its geography, heavy rainfall during the monsoon, changing weather patterns with rising temperatures leading to more frequent and intense rainfall events, snowmelt, river overflows-flooding, rapid snowmelt, dam or levee failure, coastal storms or storm surges, and tsunamis, as well as flash flooding and landslides. Coastal regions are also at risk of flooding due to tropical cyclones and storm surges.

Land-use / land cover changes such as deforestation, rapid urbanization & poor drainage conditions, and poor agricultural practices might have led to flood severity . During the last four decades, it has been observed that the frequency and severity of floods in India have been increasing. The Indian government has developed a National Disaster Management Plan to respond to floods and other natural disasters. The plan includes measures such as evacuation and rescue of people in flood-prone areas, provision of relief materials and medical aid, and the reconstruction of damaged infrastructure for flood mitigation.

1.1.1. Types of Floods in India and Scope for Mapping and Monitoring of Floods

There are several types of floods that can occur, each with its own causes and characteristics. The most common types of floods are as follows :

Riverine floods : These floods occur when heavy rainfall or snowmelt causes rivers or streams to overflow their banks. River floods can be slow-moving and occur over a period of days or weeks, or they can be sudden flash floods, which occur rapidly and with little warning.
Coastal floods: These occur when high tides, storm surges, or large waves cause seawater to flood onto coastal areas. Coastal floods are often associated with cyclones or other severe weather events.

Flash floods: These floods occur when heavy rainfall occurs in a short period of time, overwhelming the capacity of drainage systems and causing water to rapidly accumulate in low-lying areas. Flash floods can be particularly dangerous, as they can occur with little or no warning.
Urban floods: These occur in urban areas when the built environment and pavement prevent rainwater from being absorbed into the ground, causing it to accumulate in low-lying areas. Urban floods can also be caused by blocked drainage systems, overloaded sewage systems, or any other forms of infrastructure failure.
Pluvial floods: These occur when heavy rainfall exceeds the capacity of drainage systems, causing water to accumulate on the surface of the land. Pluvial floods can occur in both urban and rural areas and can be particularly damaging to infrastructure and property.
Dam or levee failures: These occur when dams or levees are unable to withstand the pressure of floodwaters, causing them to breach and release large volumes of water downstream.

Each type of flood has its own characteristics and may require different approaches for prevention and mitigation. It's important to be aware of the types of floods that can occur in different regional settings and take steps for mitigation and prevention measures. The scope of the satellite-based studies is to capture the extent of flood mapping from the onset, during progression and recession times in each year; further to prepare a cumulative flood-affected area map in the country using the satellite-derived flood maps prepared during 1998-2022. All major flood events were captured, particularly all riverine flood events during its progression and recession times were mapped using satellite data during its duration of progression and recession times. However, flash floods and short-duration events could not be mapped due to the non-availability of satellite data to capture the spatial scenario.

1.2. Flood Affected Area - Atlas

A flood affected atlas is a comprehensive document that contains information on flood-prone areas and extent of the floods in a particular region which will help the government in the planning and management of flood events through structural, non structural, and natural / social engineering measures in the flood affected zones. The preparation of a flood atlas is necessary as it helps to identify areas that are susceptible to flooding and raises the requirement for the development of regional early warning systems to mitigate the impact of floods, developing flood management strategies, and planning for emergency response measures, infrastructure development to prevent damage caused by flooding. The data and information available in flood affected area atlas would be useful for the authorities to make informed decisions and take timely action to reduce the impact of floods. It is an important tool for disaster management authorities and policymakers to make informed decisions regarding flood risk reduction, preparedness, and response in flood-prone areas.

1.3. Flood Monitoring Mechanism

Flood monitoring mechanisms in India are constantly evolving to keep pace with new technologies and changing flood patterns. The Indian government has put in place several measures to map and monitor floods, including the use of satellite data for flood mapping and early warning systems to alert people in flood-prone areas. In India, flood monitoring is carried out by various organizations such as the Central Water Commission (CWC), the National Remote Sensing Centre (NRSC), ISRO, and through inputs from India Meteorological Department (IMD). The CWC monitors flood levels and discharge data at various river sites across the country. The NRSC uses satellite data for flood mapping and also provides flood advisories to the concerned state authorities. The IMD provides weather forecasts and issues warnings for heavy rainfall events that may lead to floods. The National Disaster Management Authority (NDMA) is monitors the responses to disasters such as floods at the national level. At the state level, while State Disaster Management Authority (SDMA) is responsible for coordinating responses to disasters, including floods at the state level.

1.4. Flood scenario in India

There are several causative factors for flooding in the country. Inadequate capacity of the rivers to contain the high flows brought down from the upper catchment (outside of India) due to heavy rainfall, leads to flooding. Area having poor drainage characteristic gets flooded by accumulation of water due to high intensity of rainfall. Excess irrigation water applied to command area and increase in ground water level due to seepage from canals and irrigated field accentuate the problem of water logging, subsequently it will have impact on floods. Flooding is accentuated by erosion and silting of the riverbeds resulting in reduction of carrying capacity of river channel, leading to changes in river courses & obstructions to flow due to landslides, synchronization of floods in the tributary rivers and retardation due to tidal effects. With the increase in population and developmental activity, there has been tendency to occupy the flood plains, which has resulted in more serious nature of damage over the years. Because of the varying rainfall distribution, many a times, areas which are not traditionally prone to floods also experience severe inundation. Thus flood is the single most frequent disaster faced by the country. Floods have different dimensions, inundation due to spills over the banks, drainage congestion due to poor drainage characteristics, erosion due to change in river course are the main causes for flooding.

1.4.1. Management of Floods

In India, systematic planning for flood management commenced with the Five Year Plans, particularly with the launching of National Program of Flood Management in 1954. During the last 48 years, different methods of flood protection structural as well as non-structural methods have been adopted in different states depending upon the nature of the problem and local conditions. In order to mitigate the impact of floods appropriate flood management measures have to be implemented. These measures can be classified into structural measures and non-structural measures

Structural Measures: In this approach, physical structures are envisaged to prevent the flood waters from reaching potential damage centers. The main structural measures undertaken so far in India are viz. Embankments, Floodwalls, Flood levees, Dams and Reservoirs, Natural Detention Basin, Channel Improvement, Drainage Improvement, Diversion of flood water, Catchment area treatment/ afforestation, Anti-erosion works.

Non-Structural Measures: Non-structural measures strive to keep the people away from floodwater. It contemplates use of flood plains judiciously. This technique allows the use of floodplains by reducing the disaster dimension, while retaining its beneficial needs. Non-structural measures are floodplain zoning, flood proofing, flood forecasting and warning, regulation of reservoirs, relief and rescue operations during the flood event.

Flood affected area mapping is one of the most important non-structural measures, which facilitates appropriate regulation, and development of floodplains thereby reducing the flood impact. The recurrent flood events at frequent intervals demand the need for identification of flood hazard prone areas for prioritizing appropriate flood control measures. In this context, satellite remote sensing data plays an important role in delineating such flood affected areas.

2. Satellite Remote Sensing for Mapping and Monitoring of Flood Disaster

Satellite remote sensing can be used during flood event to monitor the extent of flooding, track the movement of floodwaters, and identify areas that are most affected. It can also help in providing near-real-time information on the flood situation and help in decision-making for disaster response and management. High-resolution sensor technology has provided immense scope to the earth resource scientists world-wide for mapping and analysis of earth surface feature details using Remote Sensing and Geographic Information System (RS & GIS).

Flood mapping: Satellite remote sensing can provide high-resolution images of flooded areas, which can be used to create flood maps. These maps can help decision-makers to identify vulnerable areas, assess the severity of flooding, and relief and recovery operations can be planned efficiently.

Flood monitoring: Satellite remote sensing can provide real-time information about flood development, extent, and flood progression. This information can be used to issue timely warnings and alerts to vulnerable population and help emergency responders to plan and carry out rescue operations.

Flood damage assessment: Satellite remote sensing can be used to assess the extent and severity of flood damage to infrastructure and other assets. This information can be used to prioritize relief efforts and to allocate resources for recovery and rehabilitation. The present study is more focussed on flood mapping, however, NRSC has made the damage assessment in several cases in the last 25 years to address the micro-level damages caused due to crops due to dam failure, and flash floods, where ever high-resolution satellite data acquisition was feasible.

Remote sensing makes observation of an object from a distance without being into actual contact. Remote sensing technique can gather data much faster than ground-based observation and can cover large areas at a time to give synoptic view. Satellite remote sensing technology has made substantial contribution in every aspect of flood disaster management such as preparedness, prevention and relief. Space systems from their vantage position have unambiguously demonstrated their capability in providing vital information and services for flood management. Satellite remote sensors cover wide area, periodicity and spectral characteristics and especially in the easiness to compare the data before and after flood disaster.

The Earth Observation satellites provide comprehensive, synoptic and multi temporal coverage of large areas in real time and at frequent intervals and thus have become valuable for continuous monitoring of atmospheric as well as surface parameters related to natural disasters. Geo-stationary satellites provide continuous and synoptic observations over large areas on weather including cyclone monitoring. Polar orbiting satellites have the advantage of providing much higher resolution imageries, even though at low temporal frequency, which could be used for detailed monitoring, damage assessment and long-term relief management. Remote sensing also allows monitoring of flood event during the time of occurrence while floods are at peak. Presence of clouds can hamper satellite optical observations of floods during monsoon season. Microwaves, which has got all weather capability helps under these circumstances. Synthetic Aperture Radar (SAR) a microwave sensor aboard RISAT 1, RISAT 1A, ERS and Radarsat 1/2/ satellites can achieve regular observation of the earth’s surface, even in the presence of cloud cover.

SAR images are also particularly good at identifying open water - which looks black in most images. During last two decades satellite remote sensing has been operationally used for flood disaster management in India. The potential use of remote sensing technology for flood disaster management are for flood inundation mapping and monitoring , Rapid and scientific based Damage Assessment, - Monitoring and mapping of flood control works and changes in the river course, Identification of river bank erosion, - Identification of chronic flood prone areas, Improvement in flood forecasting & warning models, etc. List of frequently used satellites and sensors for flood management in India are shown in Table.2.1.

Table.2.1. List of frequently used satellites/sensor for flood mapping, monitoring

S. No.	Satellite	Sensor	Spatial Resolution
1	IRS-1C & 1D	WiFS	188 m
		LISS-III	23.5 m
		PAN	5.8 m
2	RESOURCESAT-1, RESOURCESAT-2 & RESOURCESAT-2A	AWiFS	56 m
		LISS-III	23.5 m
		PAN/L4-MX	5.8 m
3	RISAT 1	SAR	25m, 50 m
4	IRS-P5 CARTOSAT-1	PAN	2.5 m
5	CARTOSAT-2	PAN	1m
4	RADARSAT-1& RADARSAT-2	SAR	100m, 50 m
6	SENTINEL 1A & SENTINEL 1B	SAR	10m
7	Cartosat 2E	PAN,MX	0.65m,2.00m
8	Cartosat 3	PAN,MX	0.28m,1.12m
9	RISAT 1A (EOS 4)	MRS CRS	33m 50m
Satellite data received from International Charter during severe Floods and Cyclones Events: • Radar (high resolution and very high-resolution sensors): RADARSAT-2, TerraSARX, TanDEM-X, Sentinel-1A/B, ALOS-2, KOMPSAT-5 and GF-3. • Optical (high resolution and very high-resolution sensors): UK-DMC 2, Landsat 7 and 8, VRSS-1, SPOT-6, SPOT-7, PLEIADES 1A and 1B, PROBA-V, GF-1, GF-2, GF4, CBERS-4, KOMPSAT-2, KOMPSAT-3, KOMPSAT-3A, Cartosat-2, Resourcesat2, Resourcesat-2a, RapidEye, Kanopus-V, Kanopus-V-IK, Resurs-P and Sentinel2A/B.			

2.1. Initiatives of Department of Space (DOS) and Scope for Flood Affected Area Atlas

Department of Space (DOS) has launched Disaster Management Support Programme (DMSP) for providing aerospace information for disaster management to the nation keeping in view of the demonstrated potential of earth observation and communication satellites. ISRO has been developing techniques and methodology by integrating space based systems and services for disaster management in order to provide vital inputs and support in the event of a disaster. The programme aims at integration of space technology inputs & services on a reliable and timely basis for strengthening India's resolve towards disaster management considering the requirements such as (i) creation of digital databases at appropriate scales for facilitating hazard zonation, damage assessment, etc., in perennially disaster prone areas, (ii) development of appropriate Remote Sensing & Geographical Information System (GIS) based decision support tools and techniques and demonstrations catering to the information needs at different levels, (iii) acquisition of close contour information for priority areas, (iv) strengthening the communications backbone for addressing the real time / near real time information transfer needs and (v) networking of scientific institutions for exchange of data, information and knowledge. A Decision Support Centre (DSC) is established at National Remote Sensing Centre, (NRSC), Hyderabad is established for enabling the operational services as a single window provider, interfacing with the Central / State disaster management agencies. The important components of the DSC include satellite / aerial data acquisition strategy, providing user required information and formats, output generation, dissemination of information generated to the users through networking, support functions such as digital database, query shells, hazard zonation, etc.

3. Methodology for Satellite Based Flood Inundation Mapping and Monitoring

Satellite-based technologies and Earth Observation (EO) data are essential for the assessment of flood inundation information - a remote sensing application to support flood disaster management in India. Satellite remote sensing data can be combined with other data sources such as hydrological models and ground-based observations to improve flood forecasting and warning systems. Daily information is received through flood disaster watch enabling the tracking of the data on river water level, rainfall, spatial runoff, and other available field data is analyzed. Flood conditions in terms of flood progression, recession, and persistence are assessed using multi-date satellite data at regular intervals. This information is also used to generate flood maps that can help in identifying areas that are at high risk of flooding, and for better planning and preparedness for future floods. Satellite derived spatial flood information is used to provide up-to-date information about the extent of the flood affected area, which can help emergency responders to plan and prioritize their activities in near real time during floods,

Satellite sensors can capture images in different wavelengths such as visible, infrared, and microwave, which are used to detect changes in land cover, identify areas that are under flood inundation. Different types of satellite data can be used for flood mapping, including optical and microwave data, each with its own advantages and limitations. Optical data, for example, can provide high-resolution images, but it can be limited by cloud cover. Synthetic Aperture Radar (SAR) sensors will penetrate through cloud cover and is used for interpretation of images of the flood-affected areas. By using a combination of different types of satellite data, flood mapping can provide valuable information to support flood response and mitigation efforts.

3.1. Pre Flood Satellite Data Preparation

Pre-flood satellite data over flood-prone states are acquired and analyzed before the onset of the flood season. River bank lines, permanent water bodies, and active river channels are extracted. These datasets and layers are used as reference layer for further analysis on change detection. These images are considered as reference satellite images, and the currently acquired satellite data is geometrically co-registered for maintaining consistent positional accuracy. Various steps followed for pre–flood data generation are shown in Figure.3.1. In addition, latest Landuse / Land cover information at 1: 250000 scale is also utilized in the process of pre-data preparation (Figure.3.2)

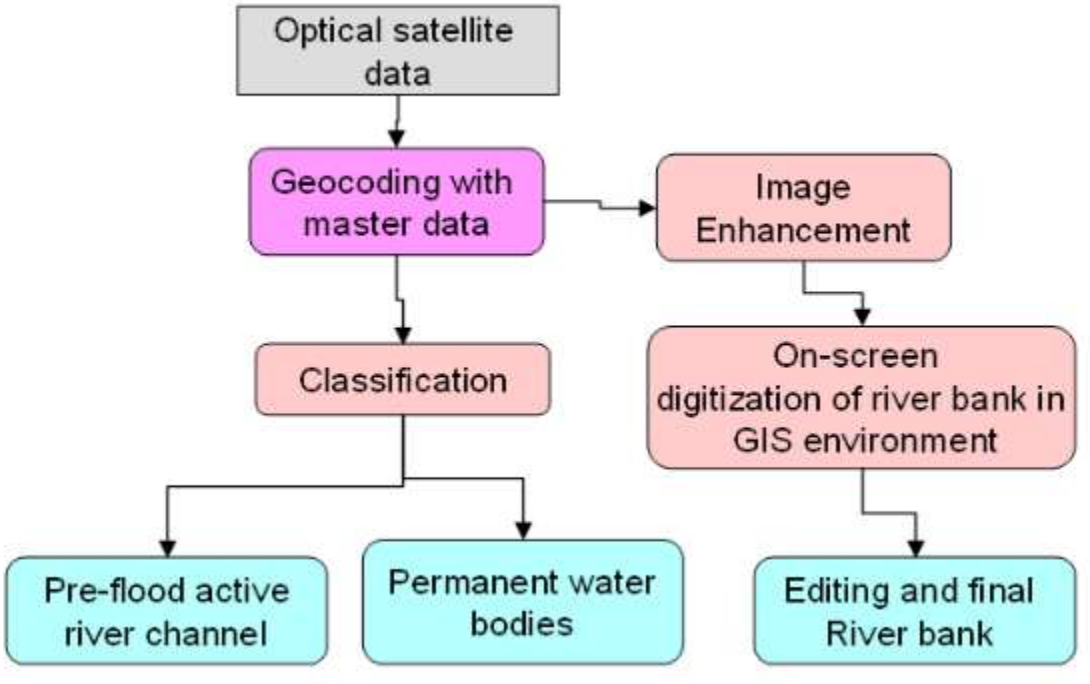

Figure.3.1. Flowchart for Pre-flood Data Preparation

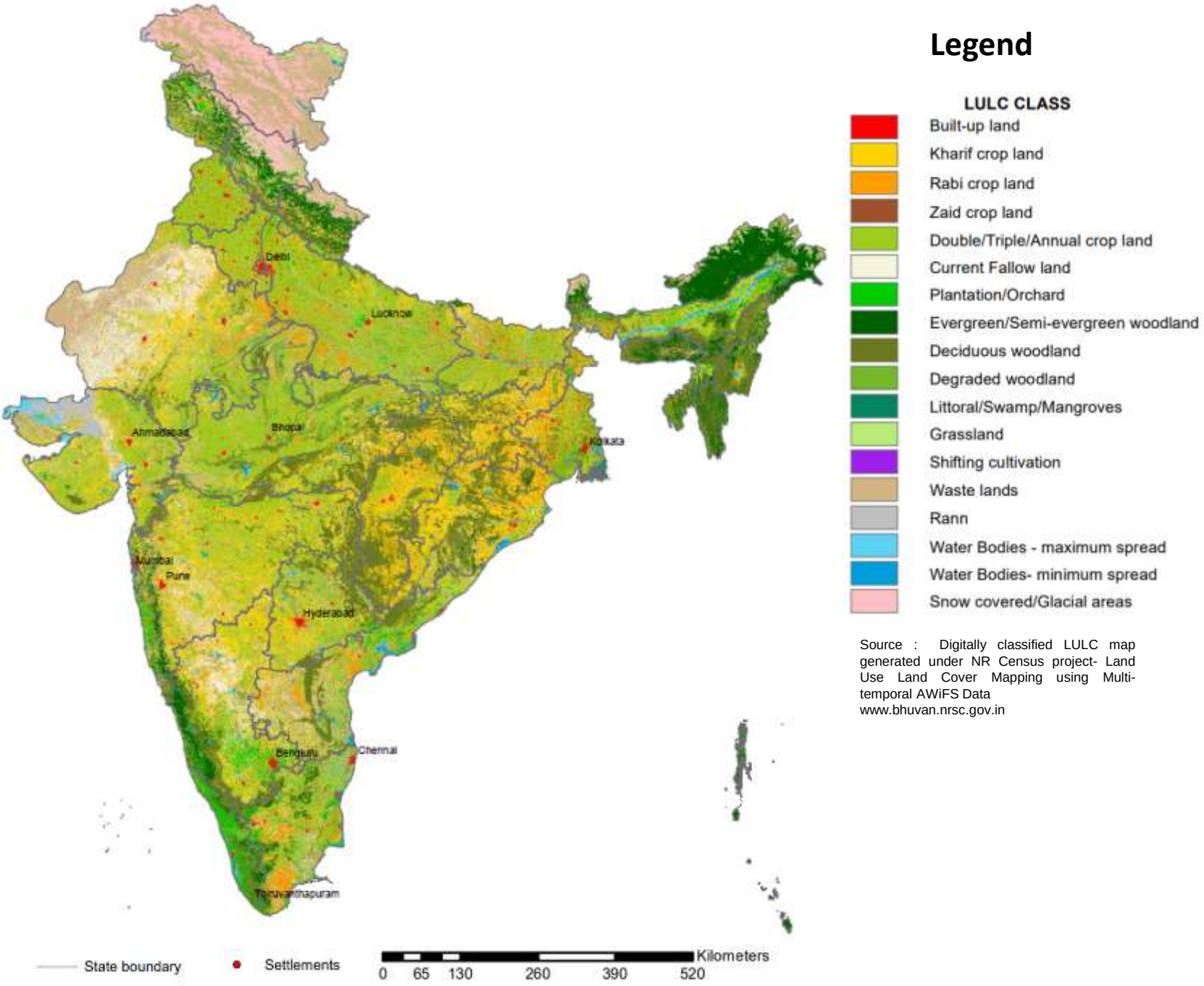

Figure.3.2. Satellite derived Landuse / Landcover Map (2021-22) at 1: 250,000 scale

4. Satellite data acquisition and analysis

Two types of satellite data (optical, microwave) are utilized for generation of spatial flood inundation mapping. Brief methodology for processing of optical and microwave satellite datasets are explained here :

4.1. Optical Satellite Data Processing

Satellite images are classified using digital image processing software to extract water pixels from the image. In case of optical satellite data, unsupervised classification is performed over optical remote sensing data to include the classes viz. main active river channel, tributaries, and water bodies. A classified image is generated, which is further converted to vector format. Enhancement techniques are used to increase the contrast between the features in the image.

4.2. Microwave Satellite Data Processing

In case of microwave satellite data a backscattering (Sigma naught) image is generated, and water bodies are extracted using a variable threshold technique model. State mask, hill mask, and hill shadow mask are applied to the extracted water layer. Further, isolated water pixels, which are not likely to be water pixels, are separated by grouping and removing them. The flow chart of the methodology for processing of SAR data, optical data are shown in Figure 4.1 and 4.2. The advantage of using SAR satellite data over optical data is its ability to penetrate cloud cover and also data acquisition during both day and night times. Water surfaces are generally smooth at radar wavelengths and can consider specular reflectors, which yield small backscatter. The surrounding terrain is assumed to be rough at radar wavelengths which exhibit diffuse scattering with moderate backscatter. Hence, water is considered low-intensity areas, whereas the surrounding terrain corresponds to brighter intensities. Thresholding is the traditional method of detecting flooding in open areas. Intensities below the threshold are regarded as flood or open water, whereas pixels with intensities above the threshold are regarded as dry land. The threshold will depend on the contrast between the land and water classes and generally needs to be set for each satellite scene. The backscatter depends on the frequency, incidence angle, and polarization and is sensitive to ripples on the water surface induced by wind waves.. The use of Synthetic Aperture Radar (SAR) is particularly useful for flood mapping as it can acquire images regardless of weather conditions and can provide high-resolution data. Additionally, SAR can provide data in multiple polarizations, which can be used to differentiate between different types of land cover and improve flood mapping accuracy.

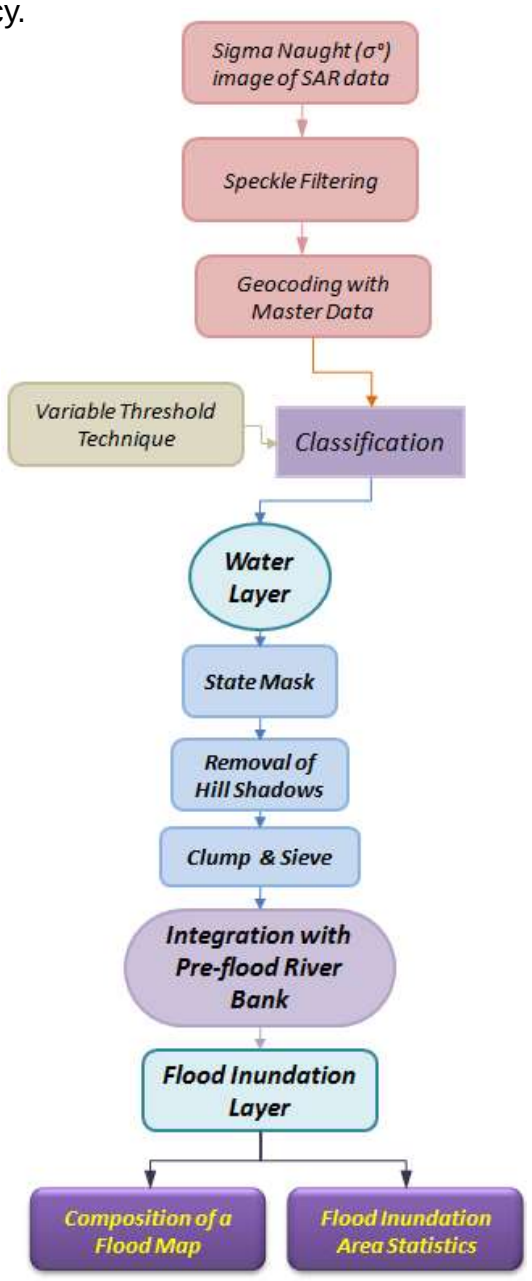

Fig.4.1 Methodology for flood mapping and monitoring by SAR satellite data

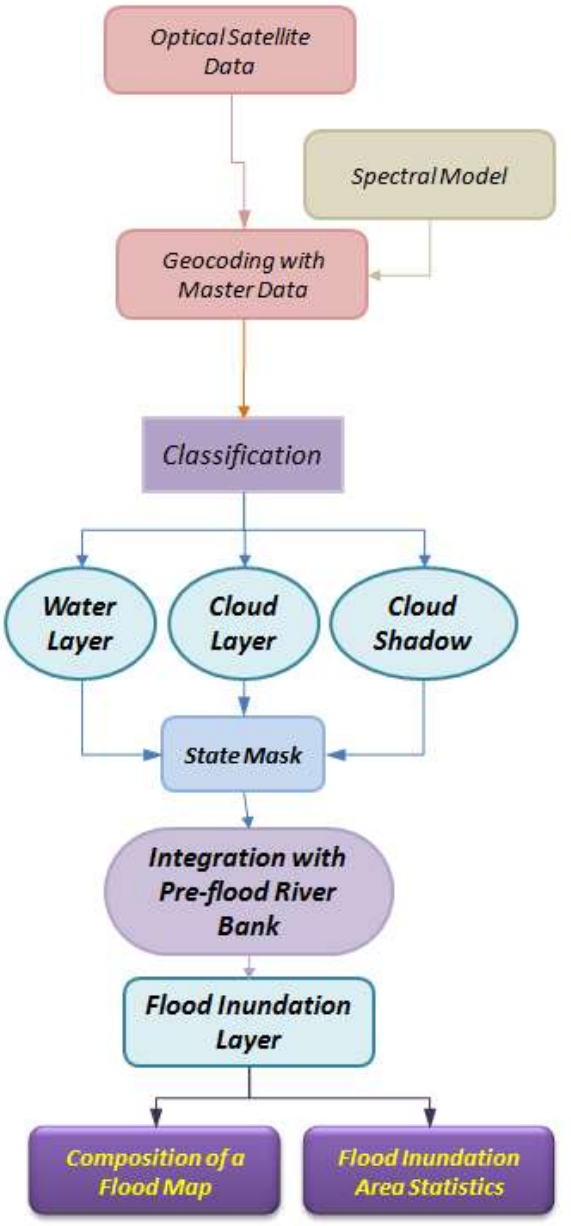

Fig.4.2. Methodology for flood mapping and monitoring by optical satellite data

5. Flood Affected Area Estimation and analysis at National Level

India is prone to floods due to its monsoon climate and the extensive network of rivers that run through the country and also affected by cyclones due to the presence of a longer coastline. As part of the Prime Minister's 10-point agenda for disaster risk reduction, maximum efforts are being put in India at State / Central level disaster management support organizations while dealing with flood preparedness, relief & rehabilitation activities during the flood, and flood mitigation through structural & nonstructural measures and this is mandated to minimize the disaster risk throughout for sustainable growth in the country.

There are several experiences in India for disaster management support organizations that call for requirements of continuous data on flood-affected areas, identification & depiction of hotspots, and initiating the strategic planning and implementation of projects for ensuring flood mitigation measures to minimize the loss of life and property.

National Remote Sensing Centre (NRSC), Indian Space Research Organization (ISRO) has been using satellites since 25 years (IRS - 1C,1D, P5, P6, Resourcesat, Cartosat, RISAT Series of satellites with multiple sensors of different spatial resolutions) to capture the spatial flood inundation during major flood events across the country which have happened due to overflow of rivers in high monsoon rainfall conditions, affect of cyclones and storm surges, heavy rainfall scenarios, etc. It is essential to prepare a Flood Affected Area Atlas to augment the event based spatial flood inundation maps to for comprehensive understanding on the severity of the flood and to provide comprehensive information about flooding in a region, which can be used to inform.

Flood mapping involves creating digital maps that show areas that are at high risk of flooding which are created using data from various sources, such as satellite imagery, topographic maps, and historical flood data, etc. A flood atlas, on the other hand, is a collection of maps and information related to flooding in a particular region. Flood atlases typically depict the information such as flood hazard, flood frequency analysis, and historical flood data. Digital archival of spatial flood maps that were generated during each event of flood disaster in last 25 years in several states are utilized to prepare a Flood Affected Areas Atlas of India. Flood Affected Area Atlas will provide the opportunity to explore the regional setting of flood risk during last 25 years and identify the areas of hotspots where recurring flood occurs and also to prioritize the requirements for flood mitigation measures.

Spatial Flood Inundation maps prepared since 25 years in the flood season of every year are utilised for generation of cumulative flood layer. Thus , the map derived is - Flood Affected Area Map in India as shown in Figure 5.1 and the same presented at National, State & district level in this report. State wise statistics on flood affected area is provide in Table.5.1. Details of each State are provided in this Atlas. Satellite image analysis and maps derived Flood Affected Area maps estimates that, there is flood affected areas in the country is around 15.75 Mha spread over 435 districts. Number of districts affected by flood and area wise categorization is provided in Table.5.2.
Flood affected area is 39.76 Lakh Ha in Bihar due to floods in Ganga, Kosi rivers affecting 38 districts which is highest in the country. Flood affected area is 26.62 Lakh Ha, in Uttar Pradesh spared over 72 districts due to floods in Ganga river system every year, Flood affected area is 24.56 Lakh Ha in Assam which spread over 35 districts due to the floods that occur in Brahmaputra , Barak rivers almost every year. Flood affected area in these 3 states amounts to 60% of total flooded area in the country.

Coastal states like Tamilnadu, Andhra Pradesh, Odisha, West Bengal are more prone to floods which is depicted in this study. Flood inundation in all other states appears to be less frequent and seasonal due to unprecedented heavy rainfall with high intensities, standing water in low lying areas.

Flood mapping and monitoring is essential for three phase of flood preparedness, during the flood and flood mitigation measures. They can help to assess the risk of flooding in a particular area through analysis of historical flood data in conjunction with the collateral information to initiate and implement the development of flood management strategies and emergency preparedness plans as preparedness.

Further, during the flood, flood maps can be used to develop emergency response plans, including evacuation routes and emergency shelters as emergency response and management. In the event of a flood, emergency responders can use flood maps to identify areas that are most at risk and to prioritize rescue and relief efforts. It will be helpful for planning and land-use management decisions, such as where to locate buildings, roads, and other infrastructure by avoiding high-risk areas and using flood-resistant design and construction techniques, thus the impact of floods can be minimized. In other words, flood maps can also be used to inform the design and construction of infrastructure, such as drainage systems and flood protection structures.

Flood maps can be used to identify flood-prone areas, infrastructure can be designed to withstand floods and minimize damage and Overall, flood mapping is an important tool for understanding and mitigating the risks associated with flooding. By identifying high-risk areas, developing flood management strategies, and implementing effective emergency response plans, the impact of floods can be reduced, and lives and property can be protected.

Table. 5.1. Flood affected area (1998-2022) Statistics at State level

S. No.	State	No. of Districts Affected	Flood Affected Area (Ha)
1	Andhra Pradesh	24	738200
2	Arunachal Pradesh	5	3373
3	Assam	35	2464958
4	Bihar	38	3976861
5	Chhattisgarh	12	12029
6	Delhi	7	5848
7	Gujarat	16	517770
8	Haryana	9	67852
9	Jammu & Kashmir	10	43022
10	Jharkhand	2	2966
11	Karnataka	26	280156
12	Kerala	10	79377
13	Madhya Pradesh	30	210809
14	Maharashtra	20	233590
15	Manipur	9	88352
16	Meghalaya	2	8787
17	Odisha	23	1424313
18	Punjab	15	142692
19	Rajasthan	10	155144
20	Tamil Nadu	24	552010
21	Telangana	14	102318
22	Uttar Pradesh	72	2662942
23	Uttarakhand	2	7604
24	West Bengal	20	1569750
TOTAL		435	15750723

Table. 5.2. Flood affected area Severity categories based district level (1998-2022) Statistics

Flood affected area (Ha)	No. of Districts Affected
>2,00,000	12
1,50,000 -2,00,000	11
1,00,000 - 1,50,000	34
50,000 - 1,00,000	50
25,000 - 50,000	48
10,000 - 25,000	66
5,000 – 10,000	52
1,000 – 5,000	76
100 – 1,000	86
Total	435

Disclaimer: *Disclaimer : Flood affected area map is a cumulative of flood inundation areas mapped from multi-date satellite data acquired and processed during 1998-2022 covering major flood & cyclone events. Flood inundation may include rain water accumulation / flood water in low lying areas. Estimated flood extent depends on availability of satellite data, it's date of overpass and coverage over flooded areas. Some of the Flash flood events could not be mapped due to non availability of satellite data in short duration. Flood affected area estimated in the study excludes river portion, permanent water bodies, salt pan and aquaculture lands in flood plains. Hence, actual flooded area may be more than the area estimated by satellite images.*

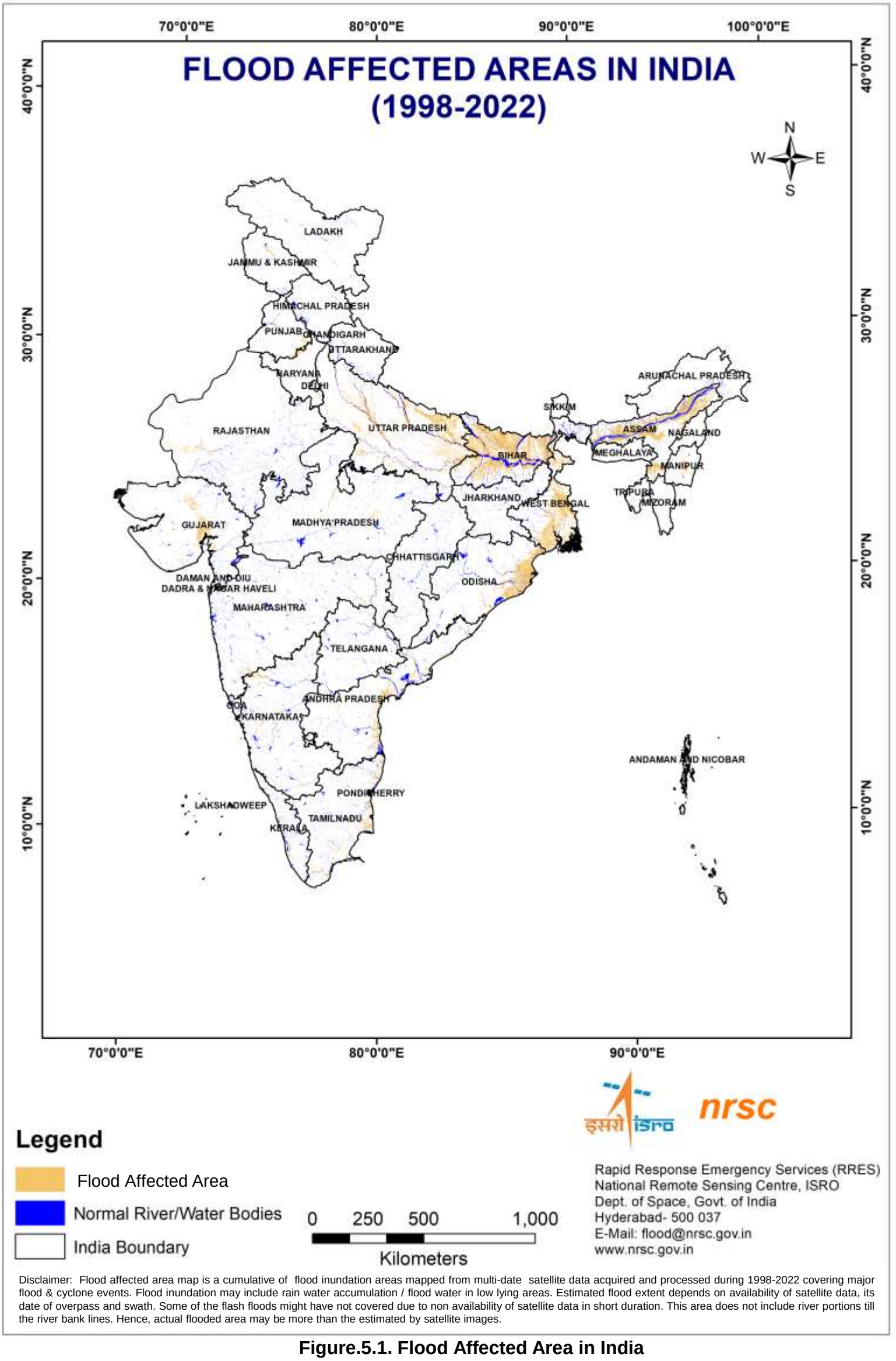

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Figure.5.1. Flood Affected Area in India

6. Andhra Pradesh

Andhra Pradesh

Andhra Pradesh is situated in the south-east part of the country and is bordered by Telangana in the north-west, Chhattisgarh and Odisha in the north-east, Karnataka in the west, Tamil Nadu in the south, and to the east lies the Bay of Bengal. Andhra Pradesh has a coastline of 974 km – the second longest coastline among the states of India, after Gujarat. The small enclave of Yanam, a district of Puducherry, lies to the south of Kakinada in the Godavari delta on the eastern side of the state. River Godavari is the largest and broadest river in the southern India, which originates at Triambakeshwar near Nasik in Maharashtra. River Krishna enters the state at Alampur after having originated at Mahabaleshwar in Maharashtra. Tungabhadra is an important tributary of the river Krishna. Nagarjunasagar Dam at Nandi Konda, Srisailam project at Srisailam and Prakasam barrage at Vijayawada, are constructed on this river. Pennar, Vamsadhara and Nagavali are other important rivers. All the rivers are rain fed and of great economic significance because they are the source for hydropower and irrigation. The two major lakes in the state are the Kolleru and Pulicat. While the Kolleru lake lies in the delta between the rivers Krishna and the Godavari, the Pulicat lake is located in the southern tip of Nellore district, close to the sea. Andhra Pradesh state is rich in reservoirs and tank resources.

All the rivers in Andhra Pradesh are basically rain dependent and they have large currents in rainy season and low currents in summer. Some rivers are even dry in summer. The major rivers in Andhra Pradesh are Godavari, Krishna, Tungabhadra, Pennar, Manjira, Nagavali, and Vamsadhara. The Krishna and Godavari rivers are the largest and broadest in South India. In Andhra Pradesh all the rivers generally flows from northwest to southeast. Except Godavari, Pennar, Krishna, Tungabhadra, Bhima, Manjeera, Pranahita, all rivers have their source at East mountainsides and destination at Bay of Bengal. The Deccan rivers (Godavari and Krishna) contribute about 30 % of the total out flow in India. Of this, the rivers that flow from the west to east account for 20 % and those from the east to west about 10 %. The Godavari and its tributaries flow through the states of Maharashtra , Karnataka, Madhya Pradesh , Orissa and Andhra Pradesh. The recorded peak discharge of Godavari at Dhawaleshwaram was noted to be 85,000 cubic metres per second (30 lakh cusecs). The Krishna is the second largest river in the State. The traditional source of the river is a spout from the cow's mouth in the ancient temple of Mahadev in Mahabaleswar in Maharashtra at an elevation of 1337m and it flows 780-kms before it enters Andhra Pradesh. The length of the Krishna river is 1400 km. The total catchment is 2,59,000 sq.km. The river gets most of its water from Western Ghats. Central Water Commission (CWC) is maintaining 20 (10 Level and 10 Inflow) Forecast Stations in Andhra Pradesh in basins of Vamsadhara, Nagavali, Godavari, Krishna and Pennar Basins. Almost all rivers are prone to floods in Andhra Pradesh as the State gets contribution from both South-West as well as North-East Monsoons and the period of flood season extends from 1st June to 31st October in Northern Coastal Andhra Pradesh, Godavari and Krishna. South of Krishna, the flood season further extends upto 31st December every year.

6.1 Major Flood Events in Andhra Pradesh

Andhra Pradesh is exposed to cyclones, storm surges, floods and droughts. Cyclones develop in the pre-monsoon (April to May) and post-monsoon seasons (October to December), but most of them tend to form in the month of November. The coastal region suffers repeated cyclones and floods. Traditionally the flood plains of Godavari, Krishna, Vamsdhara and Nagavalli have been subjected to floods due to heavy rains in the upstream catchment areas, but occasionally floods have been observed in smaller rivers as well. Cyclone induced heavy rains have been one of the prominent reason for floods in the state. The Godavari floods of 2006, Krishna floods of 2009, Floods in 2018 and 2019 were some of the most harrowing floods experience the state has felt in the recent past. According to the available disaster inventories, AP is the state that has suffered the most from the adverse effects of severe cyclones. It has been estimated that about 44 percent of AP's total territory is vulnerable to tropical storms and related hazards, while its coastal belt is likely to be the most vulnerable region in India to these natural phenomena. Along the coastline, the section between Nizampatnam and Machilipatnam is the most prone to storm surges.

Andhra Pradesh is affected with heavy to very heavy rains which has caused floods in the inland rivers between June and September. AP with its coastline of 974 km is more vulnerable to cyclones. AP is at risk of at least one cyclone each year on an average and maximum during October and November. Cyclones with moderate to severe intensity occur every two to three years, which results in huge damage to the state. The extent of damages has been increasing on an annual basis. In the last 7 years (2014-2020) major floods and cyclones like Cyclone Hudhud, Floods of 2016, Floods of 2017, Cyclone Titli, Cyclone Nivar, etc. have impacted heavily. Major floods that have affected Andhra Pradesh State are listed here Table.6.1 for which satellite derived spatial flood inundation maps were generated and disseminated to State / Central Government Disaster Support Management Organizations by NRSC, ISRO.

Table. 6.1. Major flood events in Andhra Pradesh state

S. No	Year	Description of the flood event	Districts affected
1	2005	Floods occurred during 29th Jul -12th August 2005 , 19th - 22nd Sep 2005 due to rise in water levels in Tungabhadra, Krishna Rivers.	10
2	2006	Floods in Godavari & Sabari rivers during 5th – 18th Aug 2006	3
3	2007	Floods occurred during 4th June 2007 due to heavy rains as a result of depression in Bay of Bengal and also during 4th week of October 2007 due to heavy rains.	6
4	2008	Floods occurred during 7th -13th August, 18-19th Sep, 29th -30th Nov 2008 due to heavy rains	5
5	2009	Floods occurred during first week of 4-7th, October, 2009 due to heavy rainfall. Floods Heavy rains in the catchments of Krishna, Tungabhadra rivers during the first week of October 2009 affecting Kurnool town due to backwaters of the Srisailam dam and unprecedented inflows.	4
6	2010	The low pressure developed in the Bay of Bengal on 17th May, 2010 turned into a Cyclonic Storm called "Laila". ; and Floods occurred due to heavy rainfall during the 1stweek of September 2010, 1st week November 2010.	3
7	2012	Rains due to cyclone NILAM during first week of November 2012.	6
8	2013	Floods in last week of October due to heavy rains under the influence of low-pressure and north-east monsoon	4
9	2014	Cyclone HUDHUD made a landfall on 12thth October, 2014 on the coast of Andhra Pradesh, near city of Visakhapatnam	1
10	2015	Floods due to heavy rains	5
11	2018	Floods were reported due to heavy torrential rains during 2nd week of October, 2018 (12-13th Oct) under the influence of Cyclone Titli. Further due to impact Cyclone Phethai (21st Dec 2018)	4
12	2019	Floods were reported in due to heavy rains during August, 2019 due to rise in water levels in Godavari and Krishna Rivers.	4
13	2020	Floods were mapped in the state of Andhra Pradesh 4 times during August, October and in November 2020	8
14	2021	Heavy rains are reported 4th week of July, 4th week of September, Nov, 2021 due to multiple depressions formed in Bay of Bengal. The Coastal areas suffered due to the influence of Cyclones - Jawad, Gulab and Yaas.	
15	2022	Heavy rains are reported during 14th –28 July 2022, 12th Aug-28th Aug, 12-14th Sep 2022 and rise in water levels in Godavari and Sabari rivers.	7

6.2. Flood Hazard Zonation in Andhra Pradesh

A specific study was conducted to generate the flood hazard map for Andhra Pradesh State using satellite datasets (79) acquired during the flood events of 2000-2020. A cumulative flood inundation map was generated and analysis was made with reference to the frequency of flood occurrence at spatial & temporal scales, frequency of rise in river water levels which have been recorded beyond the danger level, etc. Flood Hazard zonation map has been generated and analysis is presented at district level and spatial flood hazard zonation maps were hosted on National Data Base Emergency Management (NDEM) and Bhuvan geoportals.

Flood hazard zonation Map of Andhra Pradesh is shown in Figure. 6.1. Flood hazard area computed under various categories in Andhra Pradesh, district wise (erstwhile district list) is shown in Table.6.2 and Table. 6.3. Flood hazard analysis indicate nearly 4.92% (7.92 Lakh Ha) of land in, AP state is affected by flood during 2000-2020 out of the total state geographical area 1.60 Lakh ha, out of total 7.92 lakh ha of flood affected area in the state, about 5.81 lakh ha of land falls under very low (inundated 1 or 2 times), 1.86 lakh ha under low (inundated 3-5 times) and 23,609 ha under moderate (inundated 6-10 times) flood hazard categories.

Table.6.2. State wise Flood Hazard Zonation Categories and Area estimates in Andhra Pradesh

Sl. No	Hazard Severity	Flood Hazard Area (ha)	% Flood Hazard (wrt State Geographic Area)	% Flood Hazard (wrt Total Flood Hazard Area)
1	Very Low	581584	3.62	73.42
2	Low	186911	1.16	23.60
3	Moderate	23609	0.14	2.98
TOTAL		792104	4.92	100

Table.6.3. District wise Flood Hazard Zonation Categories and Area estimates in Andhra Pradesh

District	Very Low	Low	Moderate	Total
CHITTOOR	14486	419	0	14905
EAST GODAVARI	34483	11153	2589	48225
GUNTUR	83531	17525	409	101465
KRISHNA	37640	1422	0	39062
KURNOOL	27370	2	0	27373
PRAKASAM	70565	30900	3758	105223
S.P.S.NELLORE	99766	23727	1848	125341
SRIKAKULAM	24106	3020	0	27126
VISAKHAPATNAM	7733	1065	0	8798
VIZIANAGARAM	668	0	0	668
WEST GODAVARI	38471	7826	210	46508
Y.S.R.KADAPA	5758	0	0	5758
TOTAL	444577	97059	8814	550452

Source : Flood Hazard Zonation Atlas, NRSC, 2021

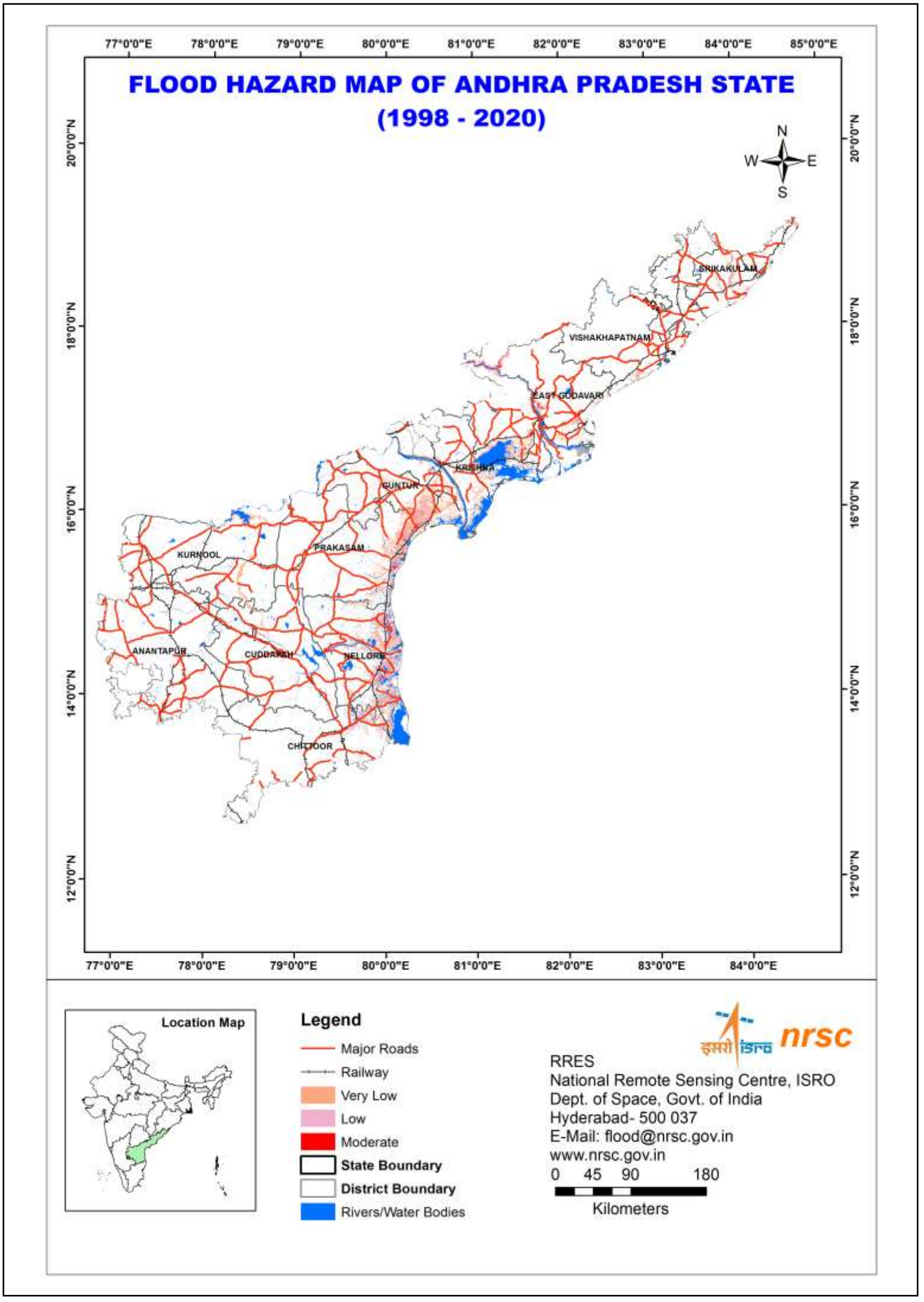


Fig.6.1 Flood Hazard Map of Andhra Pradesh State

6.3. Flood Affected Area Estimation and Analysis in Andhra Pradesh

Cumulative flood inundation maps were utilised for generation of total flood affected area map in Andhra Pradesh and is estimated as 7,38,307 ha. It is observed that, the flood affected areas in Andhra Pradesh are mainly due to rise in water levels in Godvaari, Sabri rivers in majority of the years while coastal districts were affected due to cyclones. Flood affected area map is shown in Figure.6.2. and District wise flood affected area statistics are shown in Table. 6.4. Two districts namely Sri Potti Sriramulu and Bapatla have witnessed floods to the extent of 144354 ha, 111667 ha respectively while two districts in between 50000-100000 ha, 6 districts in between 25000-50000 ha, 6 districts in between 10000-25000 ha, 8 districts <10000 ha out of total 22 districts affected in Andhra Pradesh State.

Table.6.4 District wise statistics of Flood affected area in Andhra Pradesh

S.No.	District	Flood Affected Area (ha)
1	Sri Potti Sriramulu Nellore	144317
2	Bapatla	111637
3	Tirupati	83151
4	Prakasam	60207
5	Guntur	48973
6	Srikakulam	39114
7	Nandyal	33035
8	Eluru	29809
9	Krishna	29582
10	West godavari	27397
11	East godavari	21322
12	Kakinada	18983
13	Anakapalli	17631
14	Alluri sitharama raju	16661
15	Palnadu	12630
16	N T R	11021
17	Konaseema	9844
18	Y S R	6792
19	Parvathipuram manyam	6153
20	Vizianagaram	4453
21	Anantapuram	3127
22	Kurnool	1673
23	Visakhapatnam	396
24	Annamayya	293
	TOTAL	**738200**

Glimpses of satellite images / flood inundation over the time period are depicted in this section.

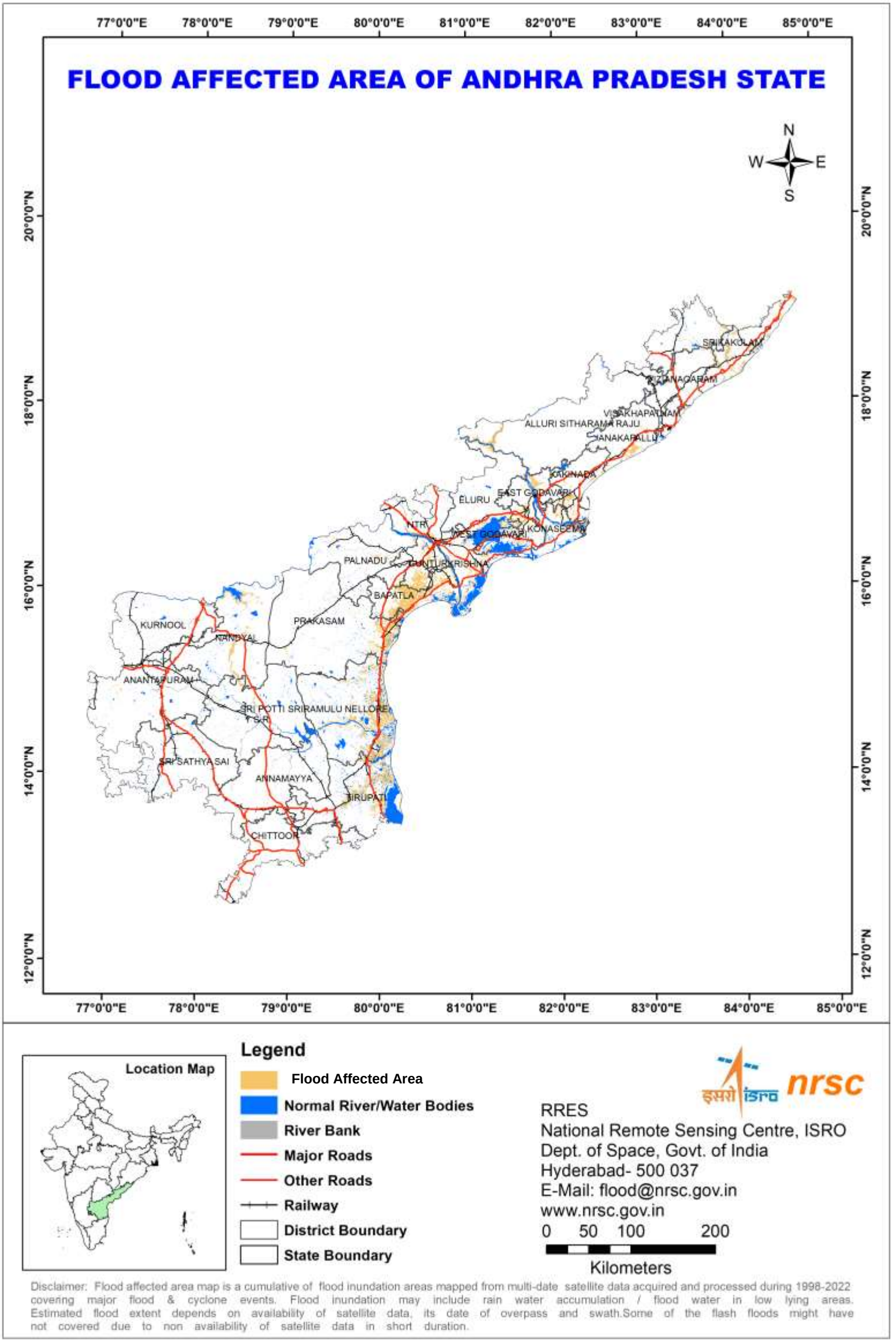
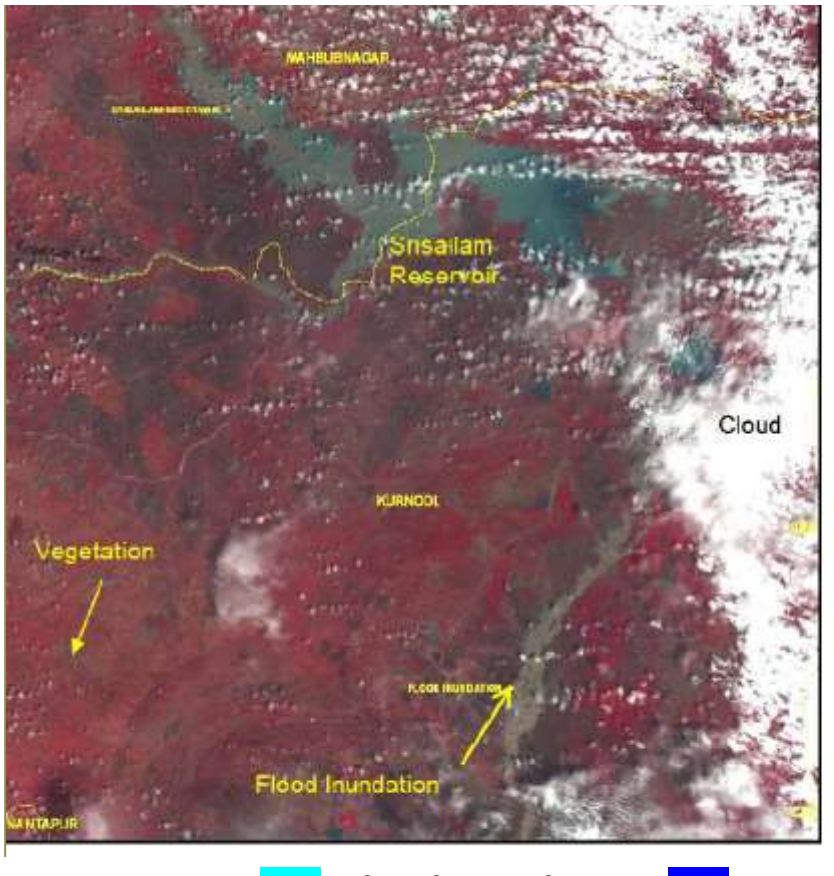
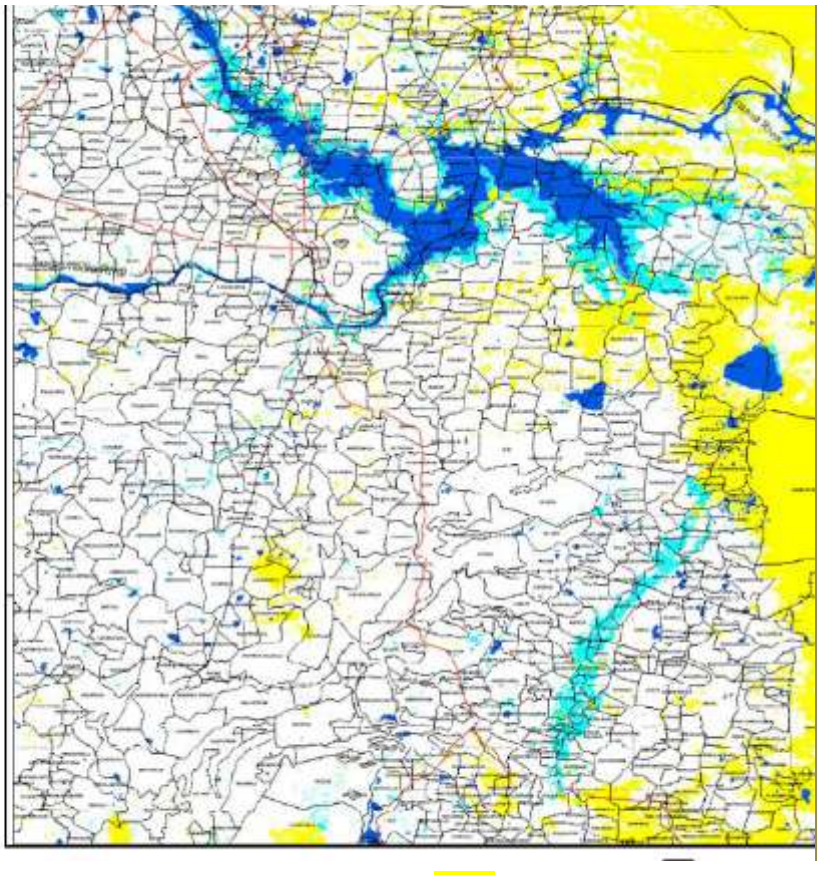


Fig.6.2 Flood affected area of Andhra Pradesh

Resourcesat AWiFS as on 04th Oct 2009

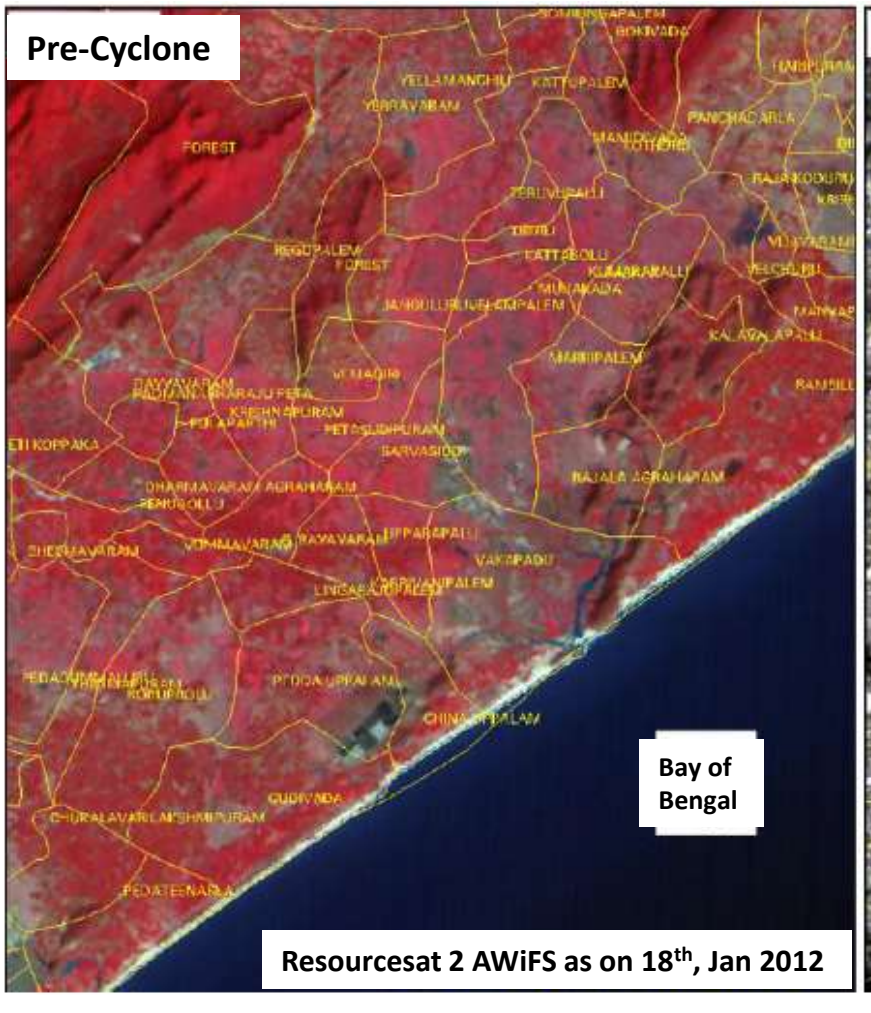


Flood Map

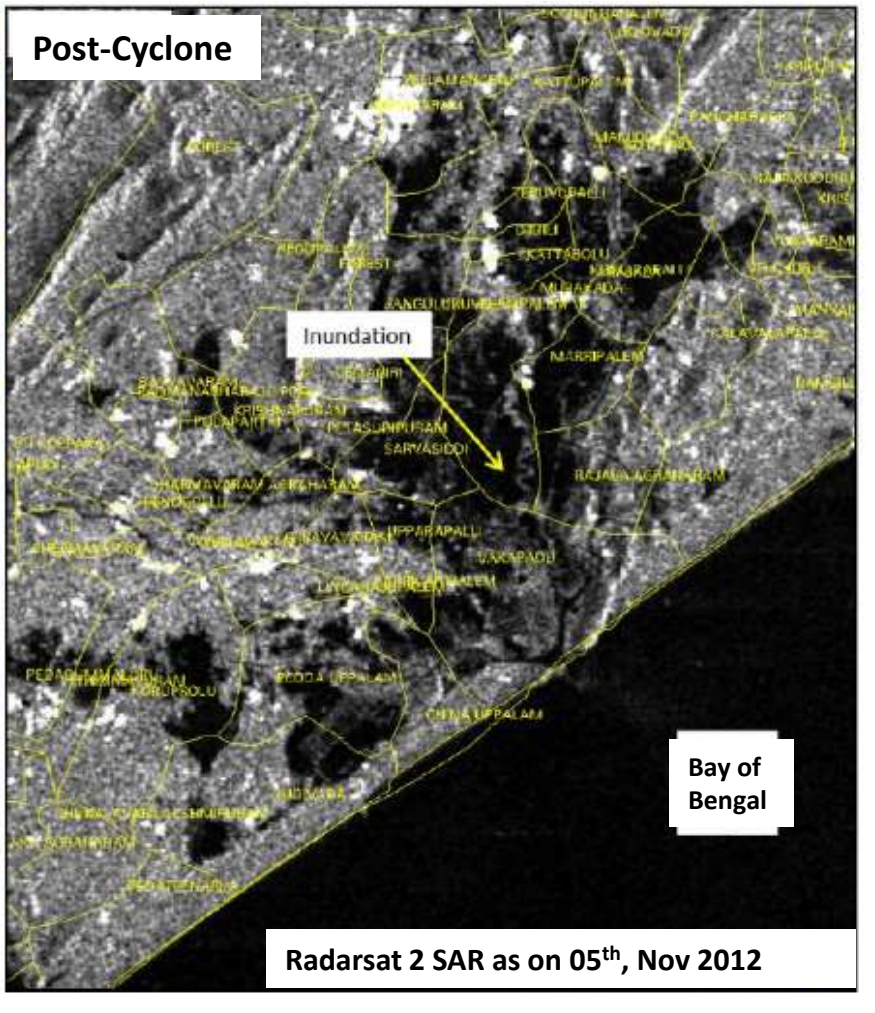


Flood Inundation Normal River / Water bodies Cloud

Flood inundation as on 4th Oct 2009 – Krishna River affecting Kurnool district



Resourcesat 2 AWiFS as on 18th, Jan 2012

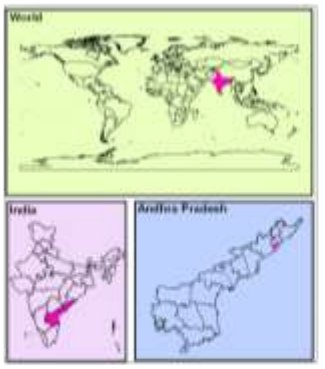


Radarsat 2 SAR as on 05th, Nov 2012

Flood inundation as on 5th, Nov, 2012 during – Cyclone NILAM , Andhra Pradesh

Cyclone : HUDHUD in Andhra Pradesh

Location Map



Very severe cyclonic storm HUDHUD over west Bay of Bengal made landfall on 12th Oct 2014 in Andhra Pradesh. High resolution satellite images are acquired through international Charter

Cyclone Track

Flood Inundation near Anakapalle Town

WorldView2 Image: 14-Oct-2014

Flood Map as on 14-Oct-2014

Infrastructure damage to the industries

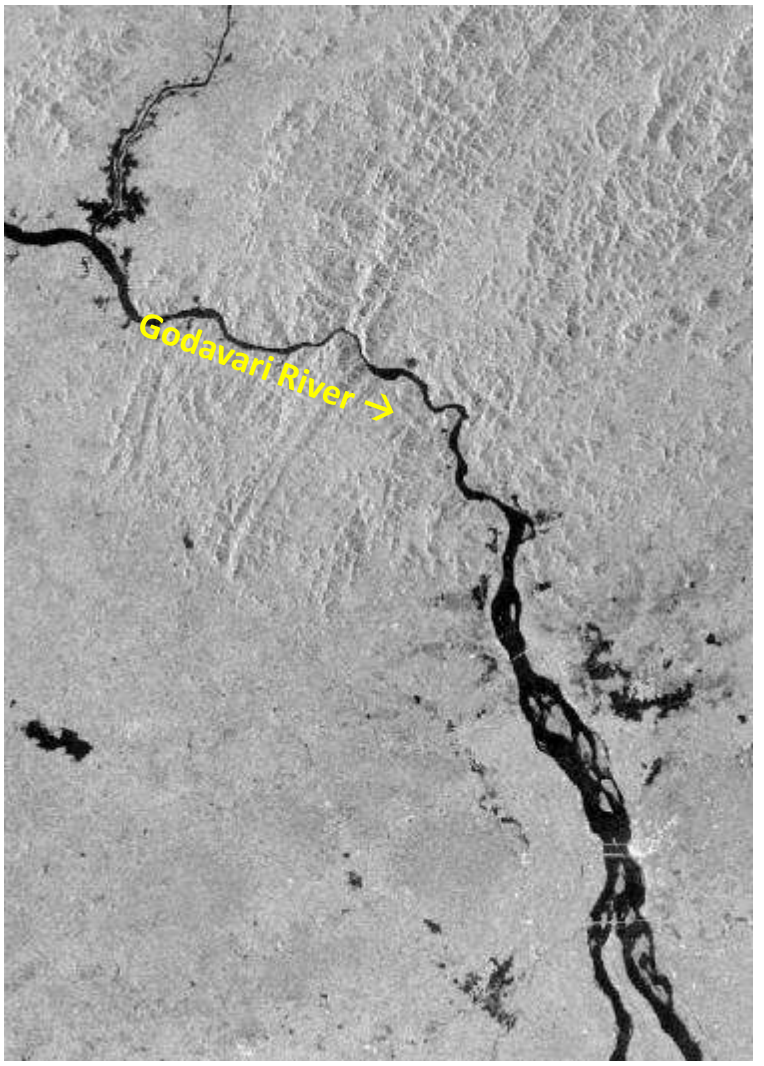
Trees damage in Andhra University

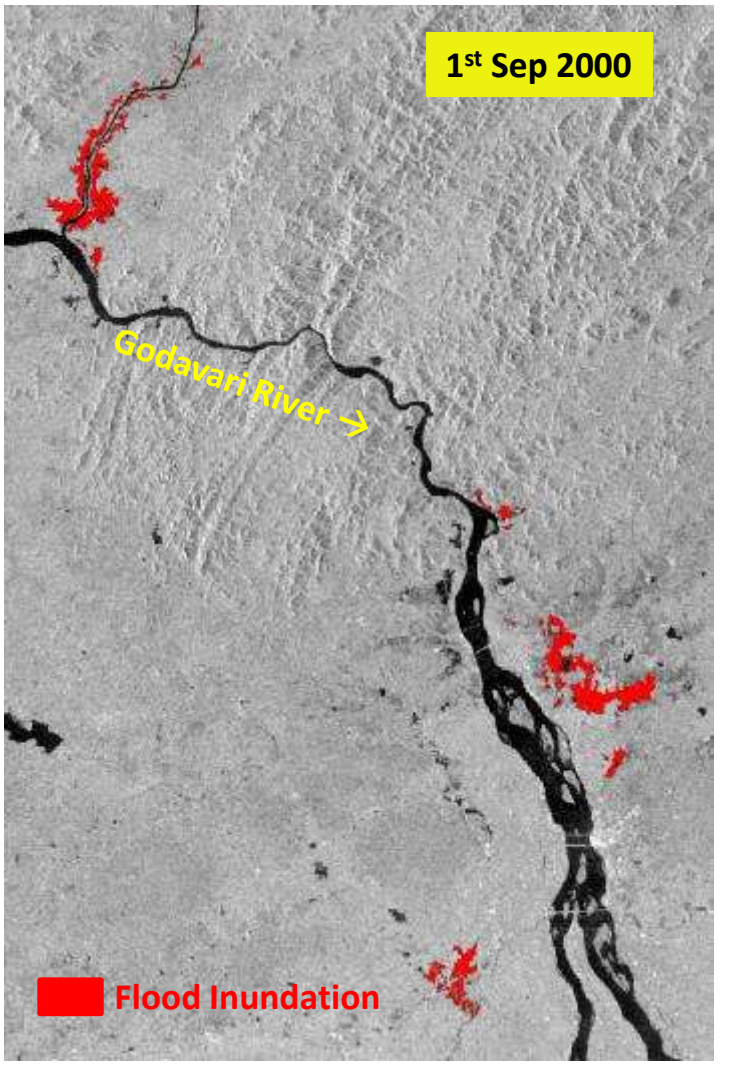
Infrastructure damage to Gangavaram Port

Trees damage Near Nadupuru Reserve Forest

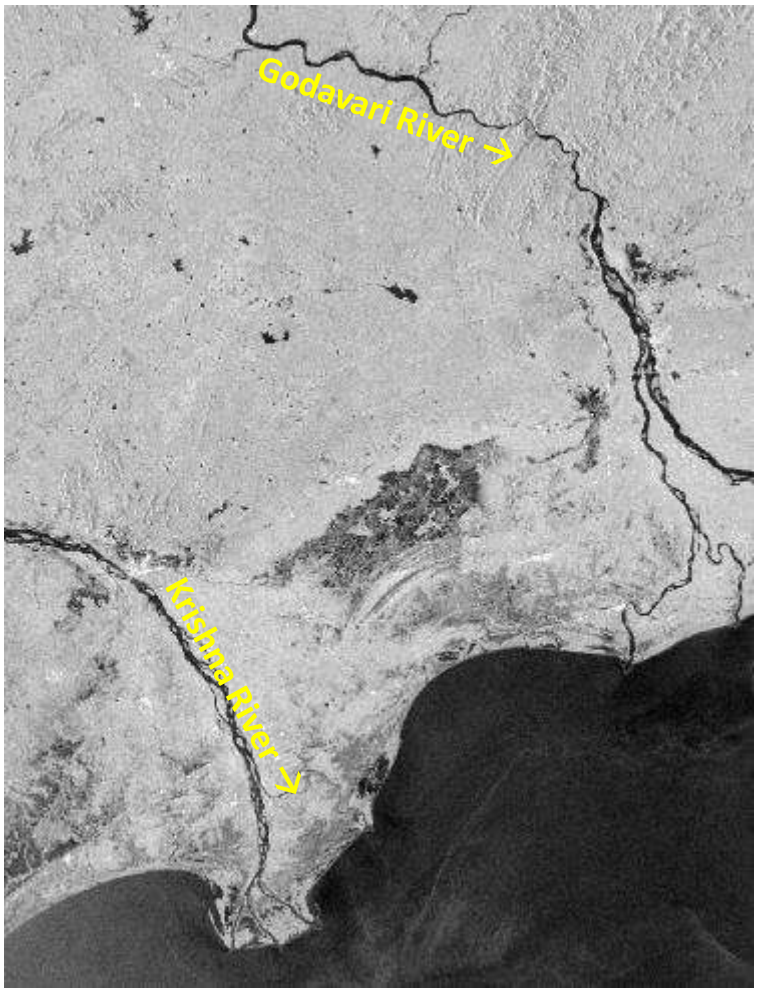
Damage in the Vizag Airport

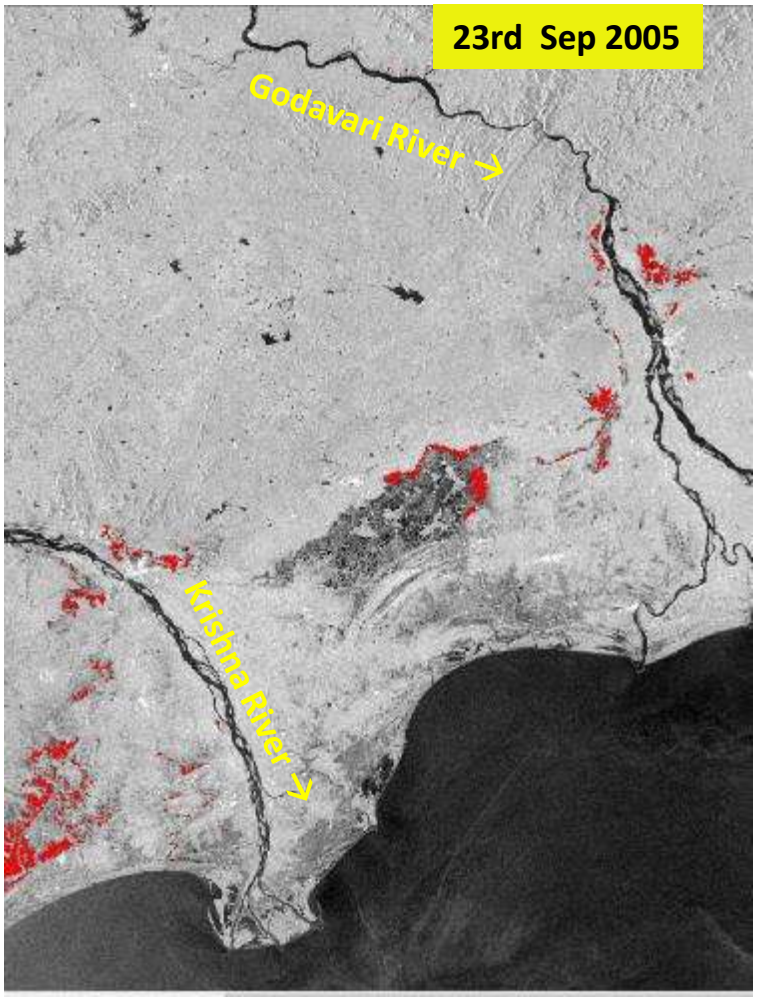
Radarsat SAR Image of 01-Sep-2000



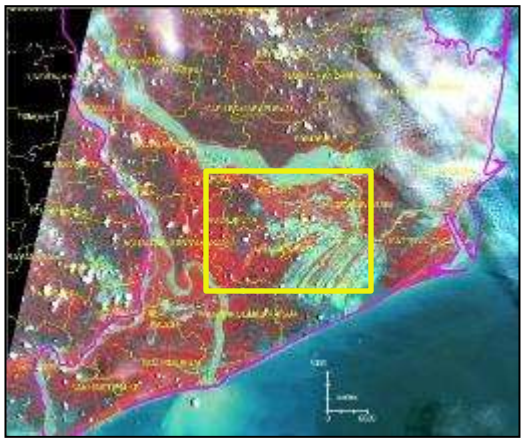


Radarsat SAR Image of 23-Sep-2005

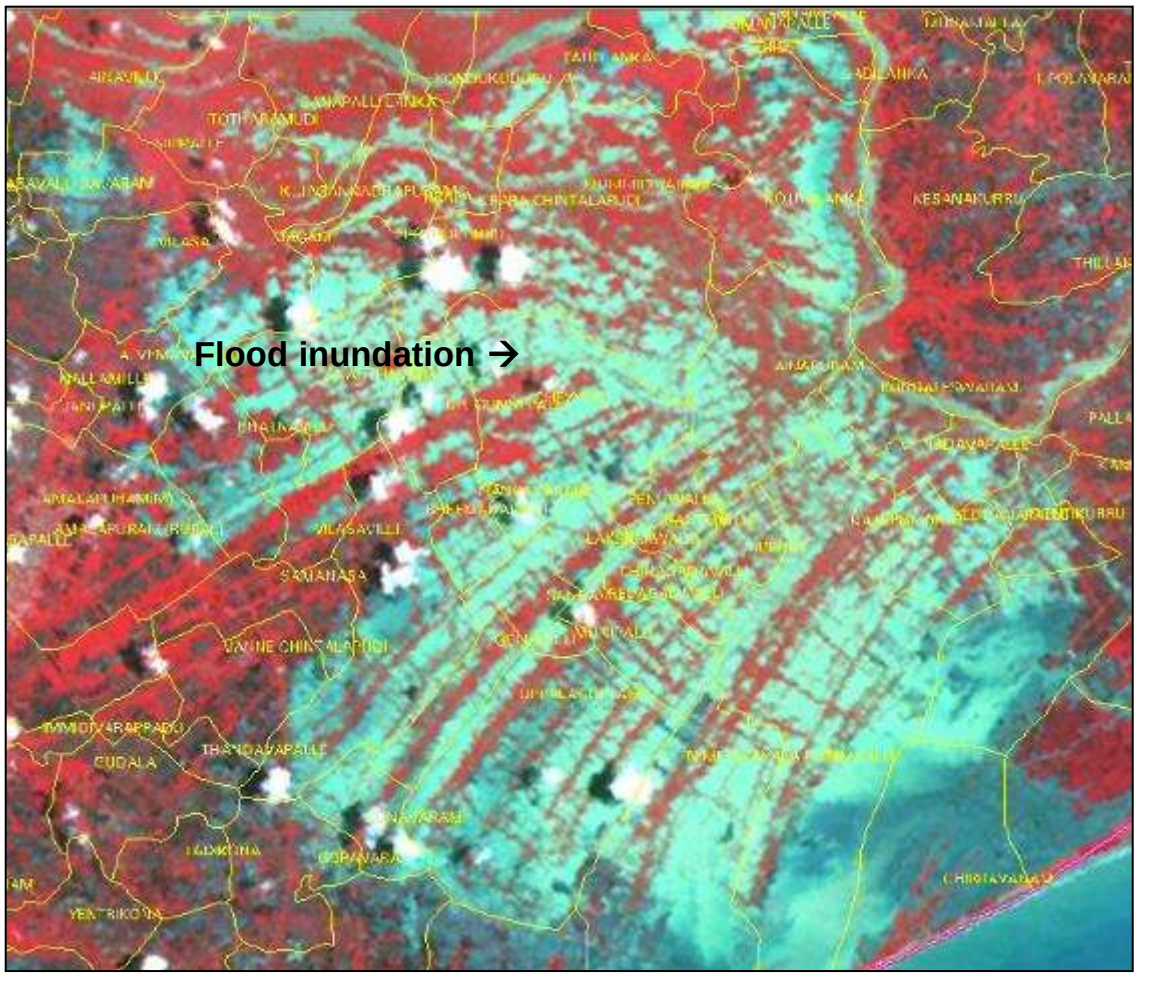




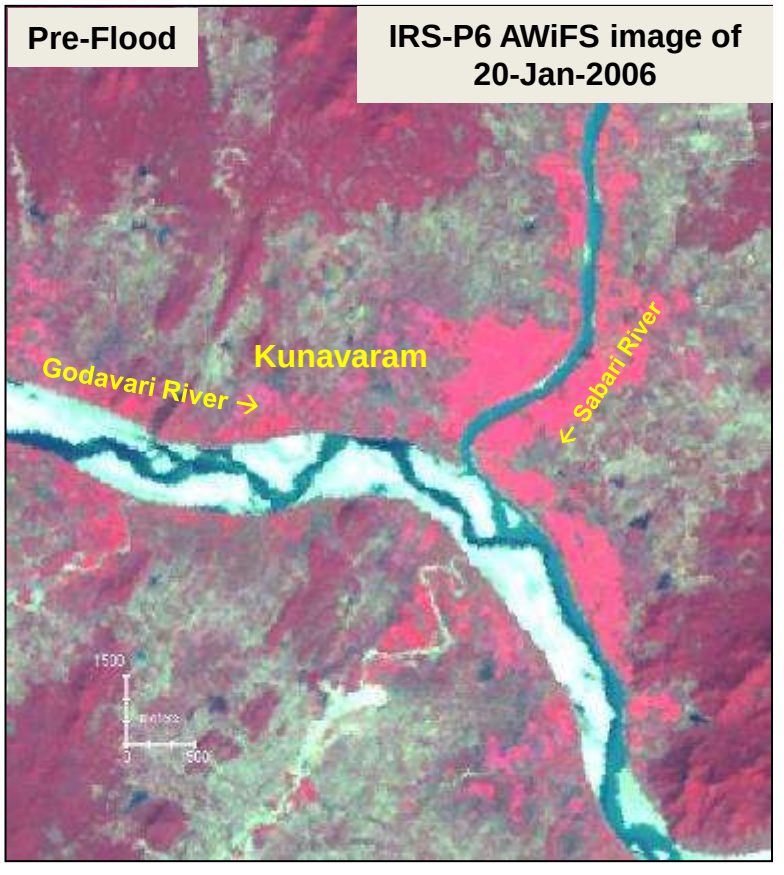
View of satellite image and flood inundation during 2000 and 2005 in Andhra Pradesh state along Godavari and Krishna Rivers

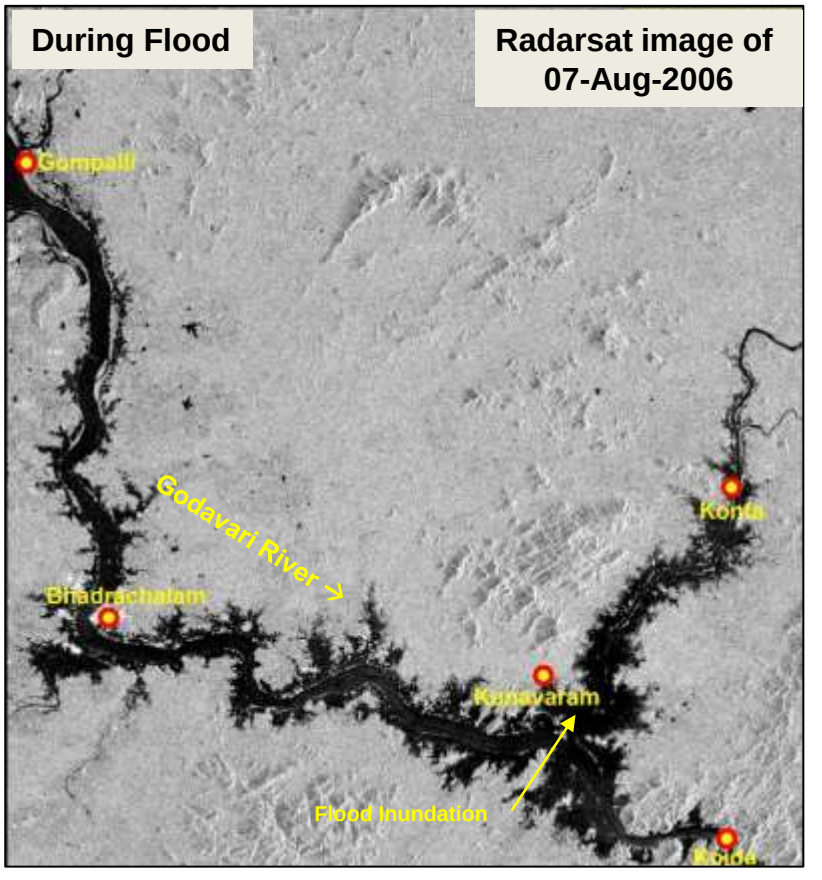


IRS-P6 AWiFS Image
10- 08-2006

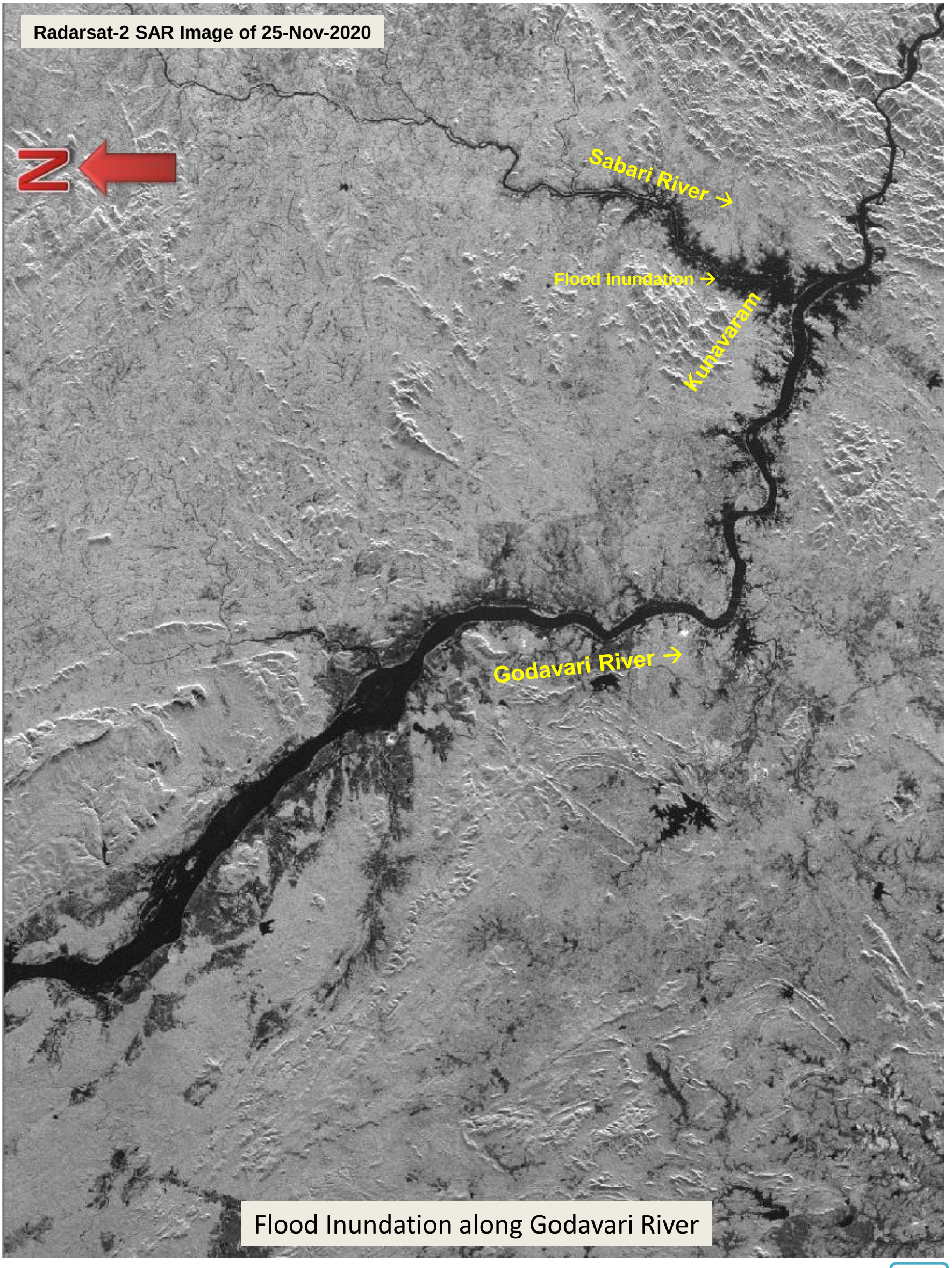


Flood inundation observed in parts of East Godavari District, Andhra Pradesh as on 10-Aug-2006

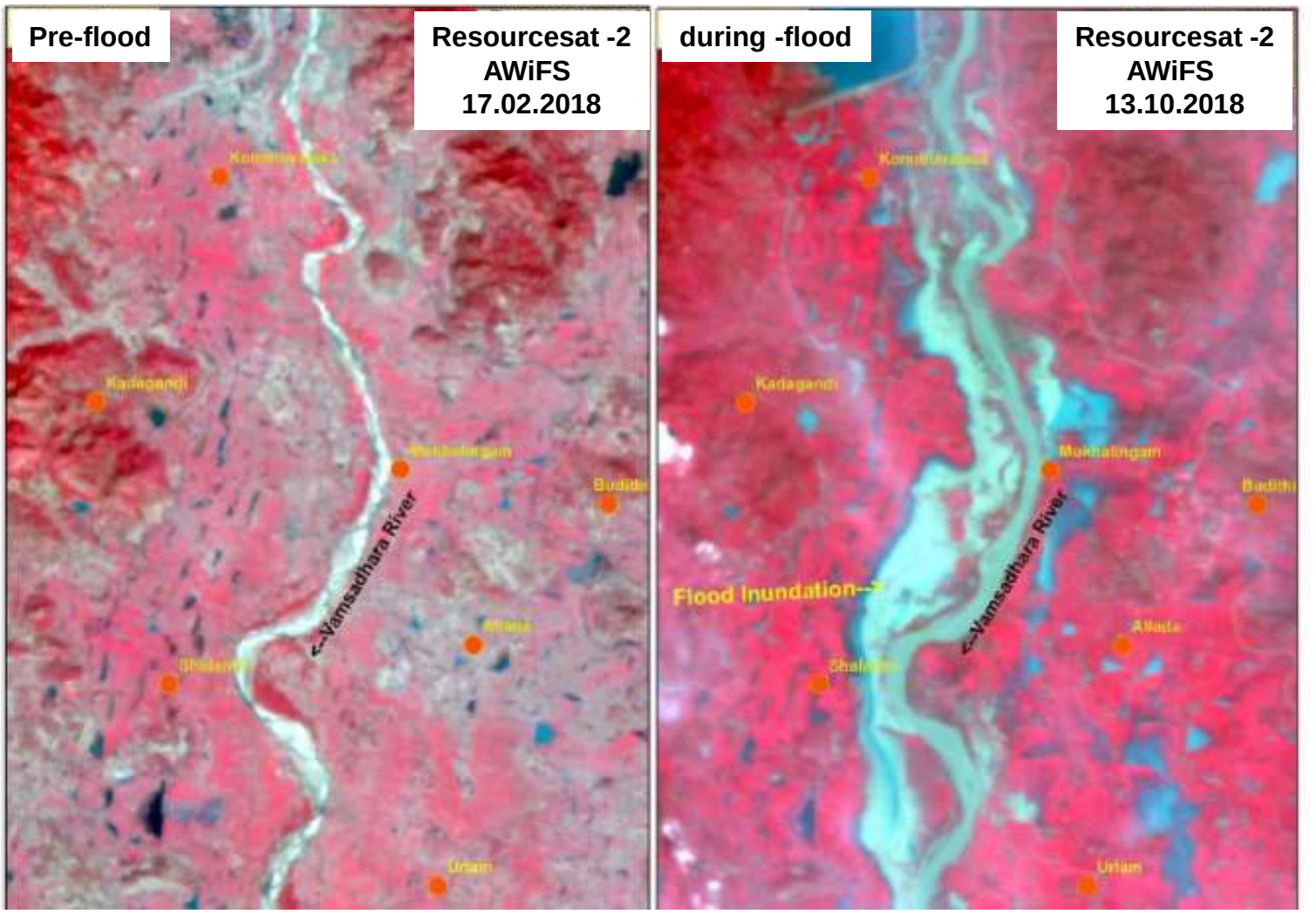




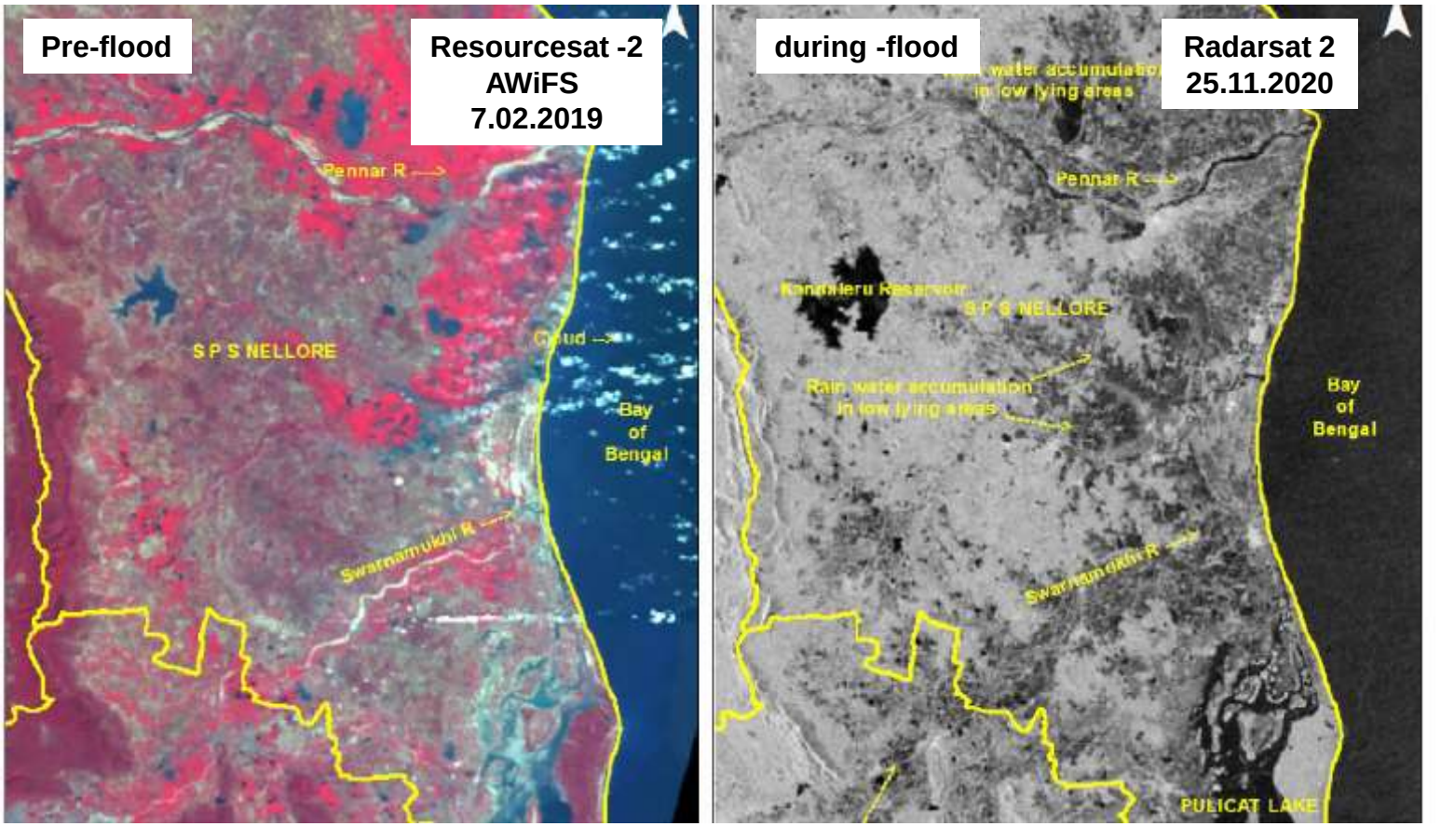
Flood inundation due to Godavari floods during August, 2006 in parts of East Godavari District, Andhra Pradesh



Flood Inundation along Godavari River

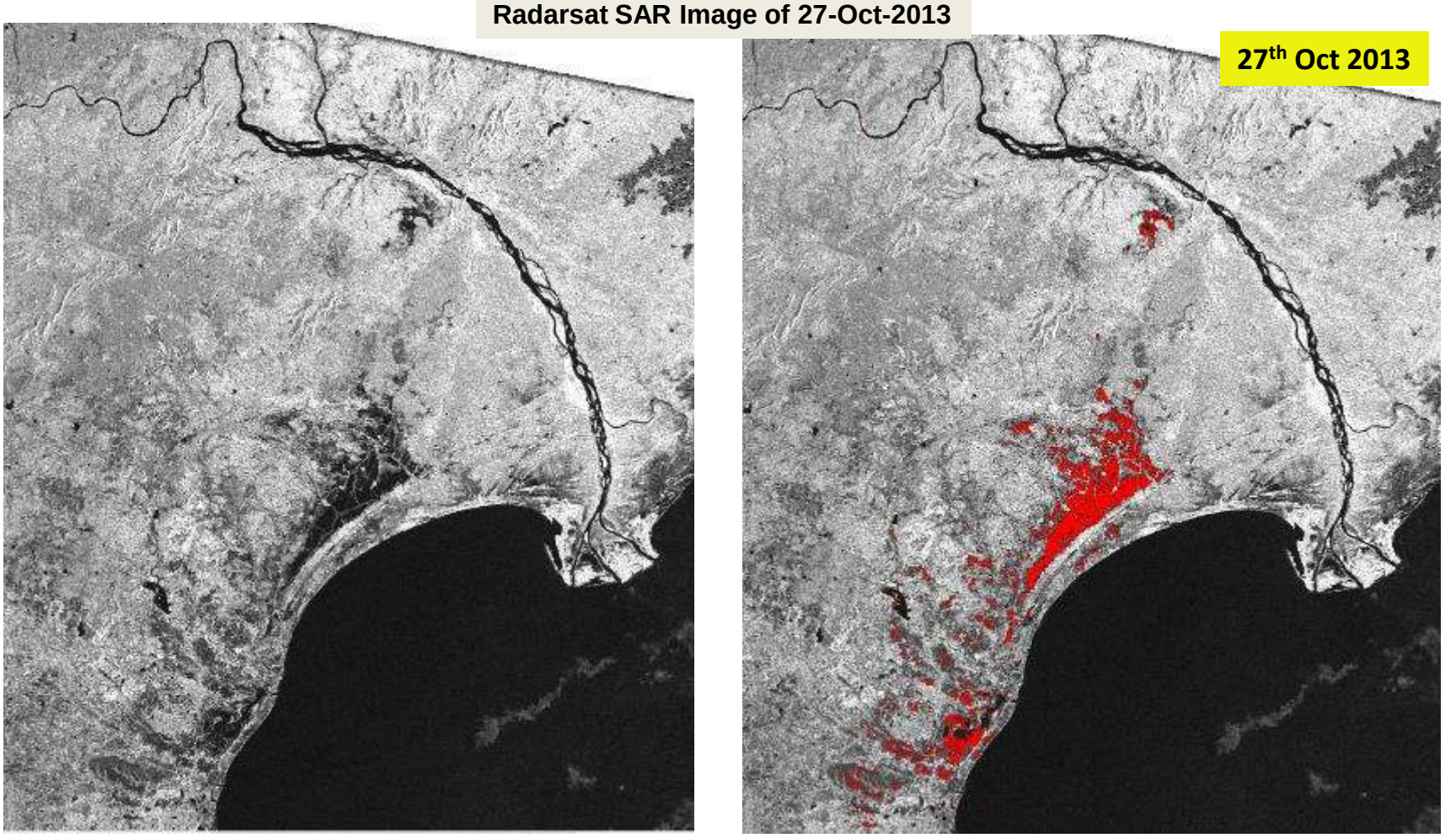


Flood affected areas in Srikakulam district during 2018 due to Cyclone Titli



Flood affected areas in part of Nellore district, Andhra Pradesh during Cyclone -NIVAR

Radarsat SAR Image of 27-Oct-2013

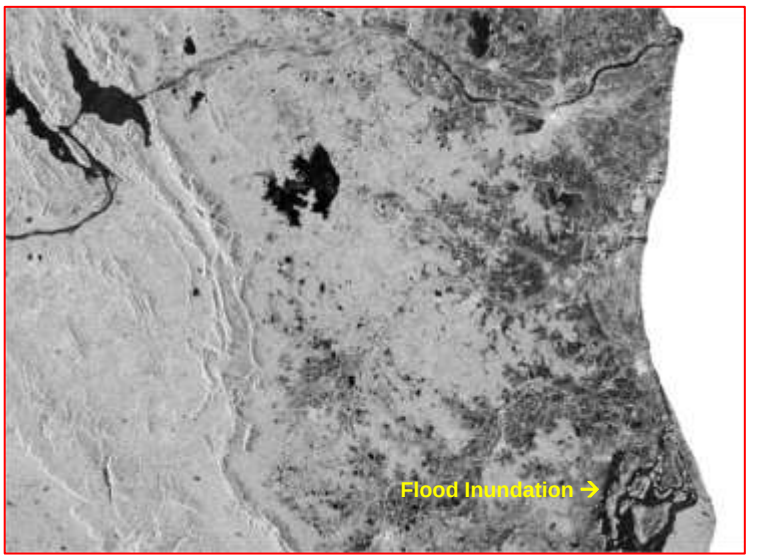


Data acquired through International Charter

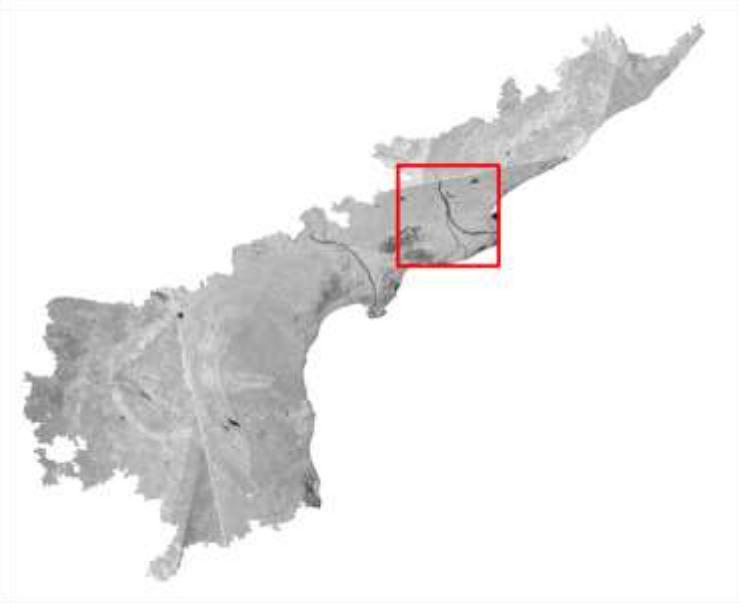
High Resolution Pleiades satellite data surrounding Polavaram project, Andhra Pradesh as on 19-Jul-2022 (acquired through International Charter)

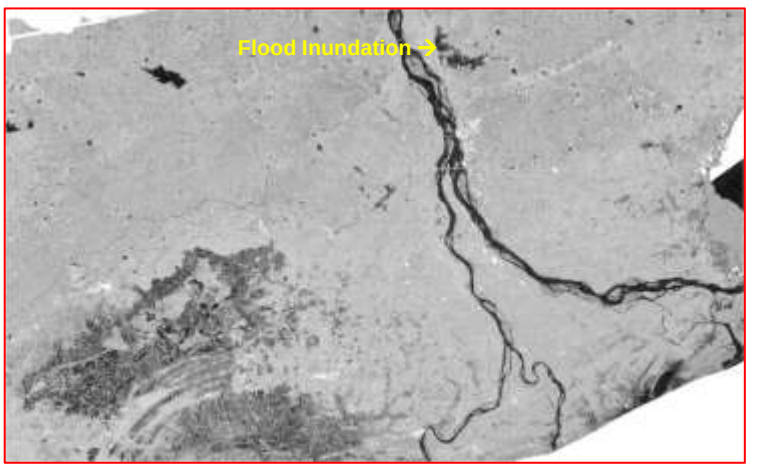
Microwave satellite images showing flood inundation in Andhra Pradesh State

2020

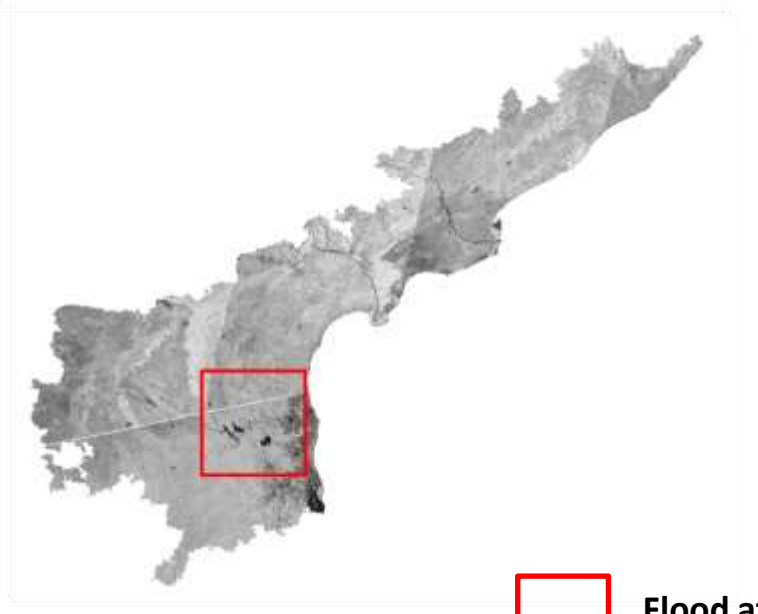


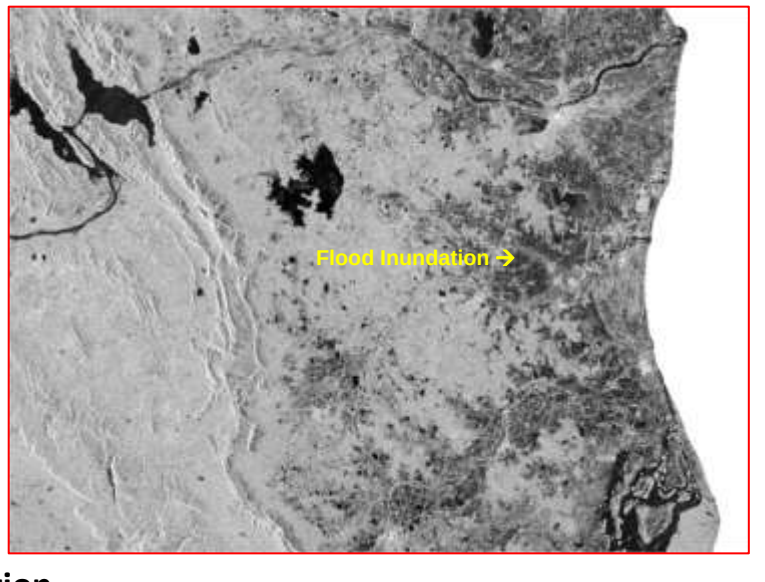
2016





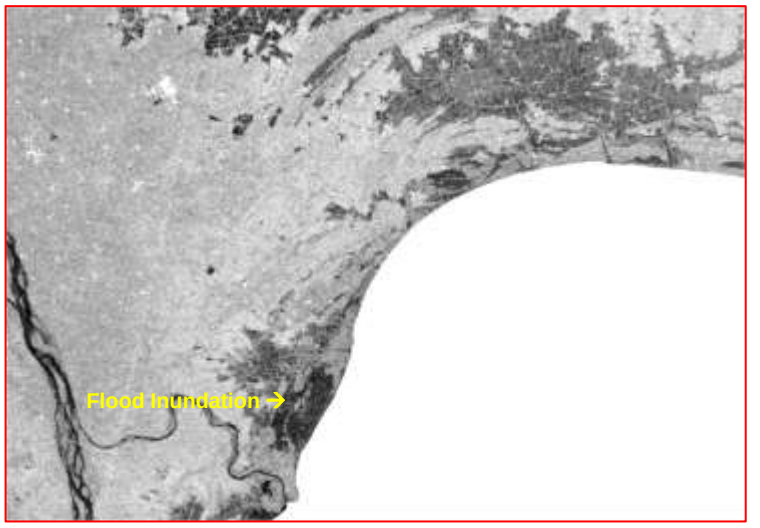
2015



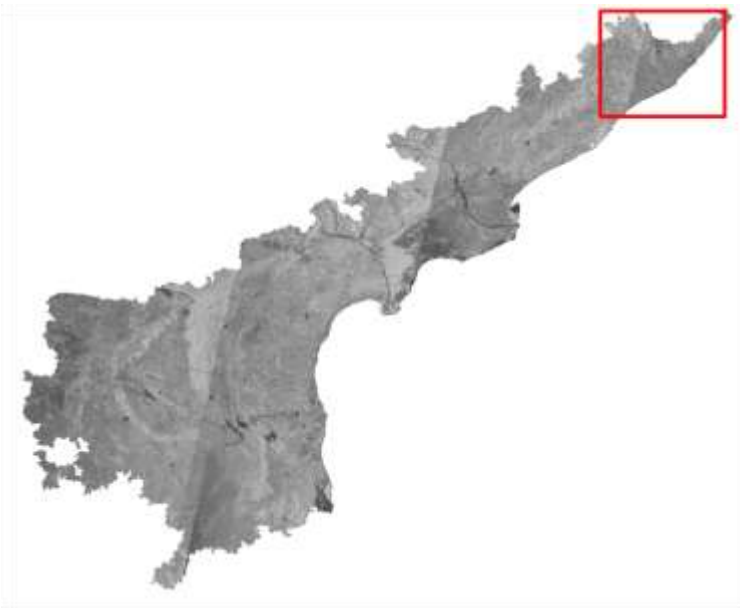


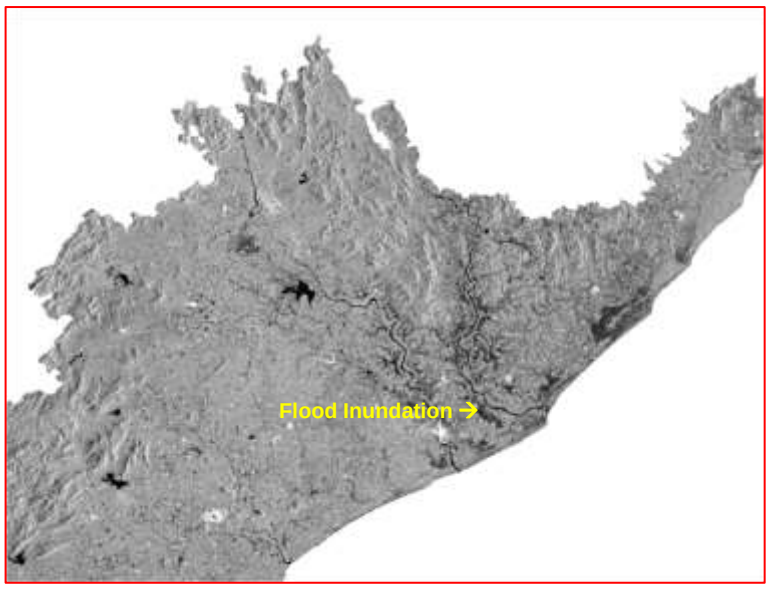
Flood affected region

2010

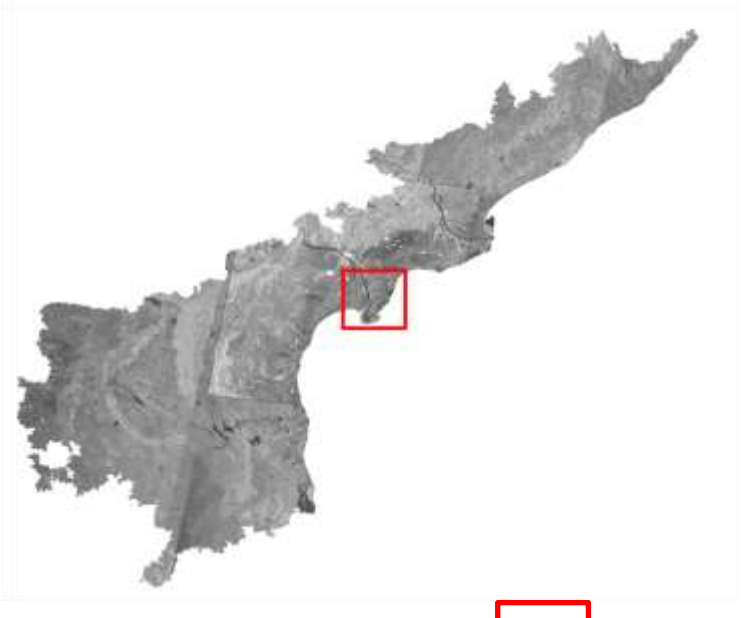


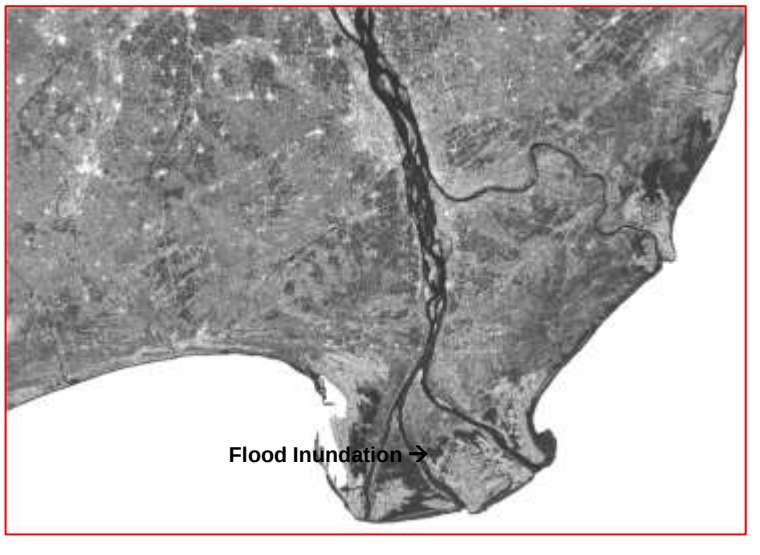
2007





2005





Flood affected region

Arunachal Pradesh

7. Arunachal Pradesh

Arunachal Pradesh state known as the land of rising sun is located in the north-eastern region of India, bordered by Bhutan to the west, China to the north and northeast, Myanmar to the east, and the Indian states of Assam and Nagaland to the south. It is the largest state in the Northeast region of India. The climate of Arunachal Pradesh varies with elevation. The low-altitude areas have a humid subtropical climate while high-altitude areas (3500–5500 m) have a subtropical highland climate and alpine climate. Arunachal Pradesh receives annual rainfall of 2,000 to 5,000 mm of rainfall annually and nearly 70%–80% is received during May to October. Arunachal Pradesh is prone to floods due to its hilly terrain, heavy rainfall, and proximity to the Brahmaputra river and its tributaries. The state is home to many rivers and tributaries and witnessed several devastating floods in the past. The state is situated in the north-eastern region of India, and most of its rivers flow towards the Brahmaputra river.

Major rivers flowing : **(i) Brahmaputra River** - It is the largest river in the state and flows from Tibet into Arunachal Pradesh. The Brahmaputra river is an important source of water for the state and plays a vital role in the state's economy, providing water for irrigation, fishing, and hydroelectric power generation. **(ii) Siang River** :- The Siang River is a tributary of the Brahmaputra river and is also known as the Tsangpo river. It originates from the Angsi Glacier in Tibet and flows through Arunachal Pradesh before merging with the Brahmaputra in Assam. **(iii) Lohit River** :- The Lohit River is another tributary of the Brahmaputra river and originates in eastern Tibet and flows through Arunachal Pradesh and Assam states and is an important source of water for irrigation and hydroelectric power. **(iv) Subansiri River** :- The Subansiri River is a major tributary of the Brahmaputra river and originates from Tibet. It flows through Arunachal Pradesh before merging with the Brahmaputra river in Assam**. (v) Kameng River** :- The Kameng River is a tributary of the Brahmaputra river and flows through Arunachal Pradesh. It is an important source of water for irrigation and hydroelectric power.

7.1 Flood Problem in Arunachal Pradesh

The floods in Arunachal Pradesh are mainly due to Lohit, Subansiri and flash floods brought in due to heavy incessant rainfall. The floods in the state were mapped once during 2004, 2016, 2017 years due to overspill of water from Lohit river banks and inundating many low lying areas along its course.Major floods that have affected the State are listed here in Table.7.1 for which satellite derived spatial flood inundation maps were generated and disseminated to State / Central Government Disaster Support Management Organisations by NRSC, ISRO.

Table.7.1 . Major flood events in Arunachal Pradesh state

S. No	Year	Description of the flood event	Districts affected
1	2004	Floods occurred during 10-17thJuly 2004	2
2	2016	Floods due to heavy rainfall	4
3	2017	Floods due to heavy rainfall	4

7.2 Flood Affected Area in Arunachal Pradesh

Multi-Date Satellite derived spatial flood inundation maps generated during three flood affected years during 1998-2002 were used to generate the cumulative Flood Affected Area Map of Arunachal Pradesh State. It is estimated that, cumulative Flood Affected Area in Arunachal Pradesh is estimated as 3373 ha affecting 5 districts of Arunachal Pradesh State. District wise flood affected area statistics depict that flood affected area is between 10,000 – 25,0000 ha in one district, while it is less than 10,000 ha. In case of four districts major flood events in Arunachal Pradesh have been mapped and reported using multi-date satellite data sets during 1998-2022. Table 7.2 shows District wise statistics of flood affected area in Arunachal Pradesh and Fig.7.1 shows flood affected area in Arunachal Pradesh.

Table.7.2 District wise statistics of Flood affected area in Arunachal Pradesh

S. No.	District	Flood Affected Area (ha)
1	Namsai	1106
2	Lower Dibang Valley	924
3	East Siang	807
4	Changlang	294
5	Lohit	242
	TOTAL	**3373**

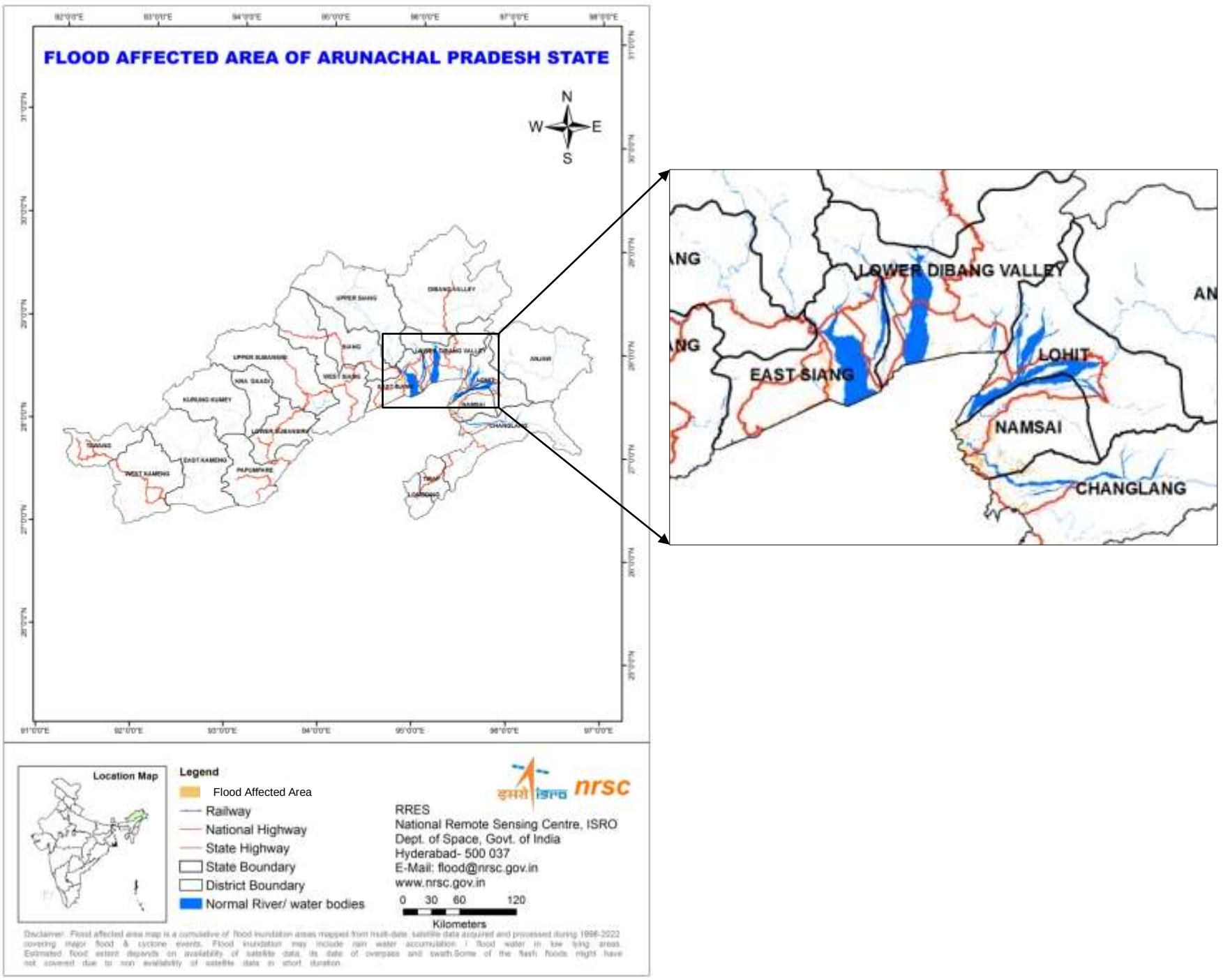


Fig.7.1 Flood affected area in Arunachal Pradesh

8. Assam

Assam is situated at the foothills of the eastern Himalayas which is the largest State in northeast India. The State of Assam comprised of two valleys namely the Brahmaputra and Barak Valley . These two valleys, which are named after the mighty Brahmaputra and Barak rivers constitutes the total land mass of the State. The geographical area of Assam is 78,438.00 Sq. Km out of which 56,194.00 Sq. Km and 22,244.00 Sq. Km fall under the Brahmaputra and Barak Valley including 2 (Two) hill districts respectively.

The unique geographical location criss-crossed by a vast network of major and minor rivers originating from the hills and mountains surrounding the State is largely responsible for the recurring floods and erosion of river banks. When the discharge in the rivers along with their tributaries synchronises during monsoon, the State faces flood devastation and the damage caused is colossal. Further, deforestation and human intervention in upstream and downstream areas of surrounding Hill States and Assam respectively has caused excessive siltation and runoff rate resulting in abnormal rise in the surfaces of major rivers. The problem of flood and erosion in Assam is menacing and probably the most acute and unique in the country. Assam popularly called as the land of the red river and blue hills. Assam is the gateway to the northeastern part of India. Assam is bordered in the North and East by Bhutan and Arunachal Pradesh. Along the south lies Nagaland, Manipur and Mizoram. Meghalaya lies to the South-West, Bengal and Bangladesh to the West.

The sub-tropical climate of Assam is characterized by high rainfall and high humidity and is worked by three dominant seasons, viz. winter (November to February), summer (March to May) and monsoon (June to October). Most of the rainfall in the state is received under the influence of the south-west monsoon between June and October. The Brahmaputra valley represents three broad climatic regions, viz. eastern, western and middle. The mean annual rainfall of eastern, western and middle regions is 245.2 mm, 1982.5 mm and 1527.4 mm respectively. In both Brahmaputra and Barak valley, the natural water availability exceeds the water need during the rainy and summer seasons. This renders the soil moist for seven to nine months and therefore, the climates of these regions qualify for udic moisture regime. During this period, the low-lying areas remain saturated and the ground water levels remain high. Such localized wet areas qualify for aguic moisture regimes. The following are the major river systems in Assam State :

Brahmaputra River System : The main river of the valley, Brahmaputra is one of the largest rivers in the world and rank fifth with respect to its average discharge. The river originates in the Tibetan plateau, flowing from west to east as the Tsangpo River, and then turns south through the eastern Himalaya as the Dihang River to enter Assam, where it is joined by other branches to form the Brahmaputra. The Brahmaputra river flows through Assam from east to west over a length of approximately 650 kilometers. During its course in Assam valley from kobo to Dhubri the river is joined by about 20 important tributaries on its North Bank and 13 on its South bank. The tributaries namely Subansiri, Ronganadi, Dikrong, Buroi, Borgong, Jiabharali, Dhansiri (North) Puthimari, Manas, Beki, Aie, Sonkosh are the main tributaries on the North while the Noadehing, Buridehing, Desang, Dikhow, Bhogdoi, Dhansiri (South), Kopili, Kulsi, Krishnai, Dhudhnoi, Jinjiran are the main tributarieson the south bank of the river Brahmaputra.Besides these, there are several other small streams which srain directly to the river.

Barak River System :The Barak River rises in the Indian State of Nagaland at an elevation of approximately 2300 meters and passes through the Manipur Hills of Manipur state over a river length of nearly 400 km. It then flows generally westward from Lakhipur through the Cachar Plains region of Assam over a length of approximately 130 km to enter Bangladesh near Bhanga.Table-8&9 show the drainage area of Brahmaputra & Barak Rivers in India.

8.1 Flood Problem in Assam

Several factors contribute to the high flood risk in Assam, which include its geographical location as it is located in a region that receives heavy rainfall, and it is situated at the foothills of the Himalayas, which means that it is prone to landslides and flash floods also in addition to the river overflows. Deforestation in the river catchments and subsequent soil erosion also may lead to the sedimentation into rivers which is leading to reduced the capacity of the land to absorb rainwater, leading to more runoff and increased flooding. Climate change is one factor leading to more extreme weather events, including heavy rainfall and flooding, and this is accelerating the flood risk in Assam.

Assam represents highly flood-prone region characterized by severe hazards of floods. Although occurrence of flood has been an age-old phenomenon in the riverine areas of this region, yet the extent of damage caused by the flood has increased significantly in recent years. The State of Assam has two valleys namely the Brahmaputra and Barak Valley. These two valleys, which are named after the mighty Brahmaputra and Barak rivers constitutes the total land mass of the State. The sub-tropical climate of Assam is characterized by high rainfall and high humidity and is worked by three dominant seasons, viz. winter (November to February), summer (March to May) and monsoon (June to October). Most of the rainfall in the state is received under the influence of the south-west monsoon between May and October.

Assam is prone to floods due to rise in river water levels in Brahmaputra and Barak rivers and its tributaries. It appears that, the Assam state prone to floods during monsoon season in more than 2 spells in every year. The list of flood events and the duration of floods which were mapped using satellite data is listed in Table.8.1. Rainfall mainly occurs during the monsoon period of June to September and the state experienced floods in several years during the monsoon season, which typically falls during June to September. Major floods that have affected Assam State are listed here in Table.8.1 for which satellite derived spatial flood inundation maps were generated and disseminated to State / Central Government Disaster Support Management Organisations by NRSC, ISRO.

8.2 Flood Hazard Zonation in Assam

Satellite derived flood mapping is carried out using multi-sensor satellite data in near real time every year since 1998 by NRSC/ISRO for providing the spatial flood inundation maps and further monitoring throughout the season. A flood hazard zonation Atlas is also prepared considering the flood inundation areas observed using 215 satellite datasets acquired during the period 1998-2015. Hazards area is classified as five severity categories viz. Very low to Very high (Table. 8.2). A total of 22.54 Lakh ha of land is affected in Assam State. Assam state is affected by flood in 22.54 Lakh ha (28.75%) Total Geographic Area (TGA) of land during the period 1998-2015. Nearly 1.55 Lakh ha of land falls under high (inundated 13-15 times) to very high (inundated 16-18 times) flood hazard categories, where area under each flood hazard category varies from 2.16 to 55.91percentage (Figure – 8.1). Following are the conclusions referred in flood hazard atlas of Assam State (1998-2015). Analysis of flood hazard index indicated that out of 34 districts lying along the banks of Brahmaputra river, about 17 districts namely Morigaon, Dhemaji, Darrang, Jorhat, Sivasagar, Charaideo, Sonitpur, Biswanath, Dhubri, South Salamara, Kamrup, Jorhat, Nalbari, Lakhimpur, Nowgong, Barpeta, Dibrugarh, Golaghat & Hailakandi districts falls under High to Very High affected districts and 9 districts falls under Moderate affected districts and 8 districts fall under Very low to Low flood affected districts. It can be observed that nearly 14.58 lakh ha of cropped area is under various categories of flood hazard. Out of which about 1.10 lakh ha of land falls under very high to high flood hazard zones. Flood Hazard Categories in Assam are given in Table-8.2.

Table. 8.1. Major flood events in Assam state

S. No	Year	Description of the flood event	Districts affected
		Floods have occurred in Assam due to rise in water levels in Brahmaputra, Barak and its tributaries in different Months in monsoon season as mentioned here	
1	1998	Floods occurred in Assam during June 1998	6
2	2003	Floods have affected in two spells during 16th 23rd June, 2003	21
3	2004	Floods occurred in 4 spells during 20-21st, April, 28th Jun- 06th Jul , 10th Jul-5th August, 10-13th Oct , 2004	9
4	2005	Floods occurred in during 20-21st, April, 28th Jun- 06th Jul , 10th Jul-5th August, 10-13th Oct , 2004	20
5	2006	Floods occurred in 3 spells during 2nd -16th Jun, 26th June, 26th – 28th July 2006	24
6	2007	Floods occurred in 2 spells during 21-26th Jaun , 14th Jul- 4th Oct 2007	21
7	2008	Floods occurred in 2 spells during 9-23rd Jul, 2nd Aug -14th Sep 2008	21
8	2009	Floods occurred during 1st Jul – 28th Aug 2009 In addition, Matmora embankment breach in Lakhimpur district.	21
9	2010	Floods occurred during in 19th Jun – 31st Jul, 17th Aug – 23rd Sep	24
10	2011	Floods occurred during in 29th Jun – 18th August 2011	16
11	2012	Floods occurred during in 6th Jun – 07th Oct 2012	28
12	2013	Floods occurred during 1-10th Jul, 9-14th Aug, 9-12th Sep 2013	27
13	2014	Floods occurred during 16th Aug – 29th Aug, 22nd – 29th Sep 2014	27
14	2016	Floods occurred during 24-26th, April, 5-29th July 2016	20
15	2017	Floods occurred during 3rd Jun -22nd Jul 2017	36
16	2018	Floods occurred during 8rd Jun -13th Sep	37
17	2019	Floods occurred during 10th Jul -2nd Aug 2019	34
18	2020	Floods occurred during 10th Jul -2nd Aug 2019	34
19	2021	Floods occurred during 7th June to 6th Sep 2021	33
20	2022	Floods occurred during 18th May – 26th May and 16th June – 17th July 2022	35

Table. 8.2. Flood Hazard Categories in Assam

Sl. No	Hazard Severity	Flood Hazard Area (ha)	% Flood Hazard (wrt State Geographic Area)	% Flood Hazard (wrt Total Flood Hazard Area)
1	Very High	48490	0.62	2.16
2	High	106659	1.36	4.73
3	Moderate	282783	3.61	12.54
4	Low	556080	7.09	24.66
5	Very Low	1260562	16.07	55.91
TOTAL		**2254574**	**28.75**	**100.00**

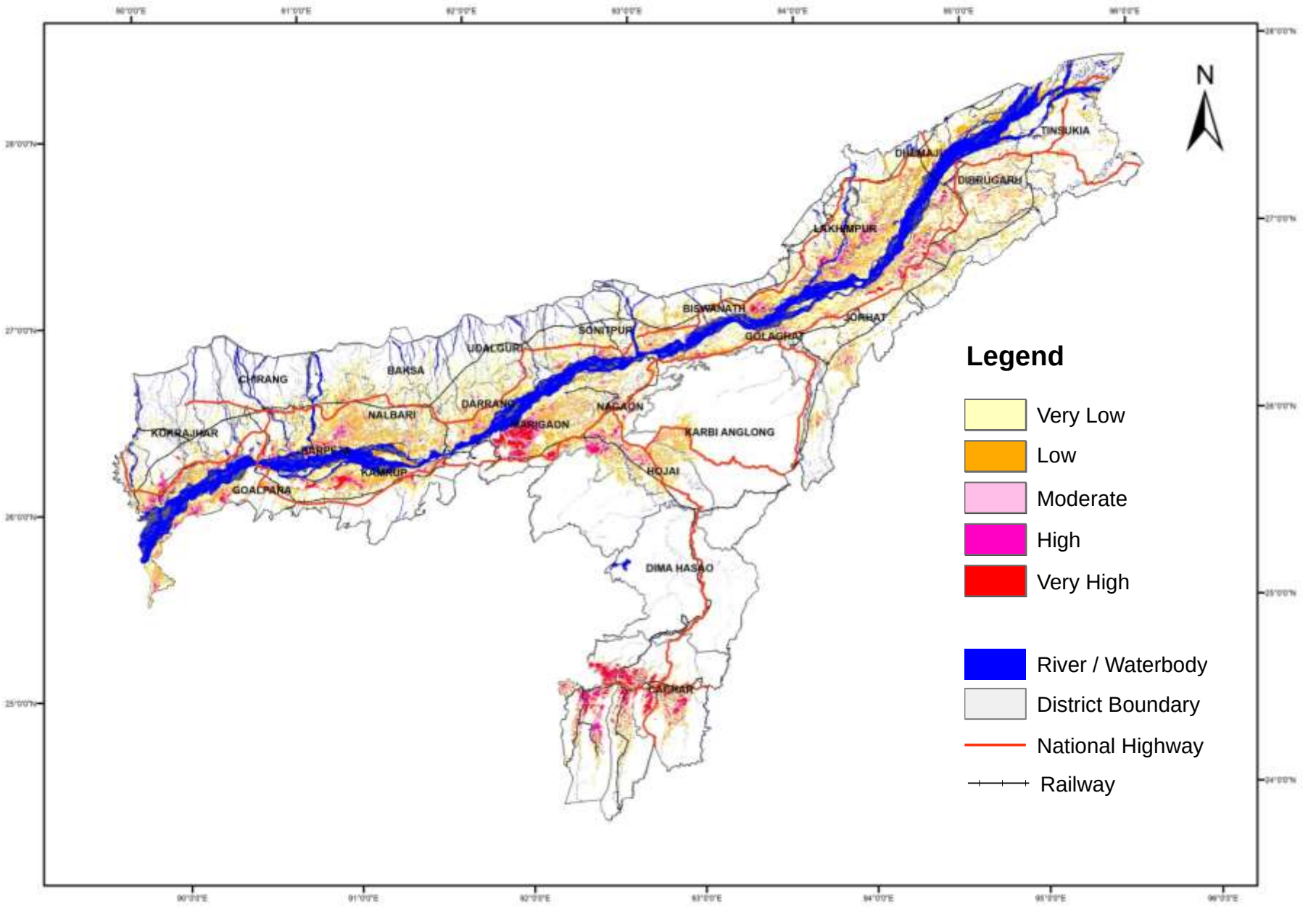


Fig. 8.1. Flood Hazard Zonation Map of Assam

8.3 Flood Affected Area in Assam

Multi-date satellite derived spatial flood inundation maps generated during 1998-2002 were utilised to generate the cumulative flood affected area map of Assam State. Cumulative flood affected area is estimated as 24.64 lakh ha affecting 35 districts of Assam State (Table 8.3). Flood affected area map is shown in Figure .8.2. District wise flood affected area statistics indicated that, the flood situation is alarming in Assam state as flood affected area is > 1,00,000 ha, 50000-100000 ha, 25000 to 50000 ha, 10000-25000 ha in 8,14,8,4 districts respectively. Dima Hasao district, indicated nearly 500 ha which is much lower compared to others. Major flood events in Assam are listed here which have been mapped and reported using multi-date satellite data sets during 1998-2003.

Table.8.3 District wise flood affected areas in Assam State

S. No.	District	Flood Affected Area (Ha)
1	Lakhimpur	164329
2	Nagaon	151385
3	Kamrup Rural	132885
4	Dibrugarh	132438
5	Dhemaji	130247
6	Golaghat	112050
7	Cachar	111810
8	Morigaon	104622
9	Barpeta	99737
10	Sivasagar	98032
11	Sonitpur	97195
12	Biswanath	88810
13	Jorhat	85492
14	Goalpara	76700
15	Tinsukia	74530
16	Dhubri	72487
17	Darrang	72391
18	Hojai	68168
19	Karimganj	65140
20	Nalbari	64099
21	Udalguri	57250
22	Majuli	50978
23	Charaideo	40724
24	Karbi Anglong	39034
25	Kokrajhar	37438
26	Hailakandi	37412
27	Baksa	35158
28	Bongaigaon	34928
29	Bajali	29447
30	Tamulpur	26168
31	South Salmara	22888
32	Kamrup Metro	22564
33	West Karbi Anglong	16216
34	Chirang	11700
35	Dima Hasao	506
Total		**2464958**

Glimpses of satellite images / flood inundation over the time period are depicted in this section.

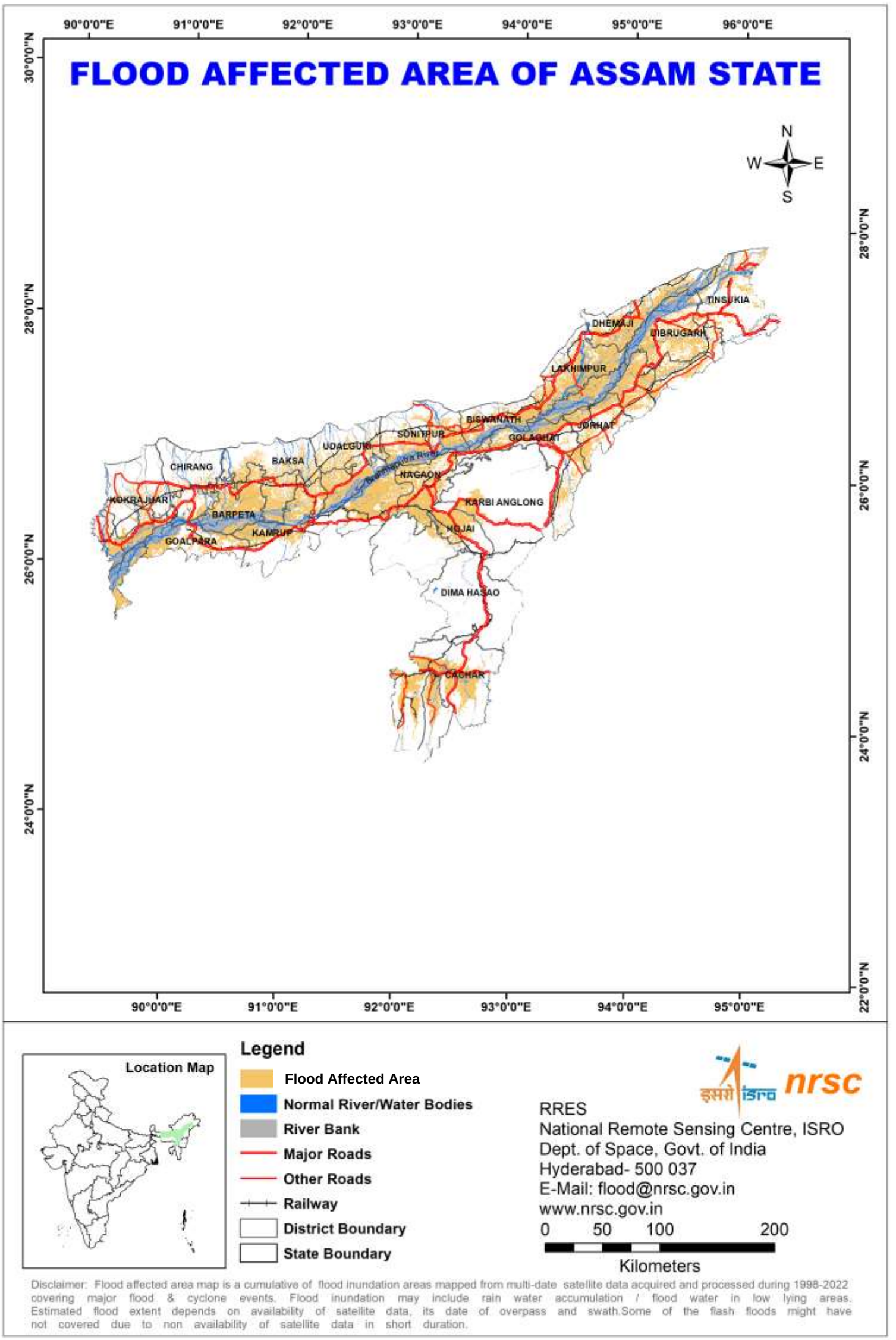
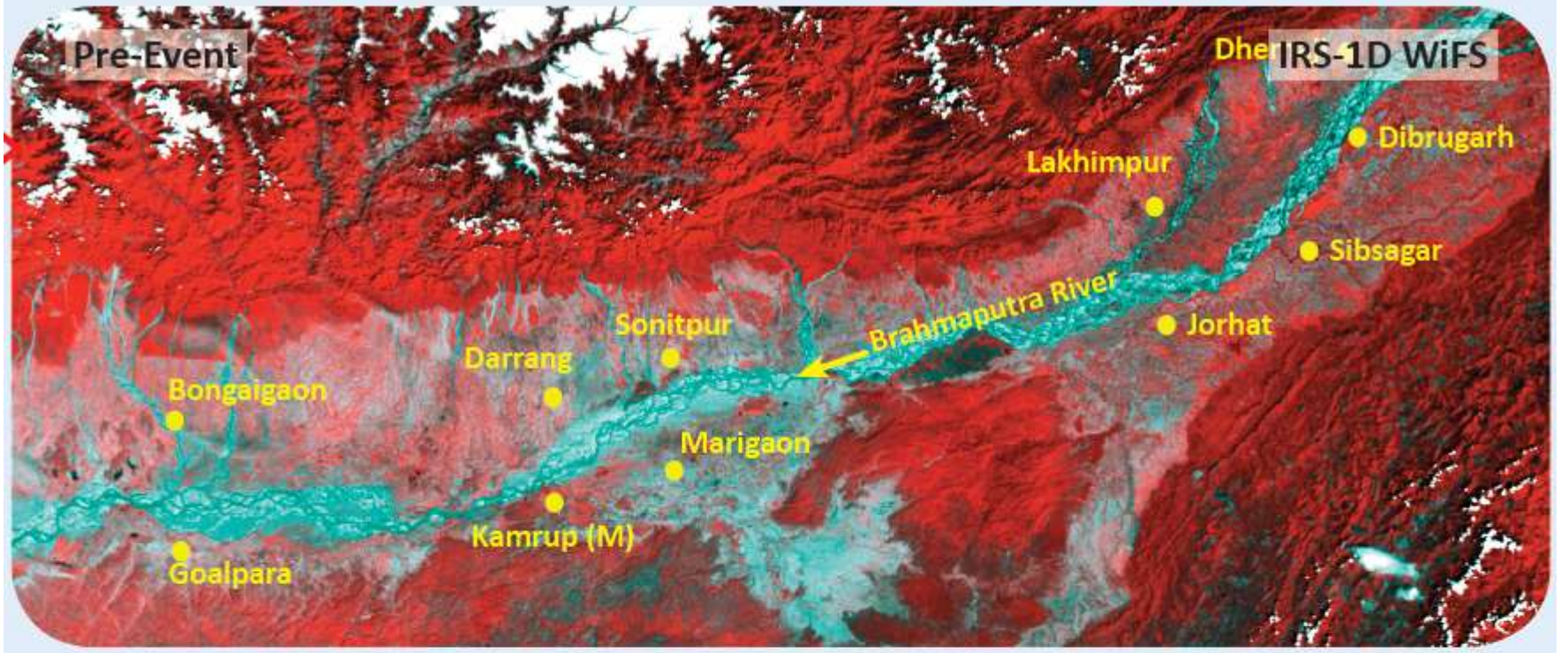
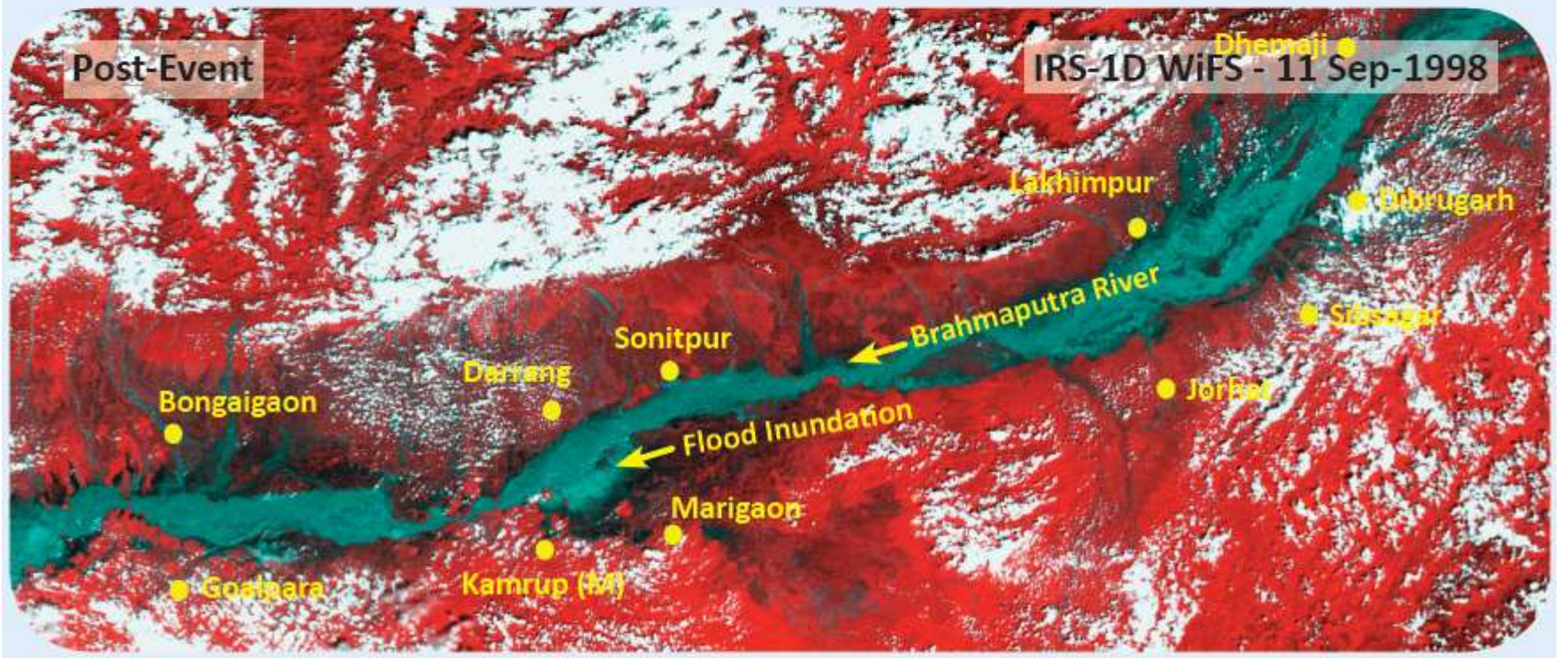
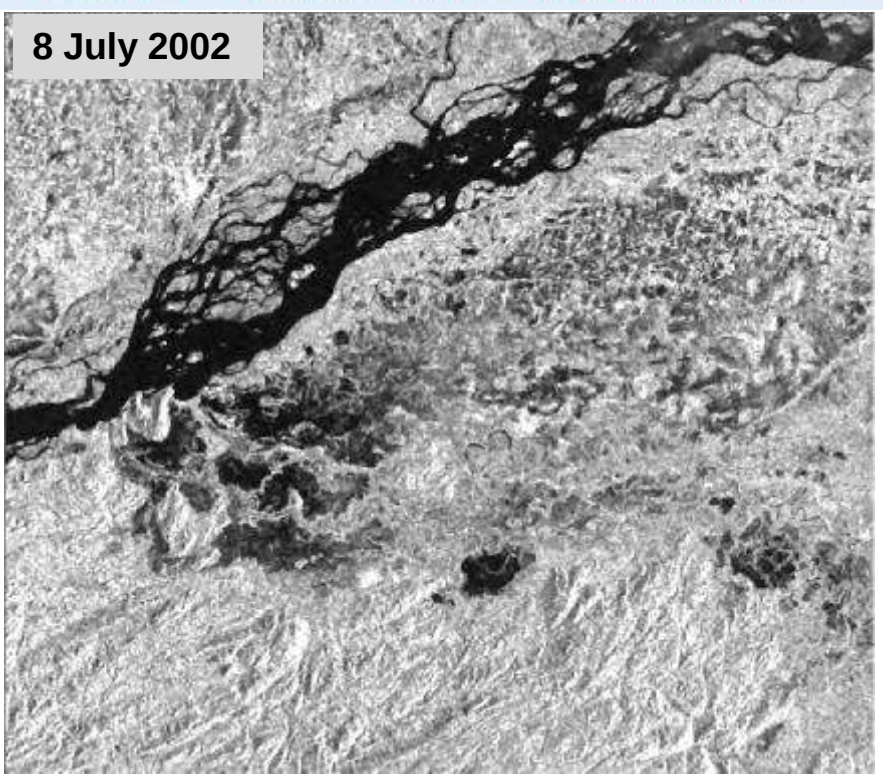
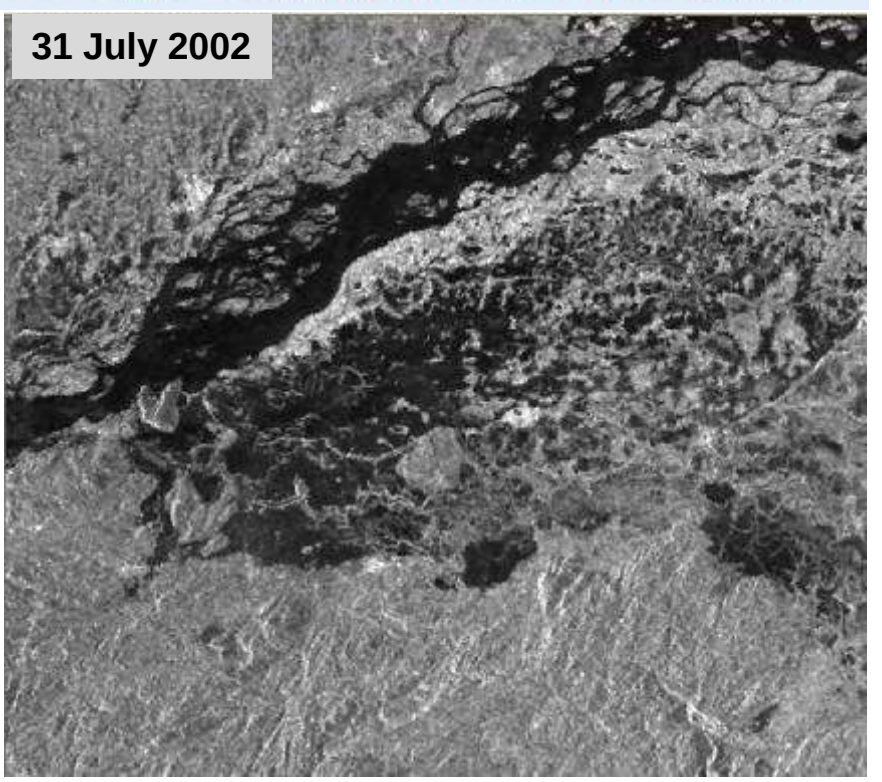


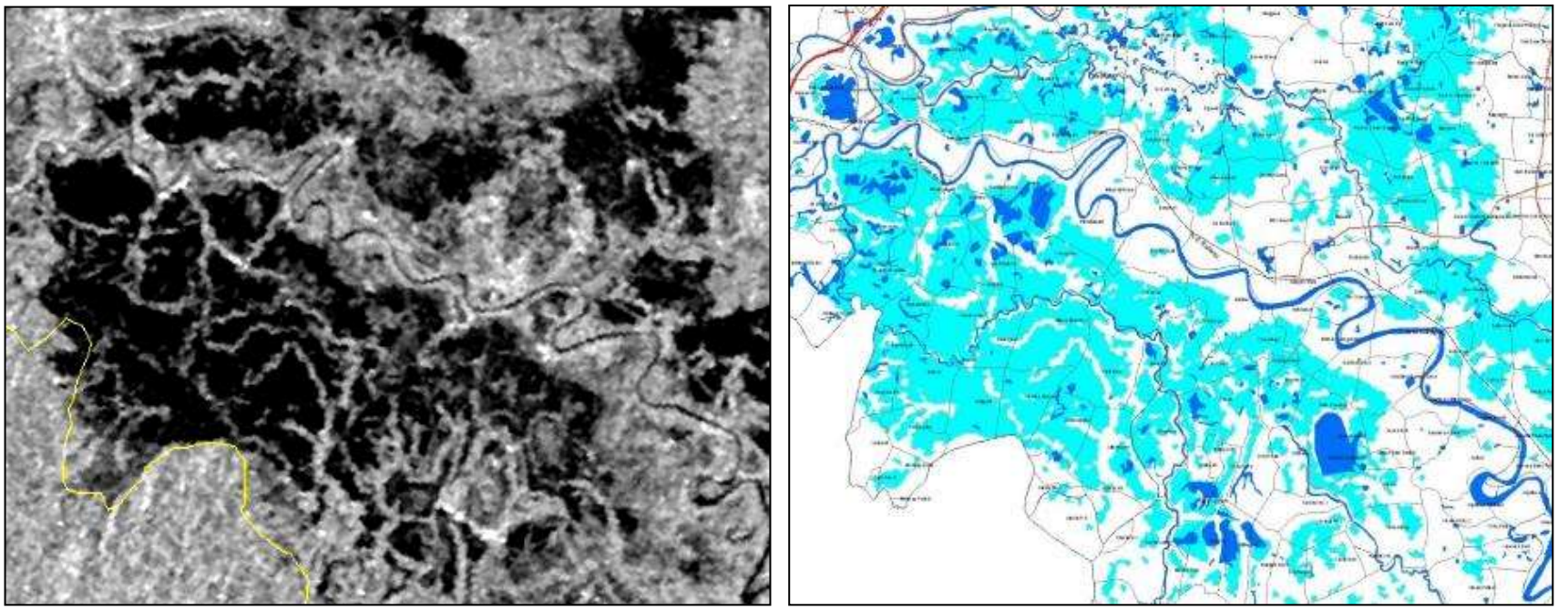
Fig.8.2 Flood affected area in Assam State


Pre-Event
IRS-1D WiFS
Dhe
Dibrugarh
Lakhimpur
Sibsagar
Brahmaputra River
Jorhat
Sonitpur
Darrang
Bongaigaon
Marigaon
Kamrup (M)
Goalpara

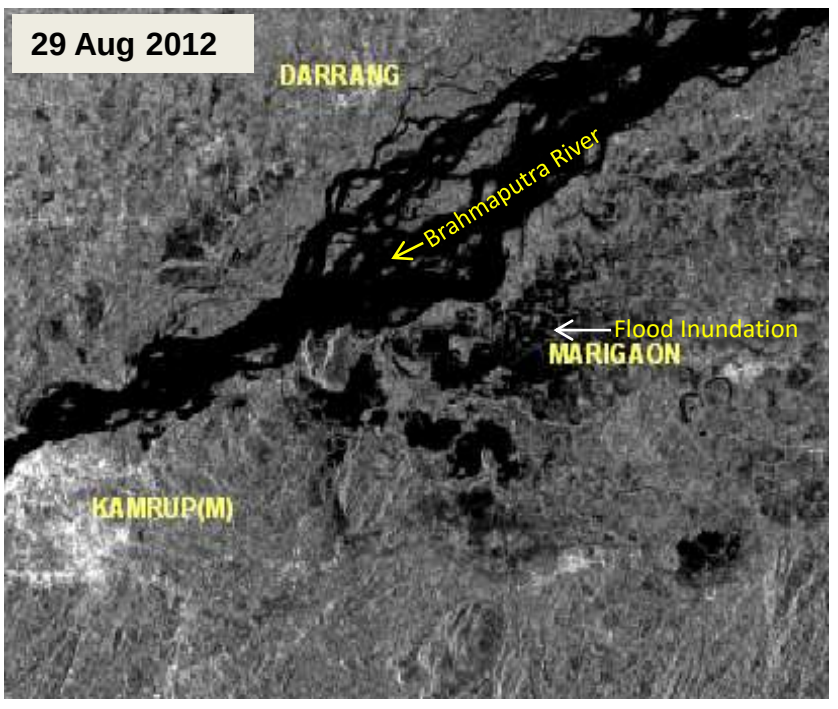

Post-Event
IRS-1D WiFS - 11 Sep-1998
Dhemaji
Lakhimpur
Dibrugarh
Brahmaputra River
Sibsagar
Sonitpur
Darrang
Jorhat
Bongaigaon
Flood Inundation
Marigaon
Goalpara
Kamrup (M)

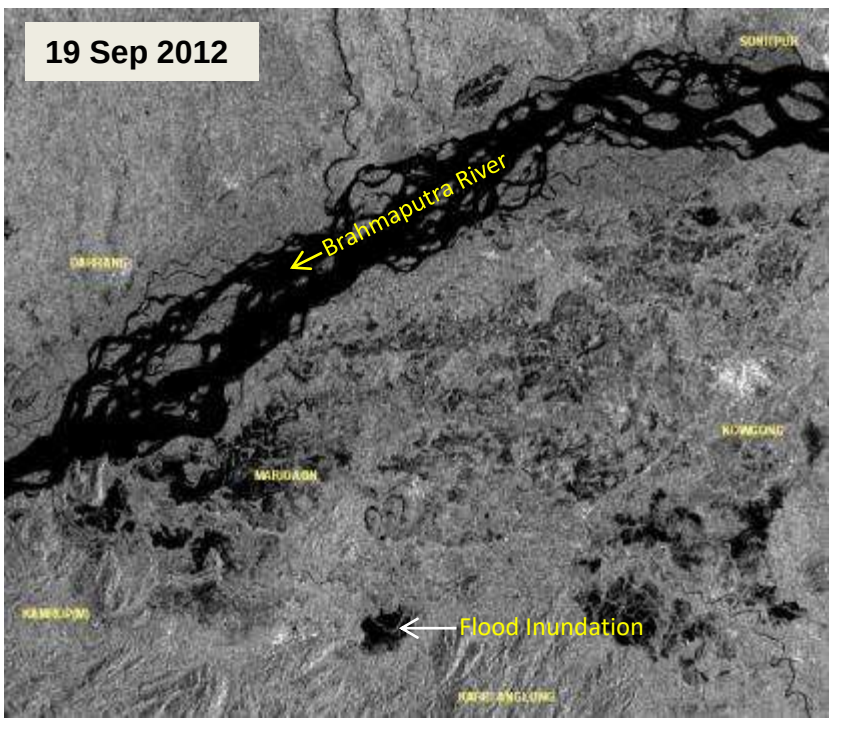

8 July 2002

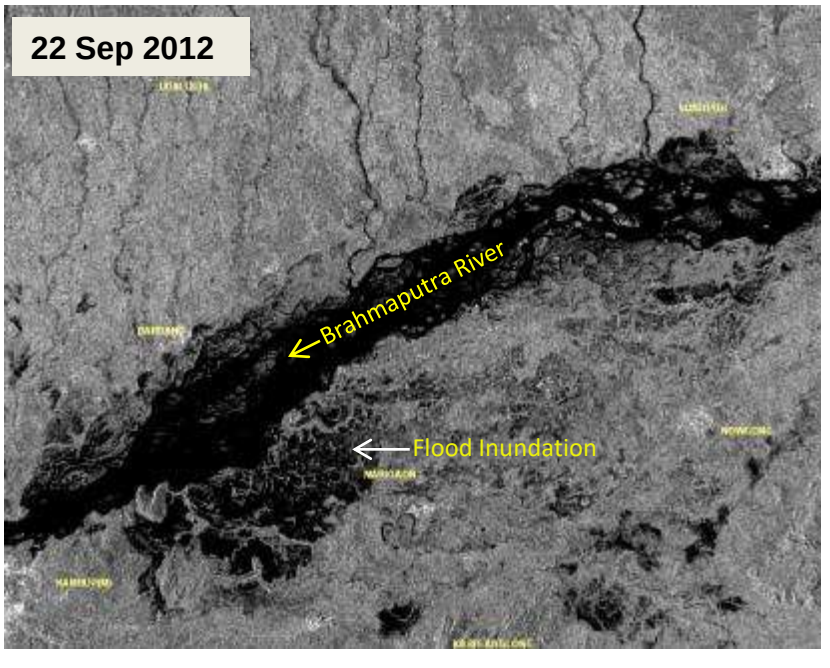

31 July 2002

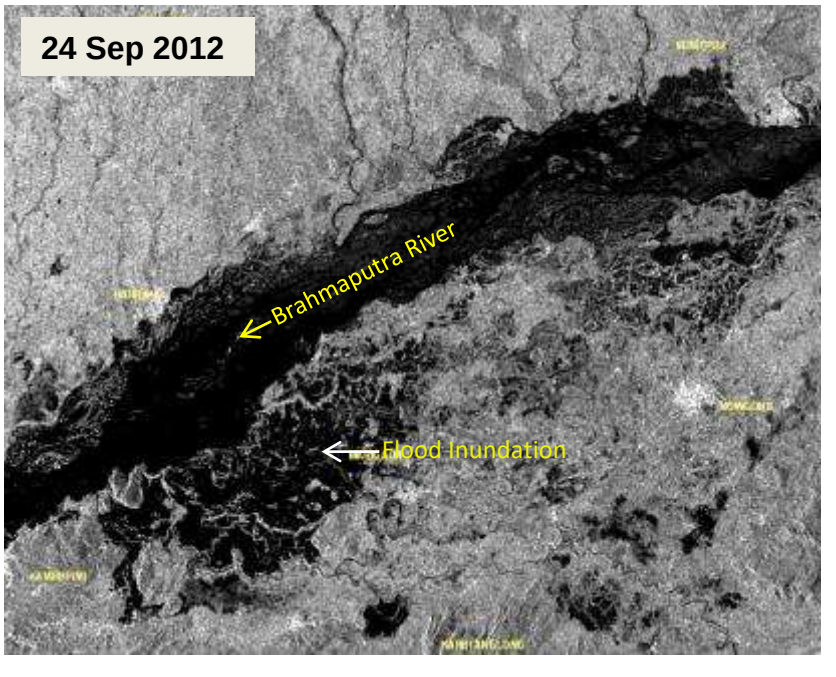


Flooded villages in Nowgong district as on 29th July 2007

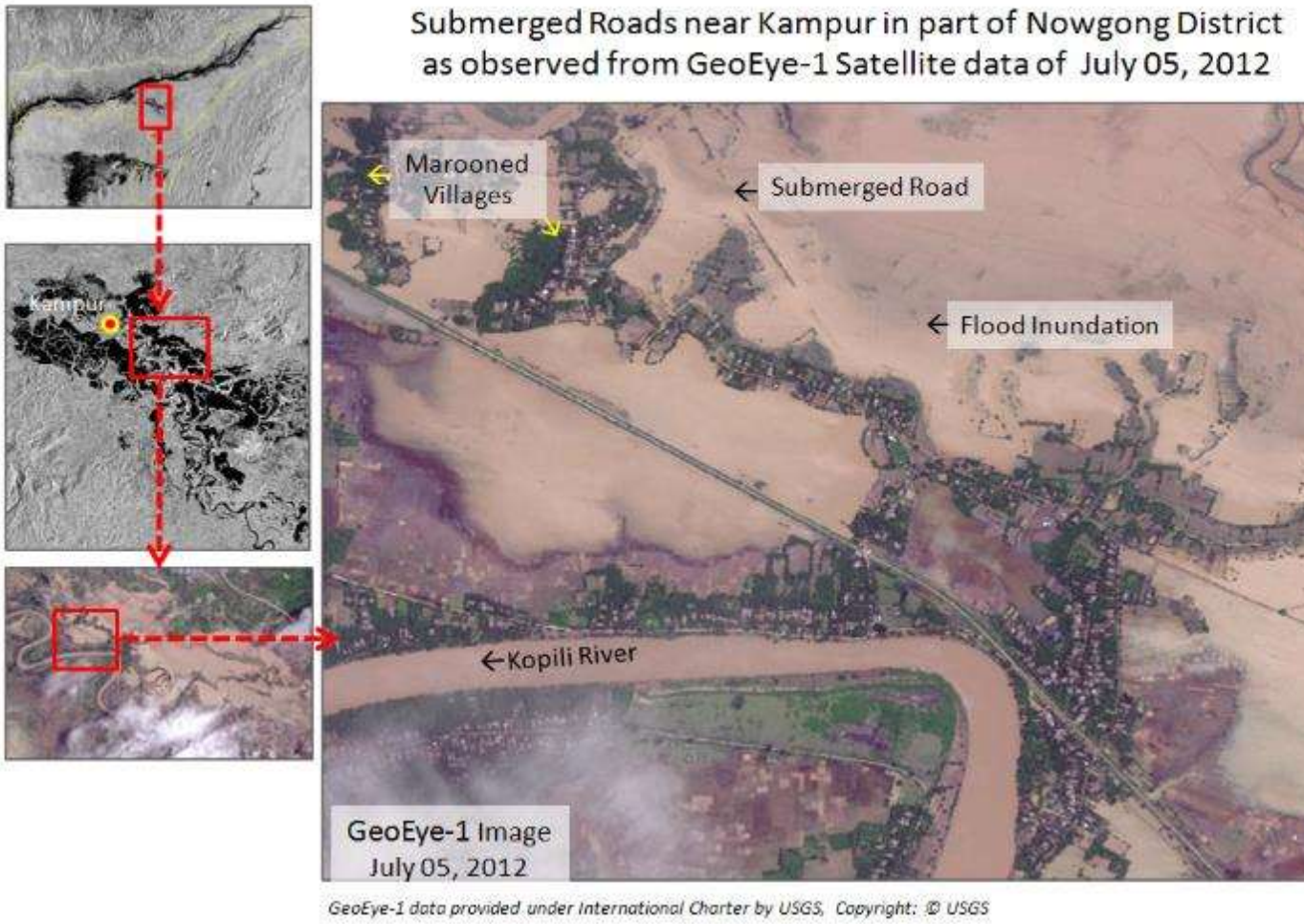








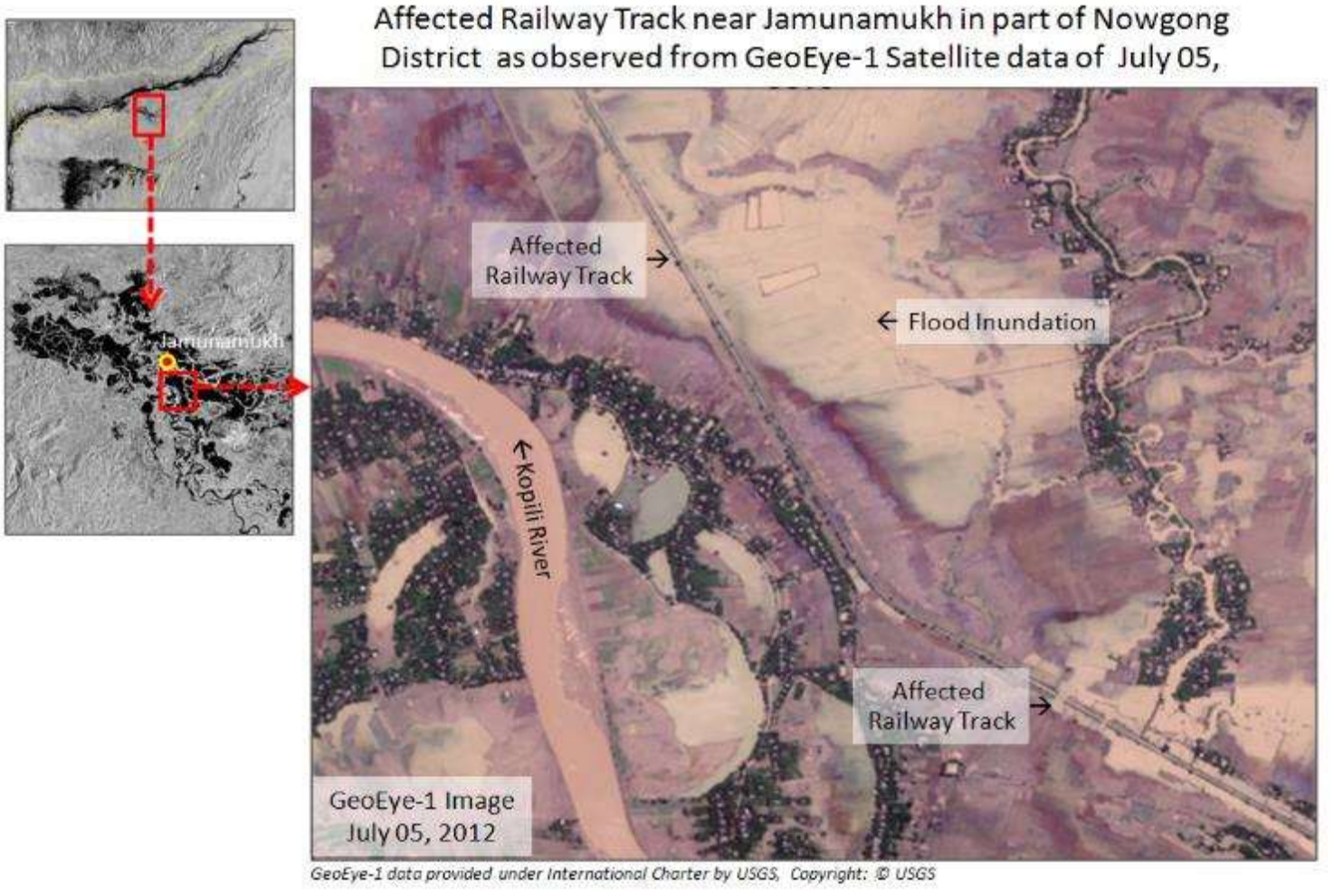
Submerged Roads



Submerged Roads near Kampur in part of Nowgong District as observed from GeoEye-1 Satellite data of July 05, 2012

GeoEye-1 data provided under International Charter by USGS, Copyright: © USGS

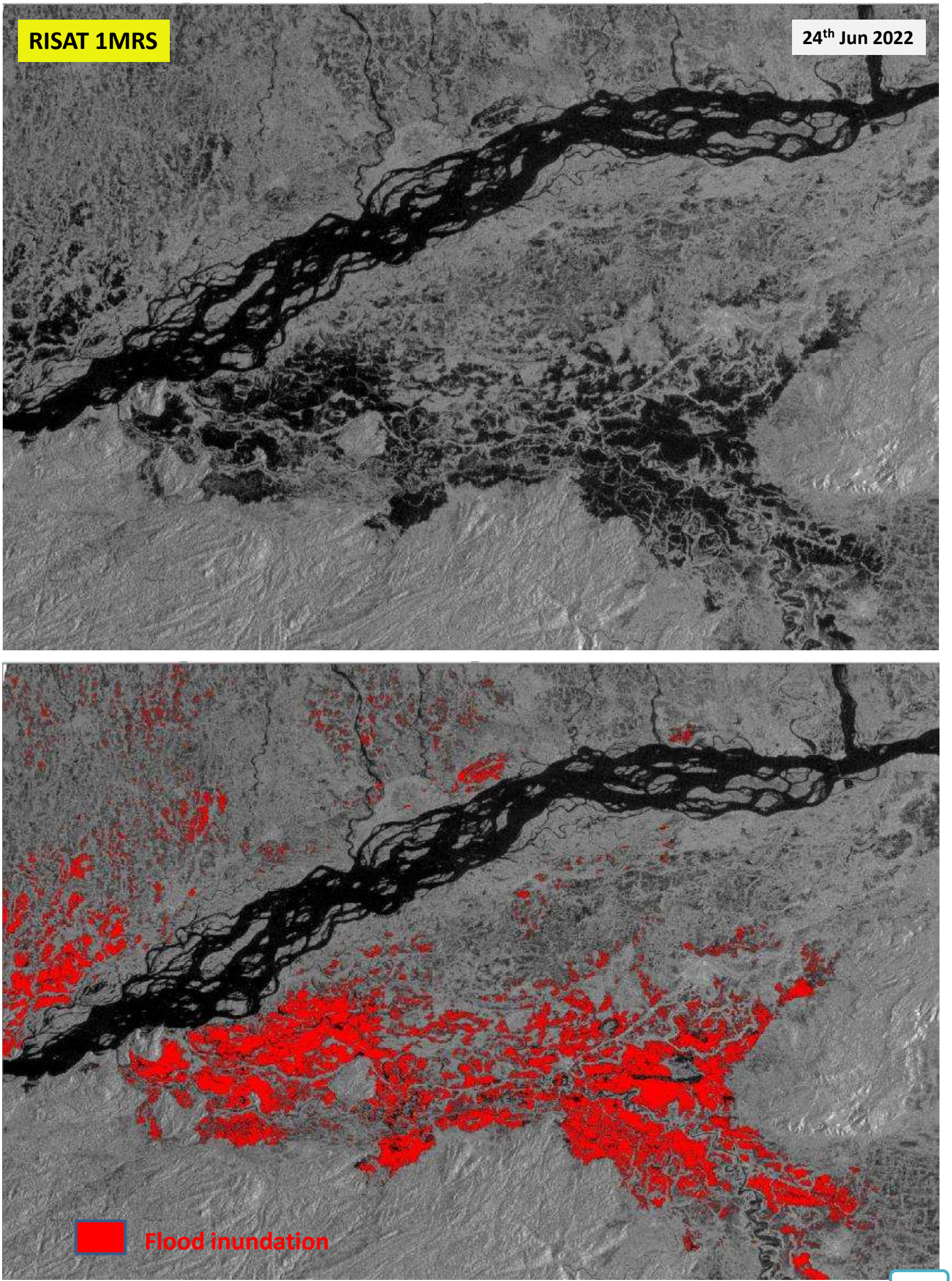
Submerged Railway Track

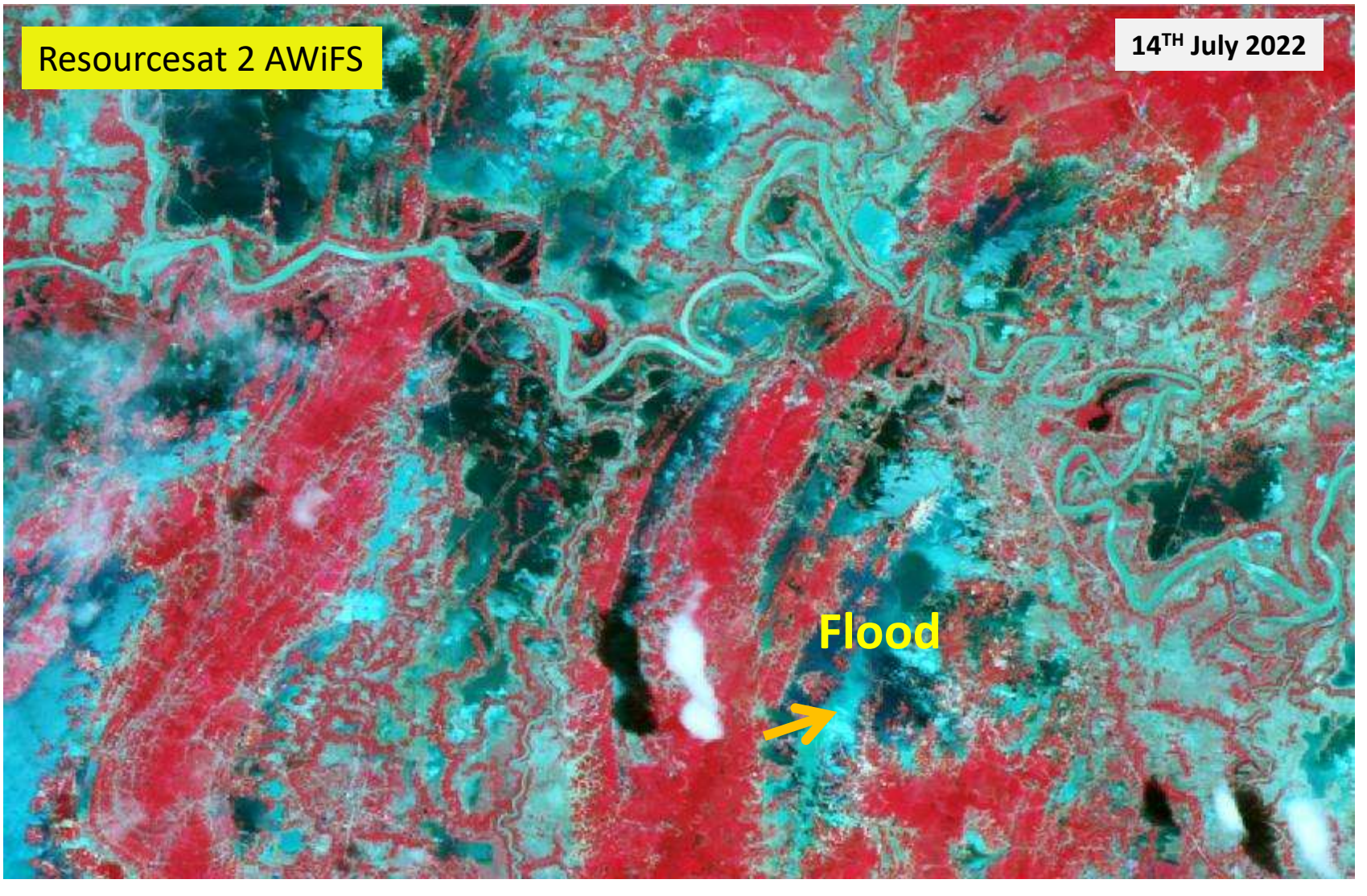


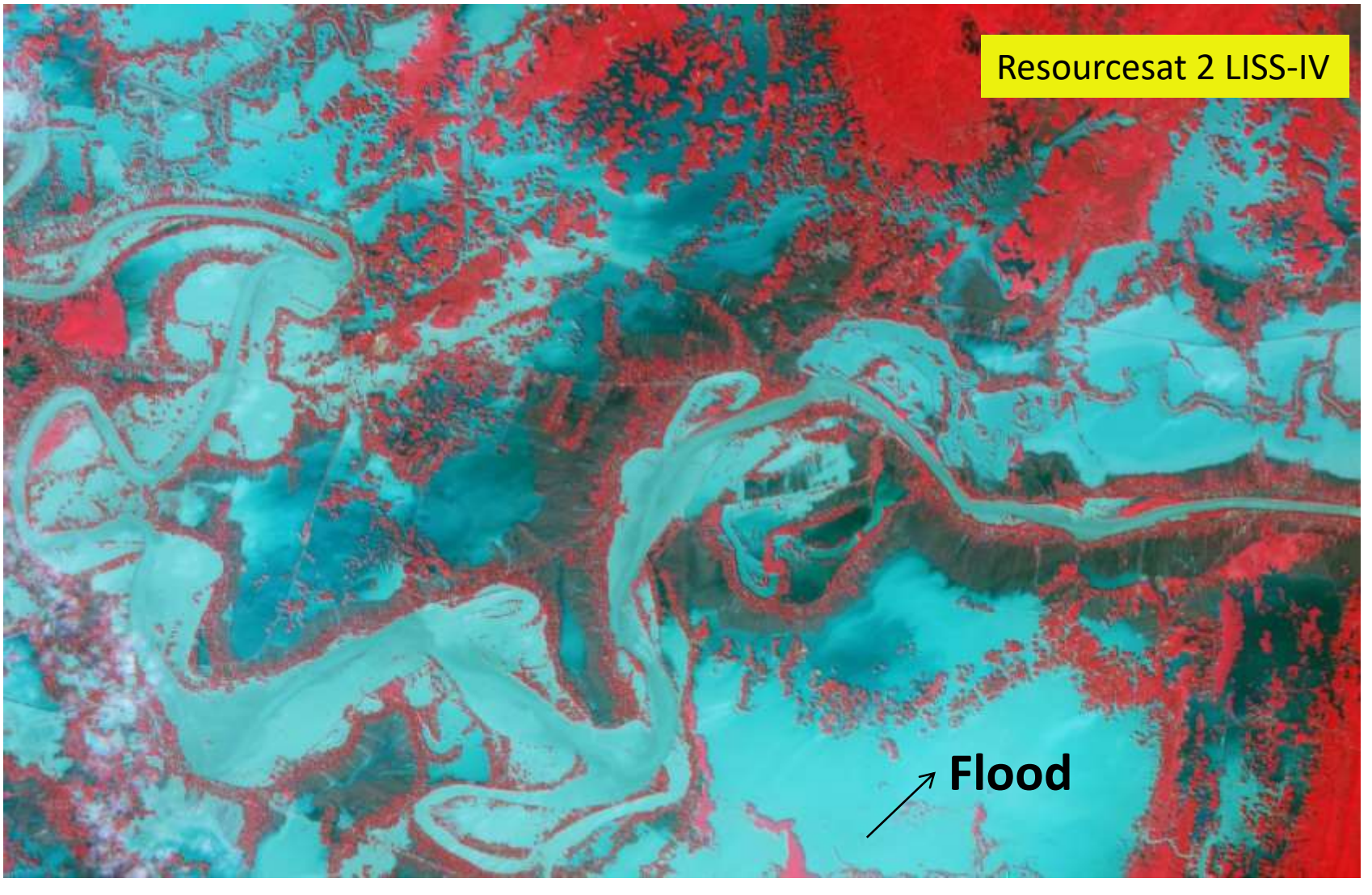
Affected Railway Track near Jamunamukh in part of Nowgong District as observed from GeoEye-1 Satellite data of July 05,

GeoEye-1 data provided under International Charter by USGS, Copyright: © USGS

Courtesy International Charter “Space and Major Disasters”

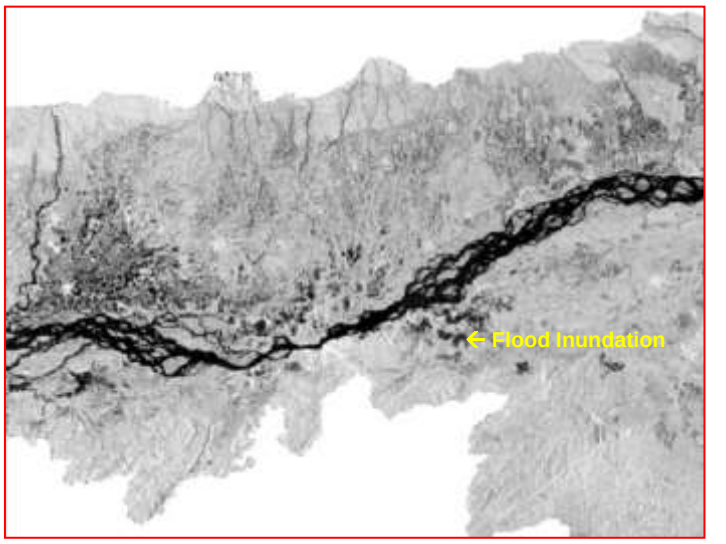

RISAT 1MRS
24th Jun 2022
Flood inundation


Resourcesat 2 AWiFS
14TH July 2022
Flood

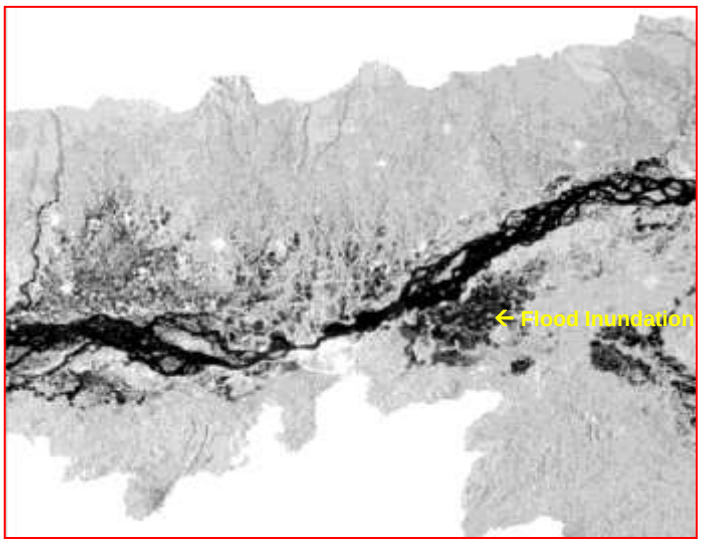

Resourcesat 2 LISS-IV
Flood

Microwave satellite images showing flood inundation in Central Assam throughout the years

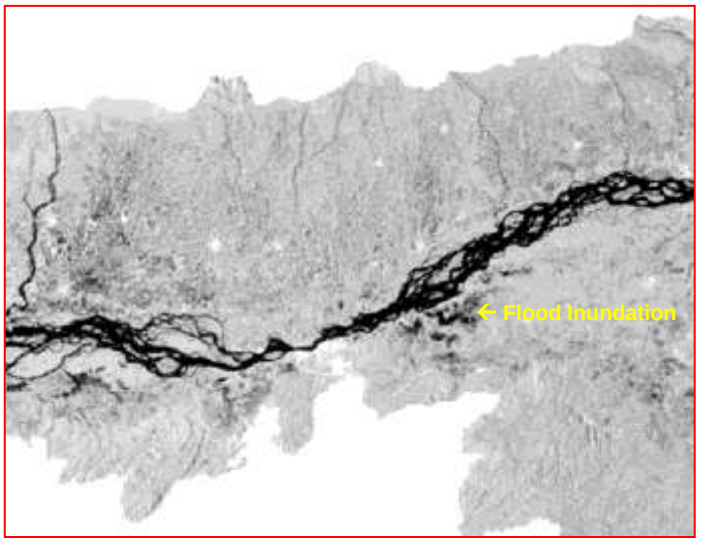
2015



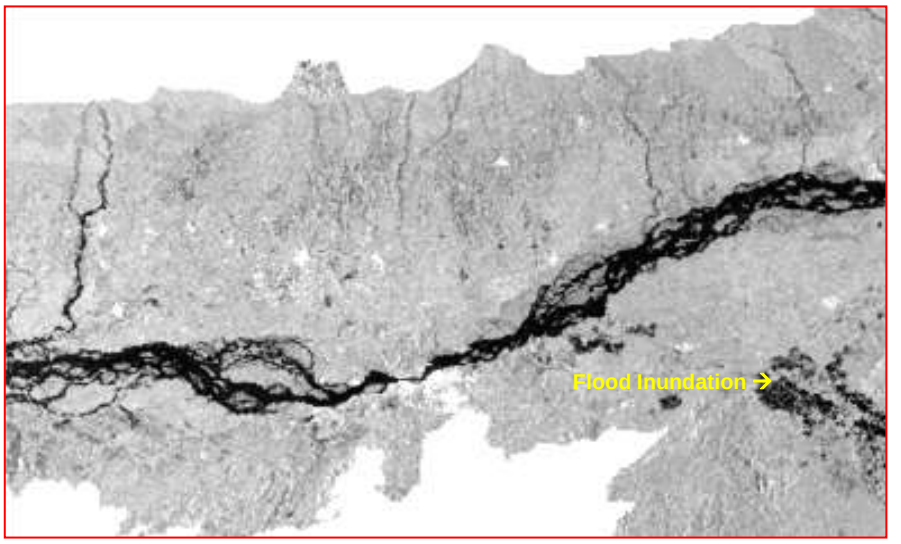
2012



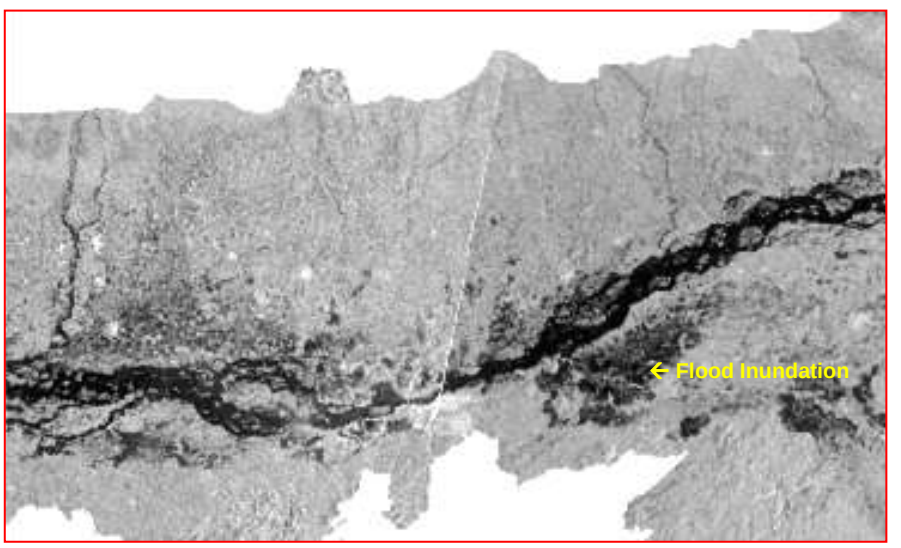
2009



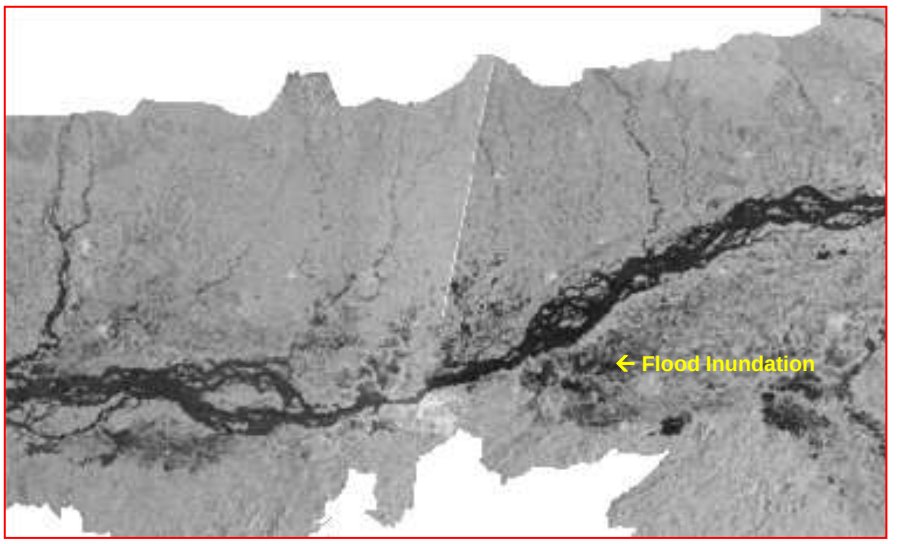
2006



2003



2000



9. Bihar

Bihar is located in the eastern part of India in the fertile gangetic plain. Bihar lies mid-way between West Bengal in the east and Uttar Pradesh in the west. It is bounded by Nepal in the north and Jharkhand in the south. Patna, capital of Bihar state is situated on the banks of the holy river Ganga. The state is located in the fertile Gangetic Plains. The Himalayan mountains are to the north, in Nepal. Central Bihar, south of Ganges. Bihar is richly endowed with water resources, both the ground water resource and the surface water resource. The state has considerable water supply from the rivers which flows within the territory of the State. The major river basins in Bihar are Gandak, Bagmati/Adhwara, Kamla-Balan, Kosi, Mahananda, Karmnasa, Sone, Punpun, Harohar, Kiul, Badua and Chandan. Ganga is the main river which is joined by tributaries with their sources in the Himalayas. Some of them areSaryu (Ghaghra), Gandak, BudhiGandak, Bagmati, Kamla-Balan and Mahananda. There are some other rivers that startfrom the plateau area and meet in Ganges or its associate rivers after flowing towards north. Some of them are Sone, UttariKoyal, Punpun, Panchane and Karmnasha. These rivers make the water available for irrigation purpose and also help ingenerating the hydro-thermal energy for the state.

As Bihar is situated in the floodplains of the Ganges, it highly vulnerable to floods. The major causes of floods in Bihar include heavy rainfall, overflowing rivers, and inadequate drainage systems. The floods in Bihar cause significant damage to infrastructure, property, and crops, affecting people every year. The major rivers passing through which are of crucial in nature due to overflows during the monsoon season and flooding in Bihar.

The Ganges is one of the most important rivers in India, and it flows through Bihar, covering a distance of around 500 km. Sone: The Sone is a major river in Bihar and a tributary of the Ganges. It originates in Madhya Pradesh and flows through Bihar before joining the Ganges at Maner. Kosi: The Kosi river is also known as the "sorrow of Bihar" because of the destruction it causes during floods. The river originates in Tibet and flows through Bihar before joining the Ganges in the state of West Bengal. Gandak: The Gandak is a transboundary river that flows through Nepal and India. The river originates in the Himalayas and flows through Bihar before joining the Ganges in the state of West Bengal. Mahananda: The Mahananda is a river that originates in the Himalayas and flows through the Darjeeling hills before entering Bihar. The river forms a natural boundary between Bihar and West Bengal before joining the Ganges. These rivers provide water for irrigation, transportation, and other economic activities. However, they also pose a risk of flooding during the monsoon season. The state government has taken several measures to manage the risks associated with these rivers, including the construction of embankments and the dredging of river beds.

9.1 Flood Problem in Bihar

The plains of Bihar, adjoining Nepal, are drained by a number of rivers that have their catchments in the steep and geologically nascent Himalayas. Kosi, Gandak, Burhi Gandak, Bagmati, Kamla Balan, Mahananda and Adhwara group of rivers which originates from Nepal, carry high discharge and very high sediment load and drops it down in the plains of Bihar. About 65% of catchment area of these rivers falls in Nepal/Tibet and only 35% of catchment area lies in Bihar.

It is reported that the plains of north Bihar have recorded the highest number of floods during the last 30 years In the years 1998, 2004, 2007, 2008, 2012,2013,2016, 2017,2018,2019,2020 and 2022 Bihar witnessed high magnitudes of flood. The total area affected by floods has also increased during last few years. Bihar also faces water logging problem. The reasons of water-logging are spilling of silted small rivers, encroachment of drainage channels, embankment induced water-logging and presence of saucer type depression locally called Chaurs.

The plains of north Bihar are some of the most susceptible areas in India for flooding. The total area affected by floods has also increased during recent years. The Kosi River is well known in India for rapid and frequent avulsions of its course and the extensive flood damages it causes almost every year. The Kosi is one of the major tributaries of the Ganga River, and rises in the Nepal Himalayas. After traversing through the Nepal Himalayas, it enters India near Bhimnagar. Thereafter, it flows through the plains of north Bihar and joins the Ganga River near Kursela, after traversing for about 320 km. The river has been causing a lot of destruction by lateral movement and extensive flooding. As its waters carry heavy silt load and the river has a steep gradient, the river has a tendency to move sideways. To check the lateral movement as well as for flood control, embankments on both sides of the river were constructed, five to sixteen km apart. Although this has confined the lateral shift of the river within the embankments, but the problem of flooding is still a challenge in this area. The problem of river flooding in Bihar is getting more and more acute due to human intervention in the flood plain at an ever increasing scale. Major floods that have affected in the State are listed here in Table.9.1 for which satellite derived spatial flood inundation maps were generated and disseminated to State / Central Government Disaster Support Management Organisations by NRSC, ISRO.

9.2 Flood Hazard Zonation in Bihar

Flood maps are prepared using long period historic flood layers derived from satellite remote sensing data where flood hazard maps help to delineate areas of land which are at risk of flooding with different frequencies. Hazard maps show a flood boundary based on different magnitudes of flood with various specific frequencies. These maps can be used to regulate developmental activities within the floodplain, so that damages can be minimized. Flood hazard maps can be used for planning of relief, rescue, and health centers in floodplains. These maps can be used as an input to promote flood tolerant crops in the floodplains. It can be very vital information in basin level disaster management plans and in disaster risk reduction activities. Satellites provide synoptic and frequent coverage of flood affected areas and thus become valuable for monitoring flood disaster. Thus satellite data can be directly used for deriving the flood inundation extent. If satellite data sets during flood times are available over a period of time for a floodplain, they can be conveniently used for hazard zone mapping. In addition, latest land use/land cover, infrastructure, settlements, etc. can also be generated from satellite data. Based on the analysis of 274 satellite datasets, acquired during the floods of 1998-2019, the flood hazard layer of the Bihar State is derived as shown in the Figure 9.2. Table 9.2 shows the flood hazard area computed under various hazard categories.

It is observed that about 37.24% (35.06 lakh ha) of land in Bihar state is affected by flood during 1998-2019 out of the total state geographical area 94.16 lakh ha .Out of total 35.06 lakh ha of flood affected area, about 1.21 lakh ha of land falls under very high (greater than 13 times), 1.71 lakh ha under high (inundated 10-13 times) flood hazard categories. Figure 9.1 shows the percentage distribution of the flood hazard area under different categories with respect to the total geographical area. About 3.99 lakh ha is under moderate (inundated 6-9 times) flood hazard category, whereas 9.22 lakh ha under low (inundated 3-5 times) hazard and about 21.11 lakh ha under very low (inundated 1-2 times) flood hazard.

Table. 9.1 . Major flood events in Bihar state

	Year	Description of the flood event	Districts affected
1	1998	Flood occurred with the new breaches in the embankments of rivers Gandak, Kosi and its tributaries during Jul-August , 1998	13
2	2003	Flood occurred in 3 spells during 30th June – 25th July , 05th – 28th August, 11th -21st August 2003	7
3	2004	Floods occurred during 22nd Jun – 31st July 2004 due to rise on water levels in rivers of Burhi Gandak, Bagmati, Adhwara, Gandak, Kamla Balan and Mahananda.	22
4	2005	Floods occurred during 21st July – 9th Sep 2005 due to heavy rainfall in Nepal Catchments due to which rise in water levels in Bagmati at Benibad, Ganga, Burhi Gandak, Bagmati, Adhwara Group, Kamala Balan, Kosi and Mahananda.	17
5	2006	Floods occurred in 3 spells during 10-15th Jun, 3-26th July, 13-15th Sep 2006 due to rise in water level in Ganga, Sone, Punpun, Bagmati, Burhi Gandak, Kamlabalan and Mahananda rivers.	39
6	2007	Floods occurred during 20-25th Jun, 10th -12th Oct due to rise in water levels in Burhi Gandak, Bagmati, Adhwara, Gandak, Kamla Balan and Mahananda rivers	36
7	2008	The breach in the eastern embankment of Kosi river near Kusaha village in Nepal on 18th August, 2008 led to extensive flooding in northern districts of Bihar	25
8	2009	Floods occurred during 29th July – 10th Oct 2009 due to rise in water levels in Kosi, Gandak, Budhi and Bagmati floodng after the Bagmati river breached its embankment.	
9	2010	Floods occurred during 29th July – 10th Oct 2009 due to rise in water levels in Kosi, Gandak, Budhi and Bagmati; The Saran embankment, under severe strain from the rising Gandak River, breached near Semaria in North Bihar's Gopalganj district	37
10	2011	Floods occurred during 2nd Jul – 9th Oct 2011 due to rise in water levels in Kosi, Mahananda, Gandak, Bodhi and Bagmati rivers.	18
11	2012	Floods occurred during 18th Jul – 25th Jul and 20th Sep -25th Sep rise in water levels in Kosi, Bagmati, Ghaghra rivers	38
12	2013	Floods occurred during 13th Jul – 11th Sep 2013 due to rise in water levels Kosi river at Basua in Supaul, Mahananda	37
13	2014	Floods occurred during 17-27th Aug 2014 due to rise in water levels in Kosi, Ghaghra, and Ganga	37
14	2016	Floods occurred during 27th Jul – 10th Sep due to rise in water levels Kosi, Ghaghra, and Ganga	36
15	2017	Floods occurred during Jul-Sep , 2018 due to rise in water levels Kosi, Ghaghra, and Ganga	38
16	2018	Floods occurred during 13th -30th August, 8-25th Sep 2018 due to rise in water levels in Mahananda, Bagmati and Kamalabalan rivers	38
17	2019	Floods occurred during 11th Jul -22nd Aug , 20th Sep – 11th Oct due to rise in water levels in Mahananda, Bagmati, Kamla Balan,River Adhwara,Burhi Gandak,Kosi and Gandak river levels.	34
18	2020	Floods occurred due to rise in water levels in Kosi, Bagmati, Gandak and Ganges rivers	39
19	2021	Floods occurred during 17th Jun -22nd Oct due to rise in water levels in River Gandak, Mahananda, Parman, Kamla, BurhiGandak, Kosi, Bagamati, Adhwara and Kamalabalan rivers.	35
20	2022	Floods occurred during 25th Jul – 20th Oct 2022 due to rise in water levels Ganga, Kosi, Adhwara group and Bagmati rivers.	33

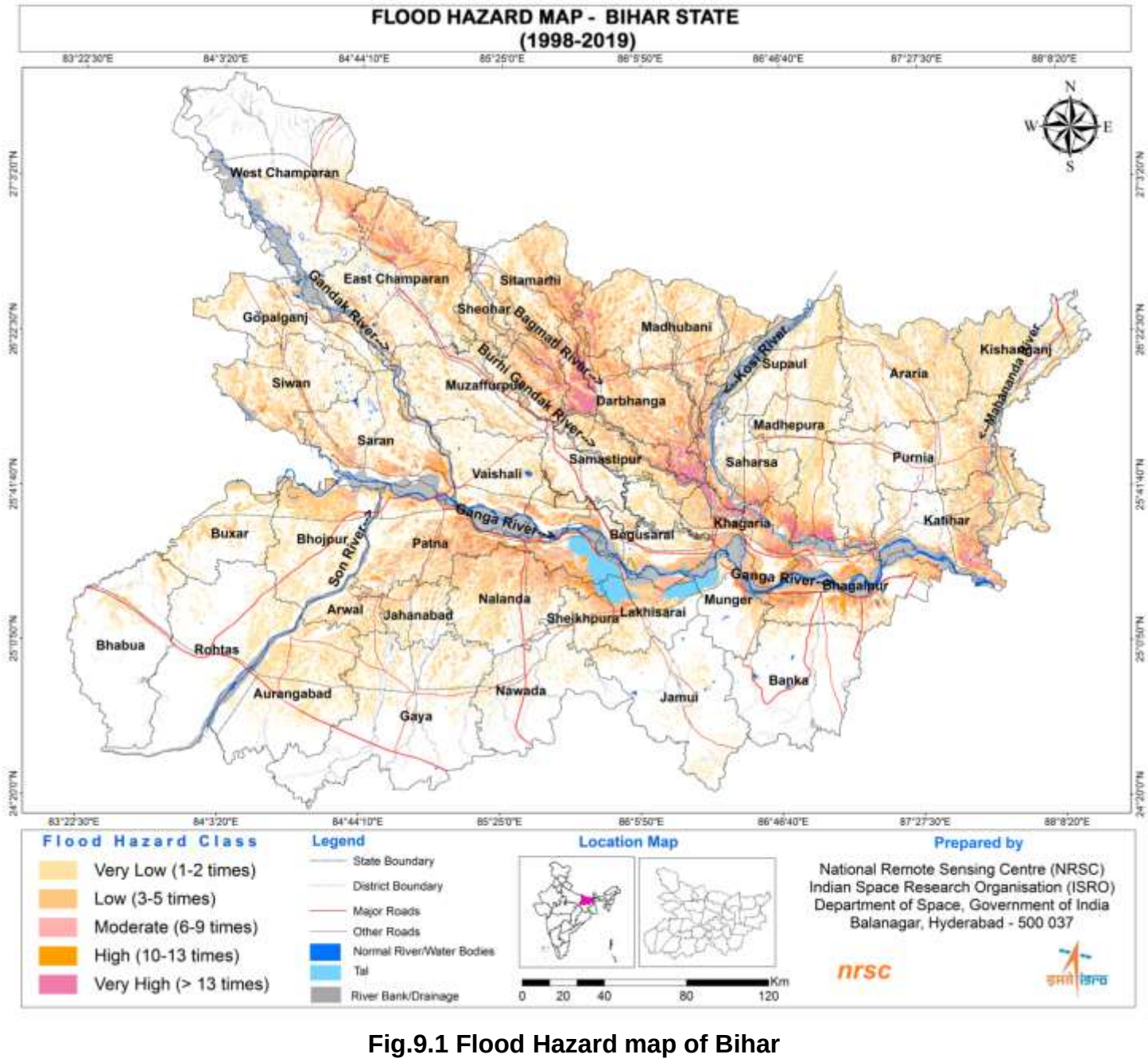


Fig.9.1 Flood Hazard map of Bihar

Table.9.2 Flood Hazard Area under Various Categories

Sl. No	Hazard Severity	Flood Hazard Area (ha)	% Flood Hazard (wrt State Geographical Area)	% Flood Hazard (wrt Total Flood Hazard Area)
1	Very High	113481	1.21	3.24
2	High	160952	1.71	4.59
3	Moderate	376118	3.99	10.73
4	Low	867740	9.22	24.75
5	Very Low	1987890	21.11	56.70
	TOTAL	**3506181**	**37.24**	**100**

9.3 Flood Affected Area in Bihar

Cumulative flood inundation maps were utilised for generation of total flood affected area map in Bihar and is estimated as 39,76,861 ha. It is observed that, the flood affected areas in Bihar are mainly due to rise in water levels in Ganga, Kosi rivers in majority of the years where in floods were occurred. Flood affected area map is shown in Figure.9.2. and district wise flood affected area statistics are shown in Table. 9.3. Flood situation in Bihar is alarming, where 21 districts in the state have flood affected area > 1,00,000 ha, 6 districts between 50,000 and 1,00,000 ha, 7 districts between 25,000 and 50,000 ha and 4 districts between 10,000 and 25,000 ha.

Table.9.3 District-wise flood affected area in Bihar state

S. No.	District	Flood Affected Area (Ha)
1	Purba Champaran	251928
2	Madhubani	233550
3	Darbhanga	211066
4	Muzaffarpur	206533
5	Katihar	171660
6	Patna	170333
7	Chhapra	160072
8	Sitamarhi	154439
9	Samastipur	151926
10	Araria	149427
11	Purnia	138824
12	Siwan	137378
13	Nalanda	135506
14	Bhagalpur	126622
15	Gopalganj	116800
16	Kishanganj	115421
17	Bhojpur	114590
18	Khagaria	110283
19	Pashchim Champaran	109814
20	Madhepura	109158
21	Supaul	102093
22	Aurangabad	94064
23	Saharsa	93975
24	Begusarai	90265
25	Vaishali	81099
26	Gaya	62341
27	Buxar	51315
28	Lakhisarai	45731
29	Jhanabad	42336
30	Rohtas	36623
31	Sheikhpura	33578
32	Munger	31883
33	Arwal	31821
34	Sheohar	25657
35	Jamui	24911
36	Bhabhua	21245
37	Nawada	20790
38	Banka	11801
	Total	**3976861**

Glimpses of satellite images / flood inundation over the time period are depicted in this section.

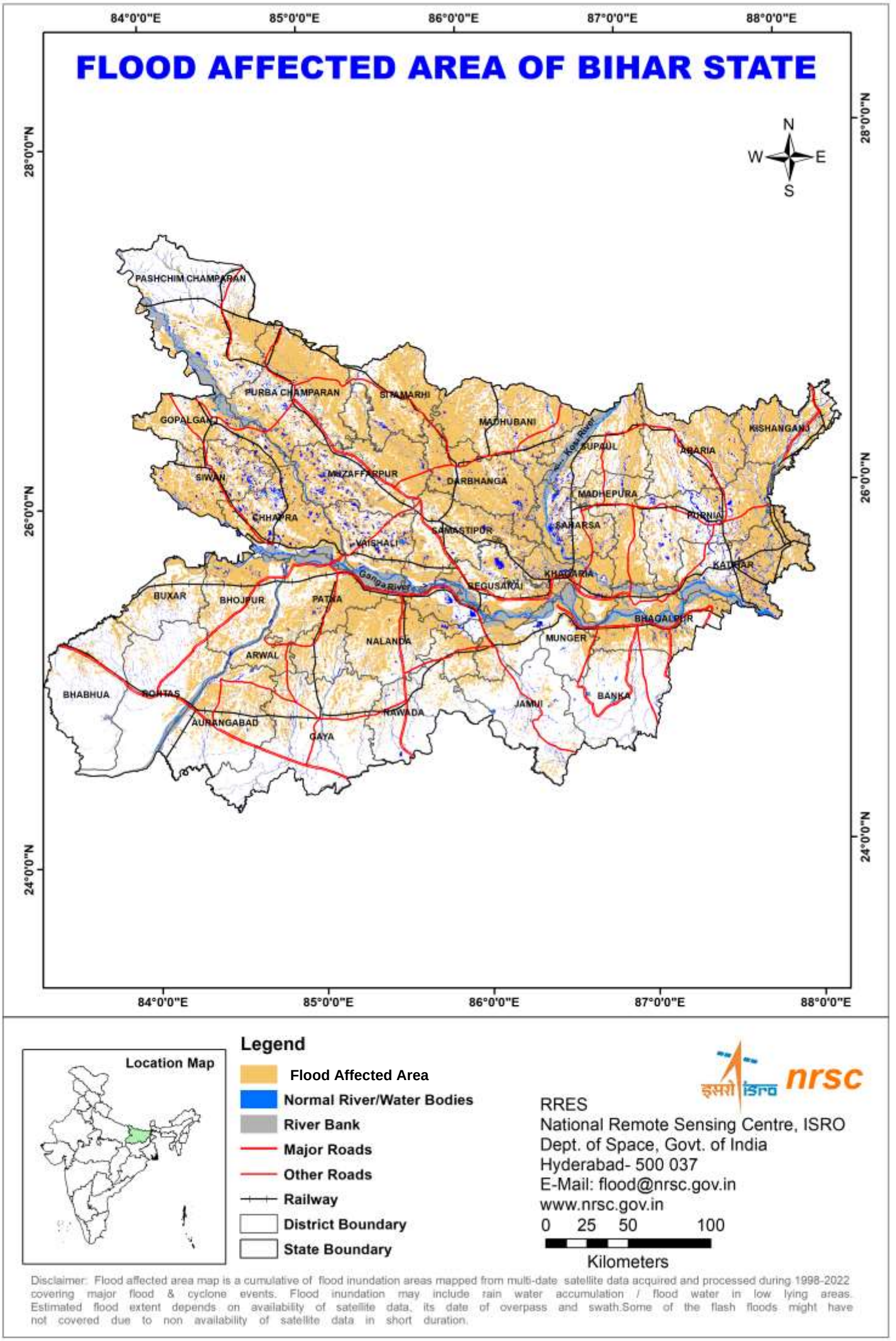
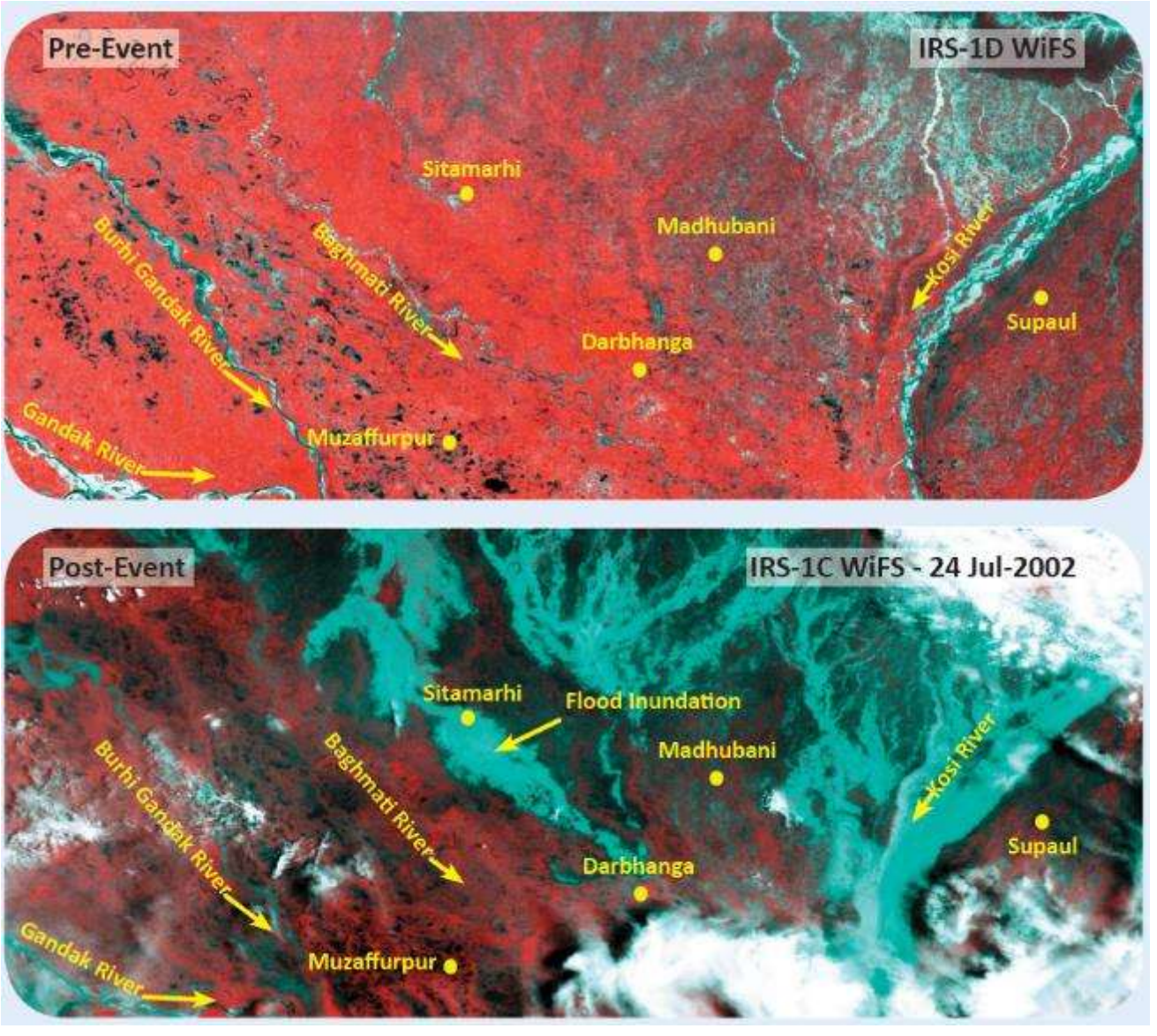
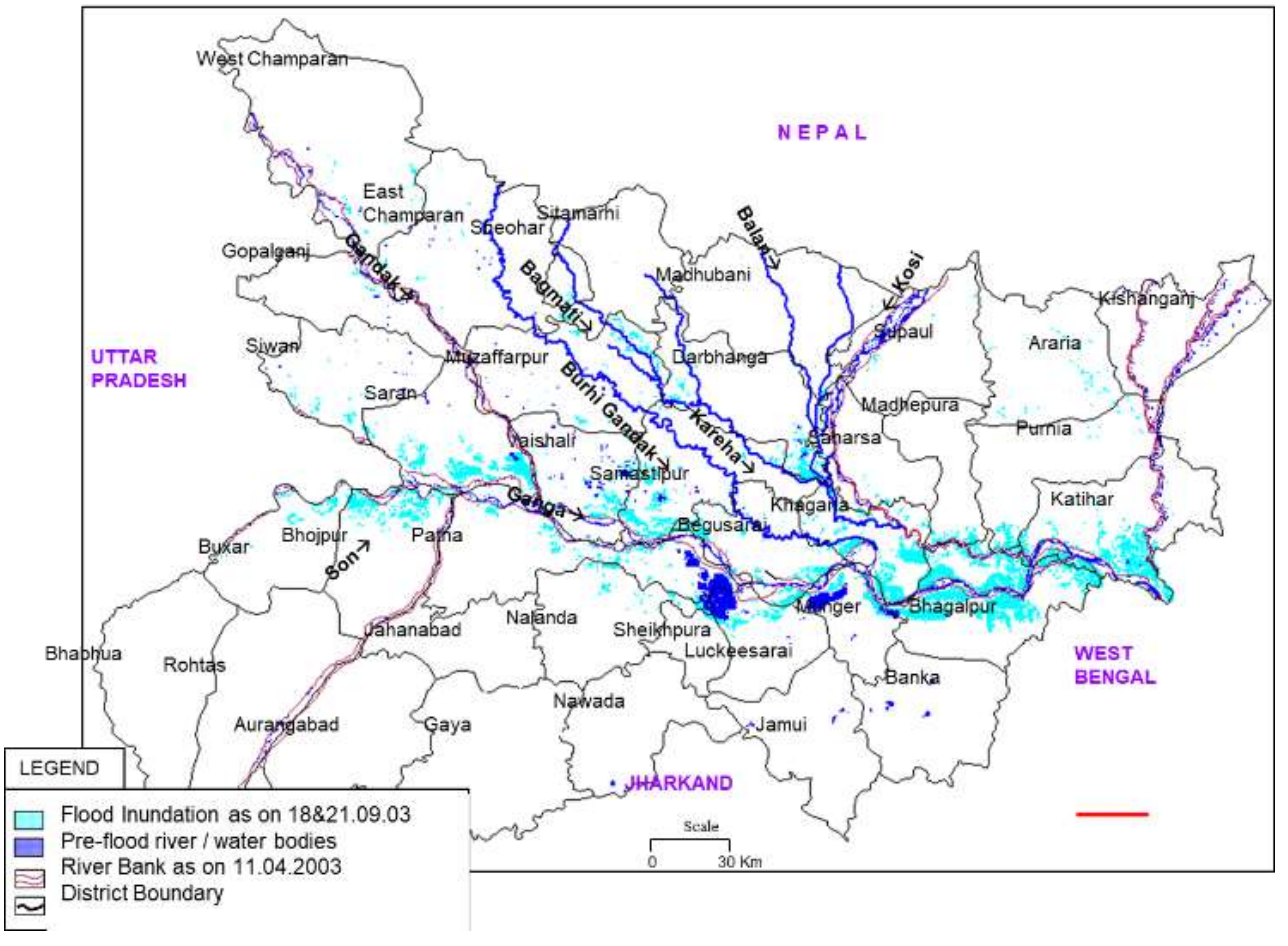
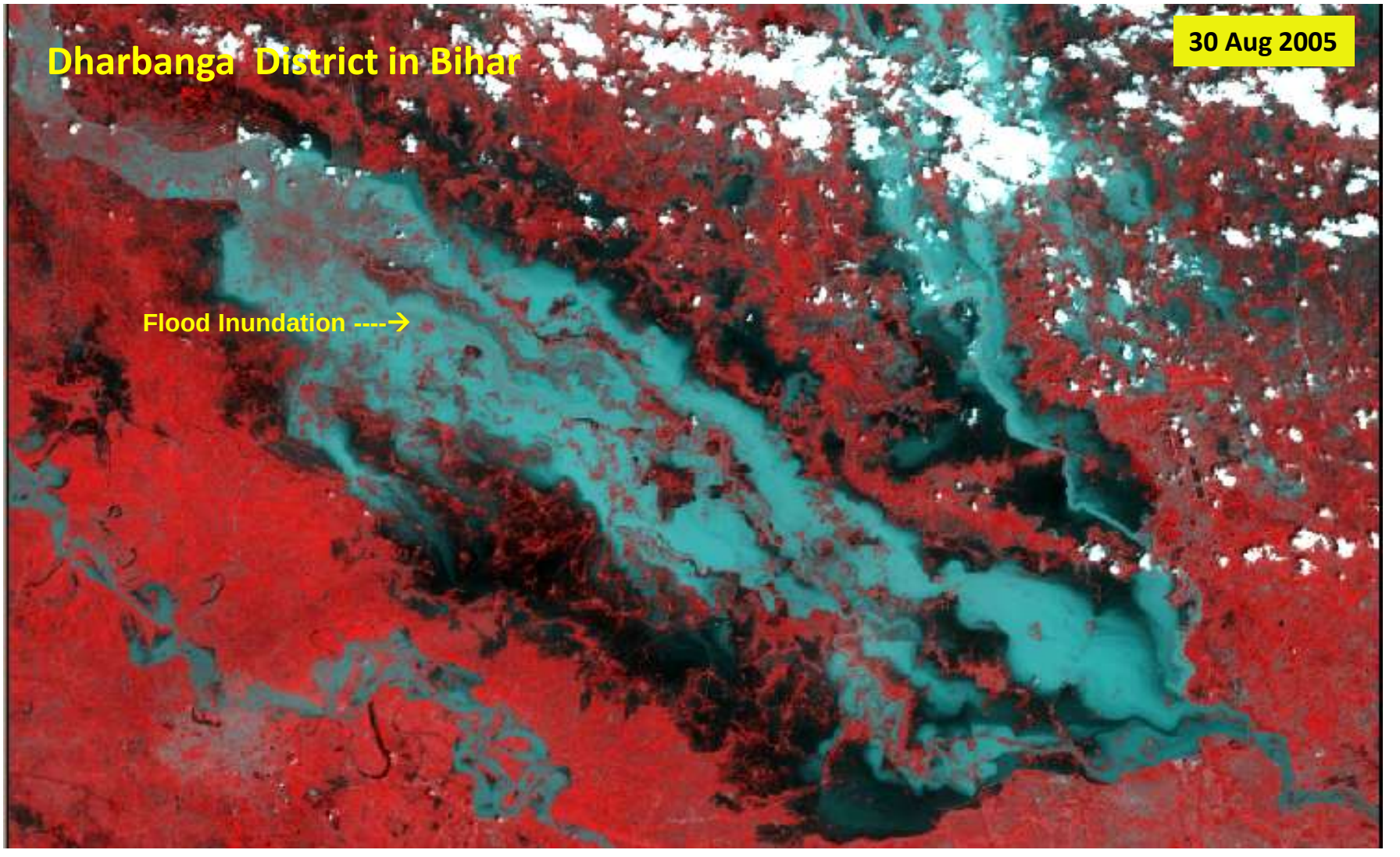


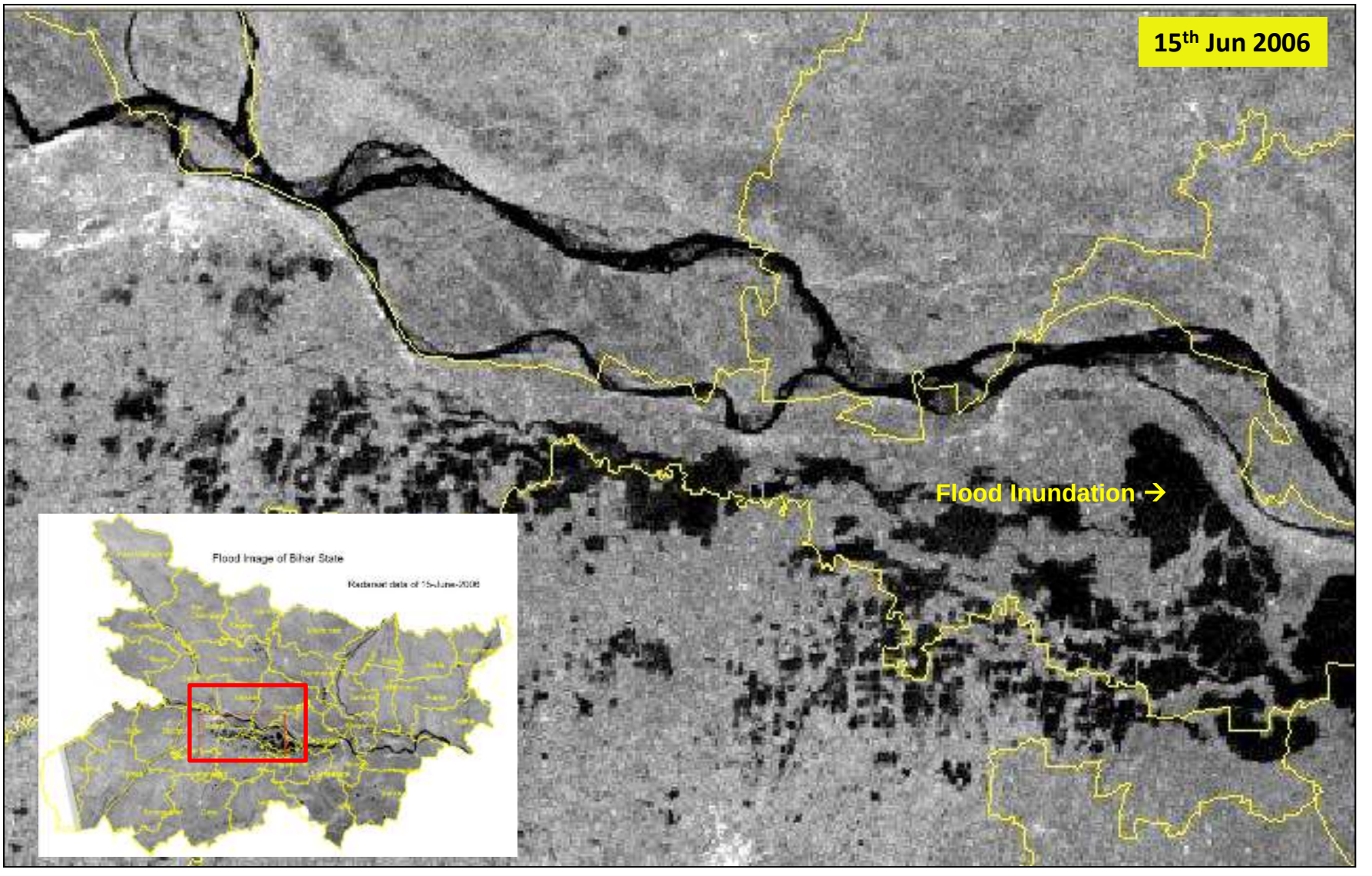
Fig.9.2 Flood Affected Area of Bihar State



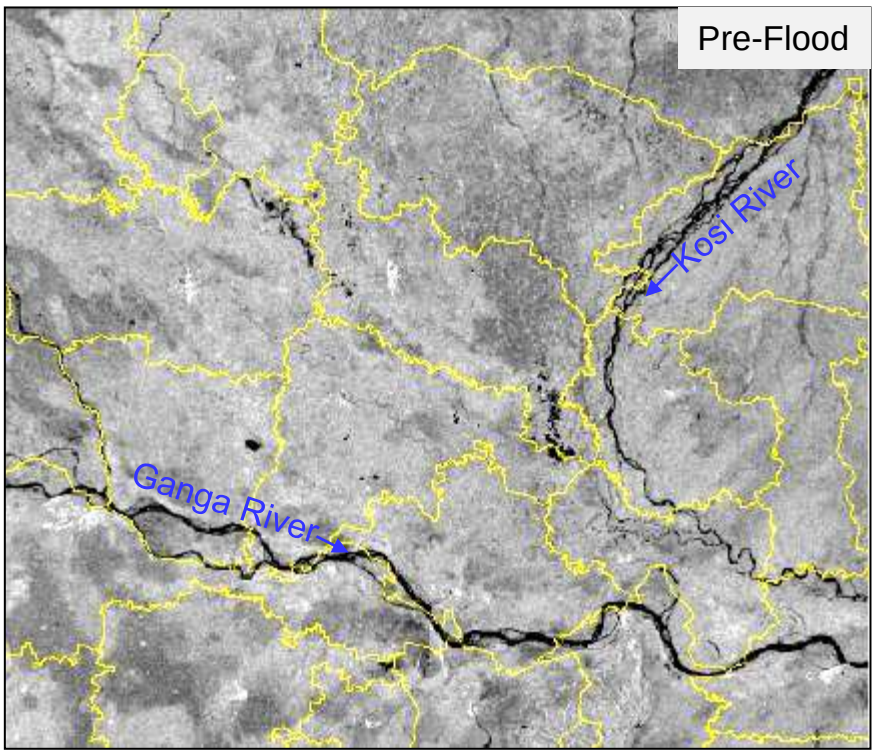
Analysis of flood inundation using Radarsat data for the dates 18 & 21-09-2003



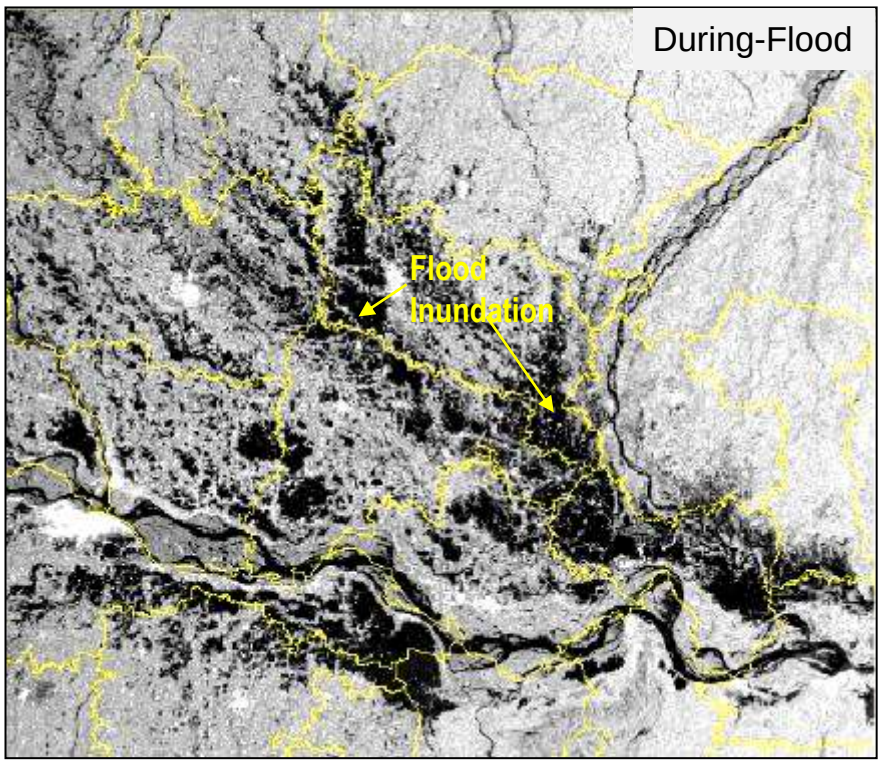

Dharbanga District in Bihar
30 Aug 2005
Flood Inundation ----→


15th Jun 2006
Flood Inundation →
Flood Image of Bihar State

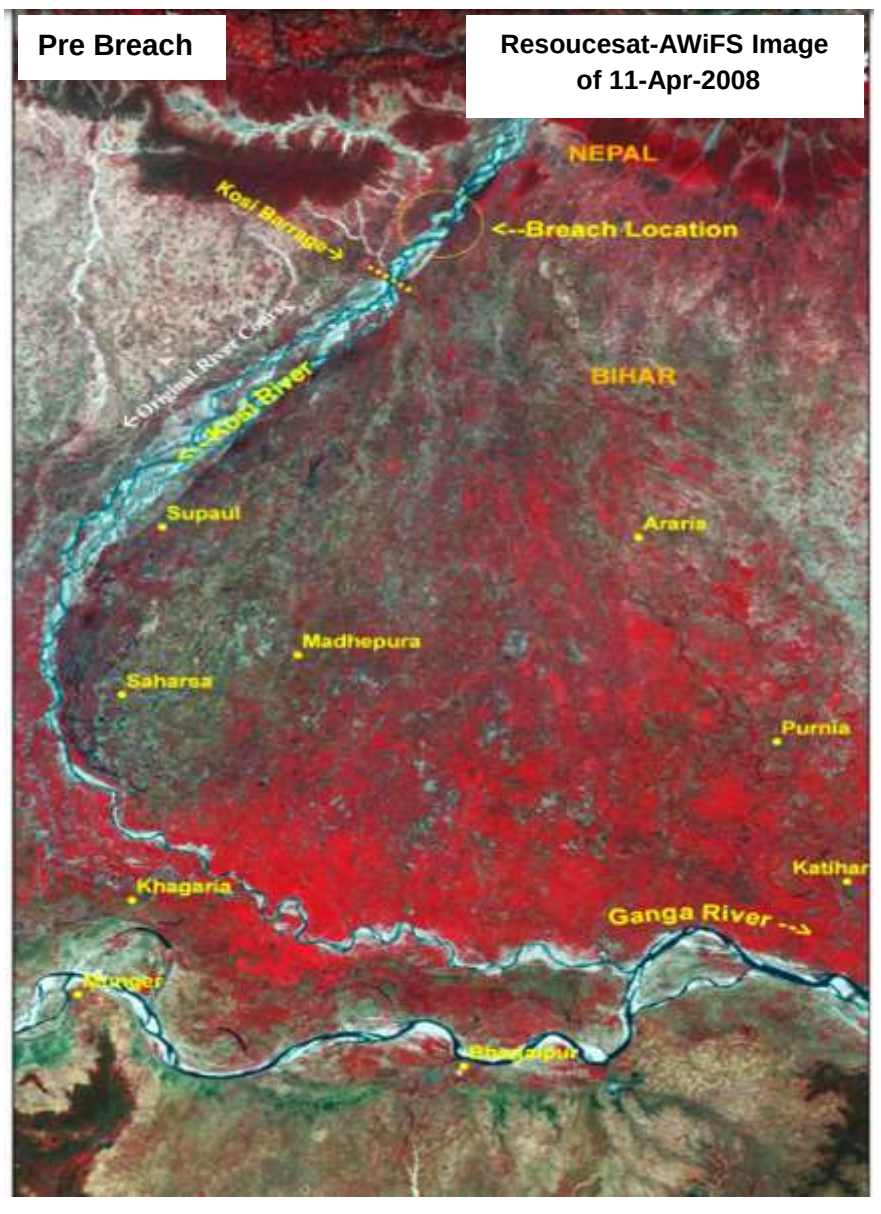
Flooding in North Bihar- As on 03-Oct-2007

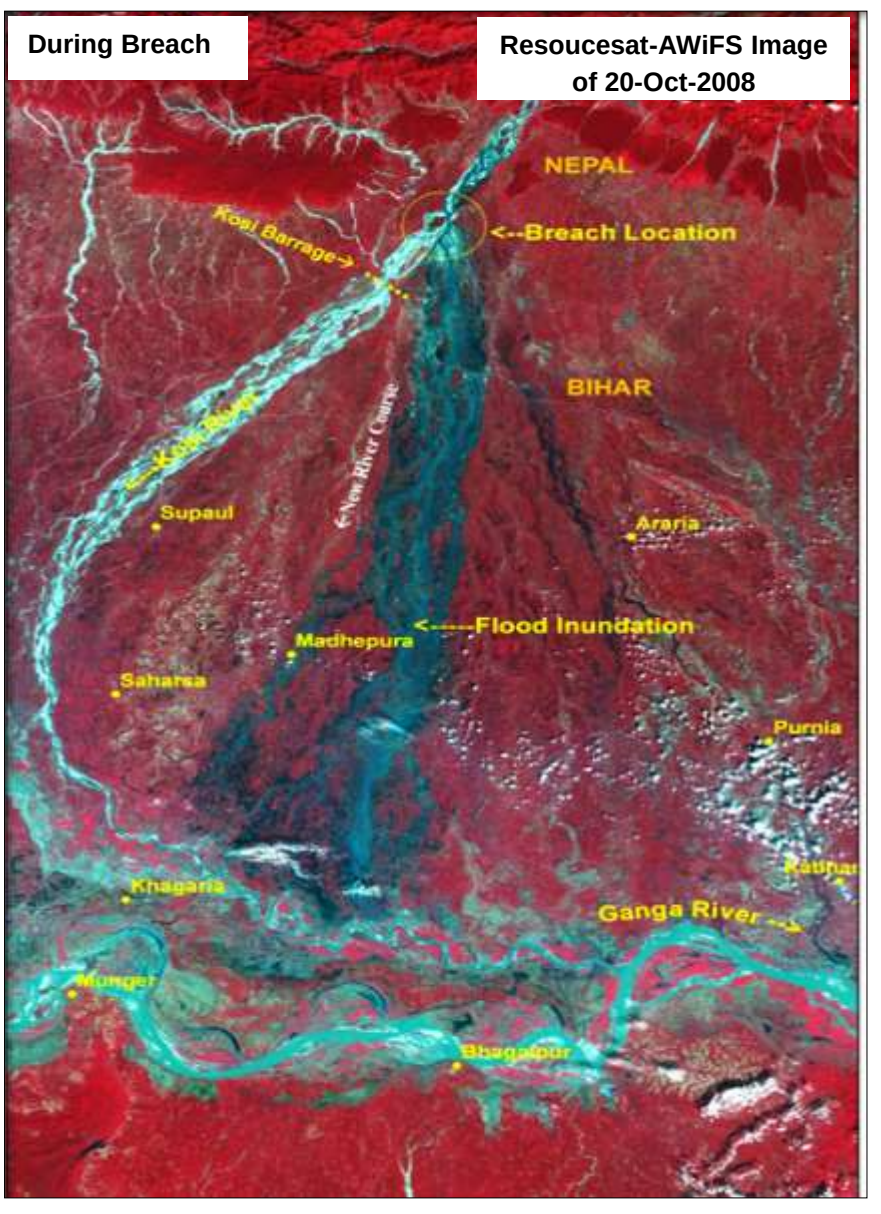


Radarsat image of 04-Jul-2007



Radarsat image of 03-Oct-2007



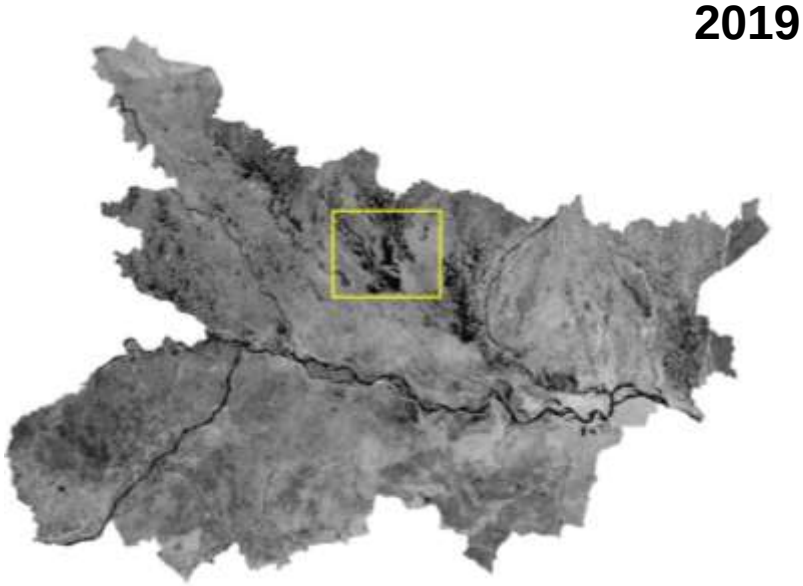


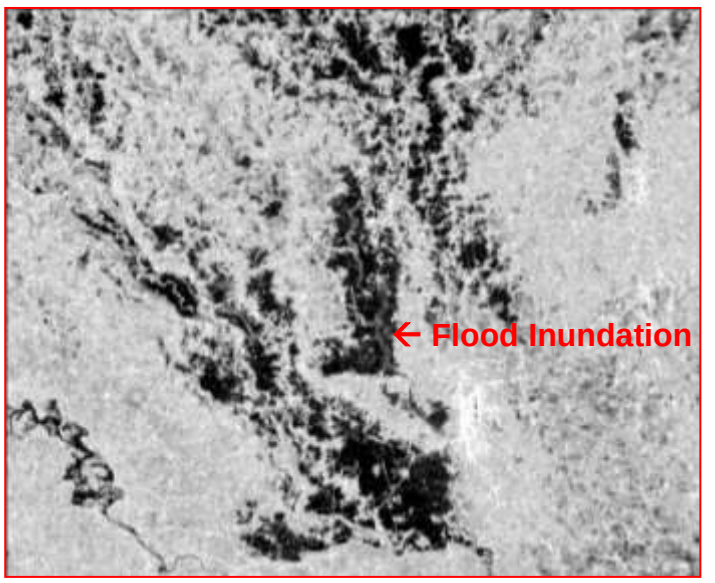

N
Ganga River
15th Oct 2022
Resourcesat AWiFS


10 Sep 2022
Cartosat 2E
Part of Saran District
Gandak River
Flood
Inundation

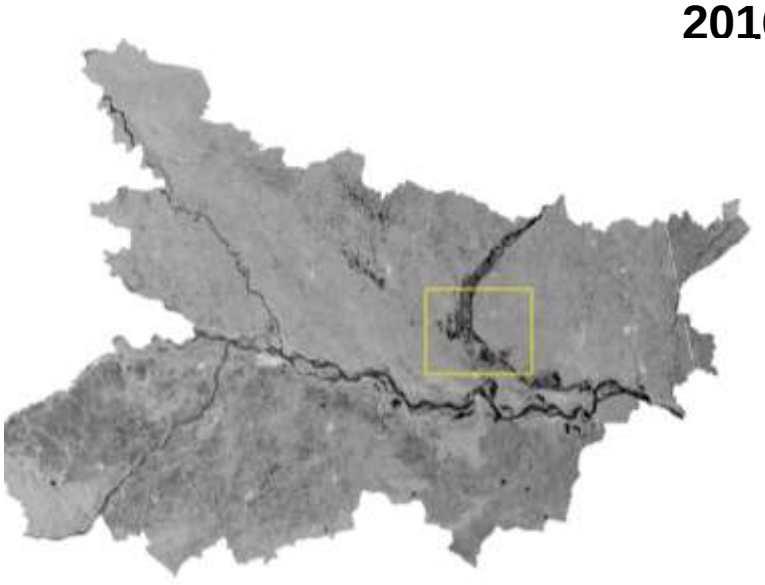
Multi mission satellite images showing flood inundation in parts of Bihar State

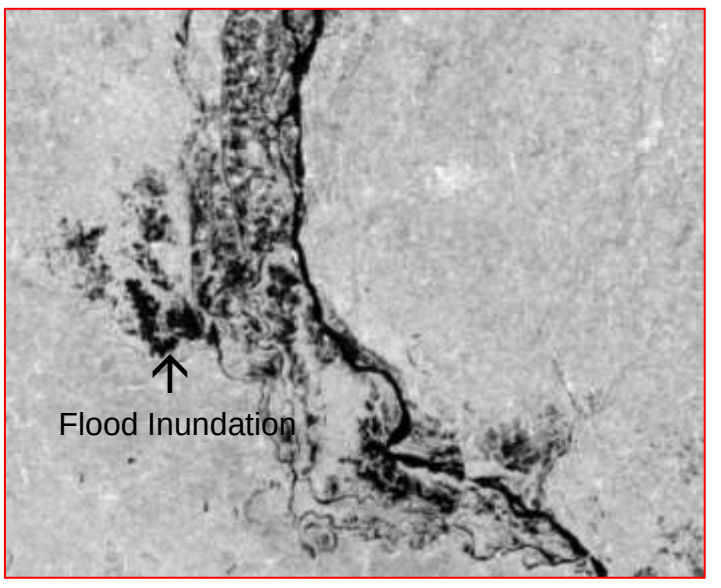
2019



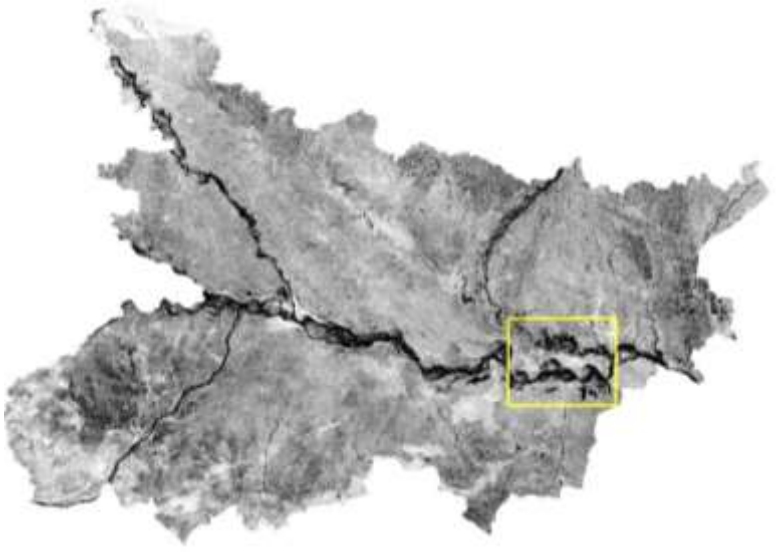


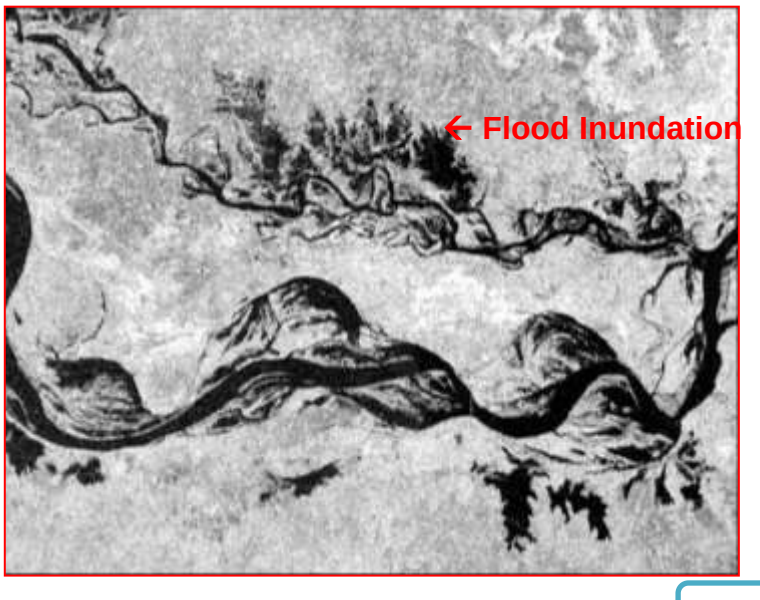
2016



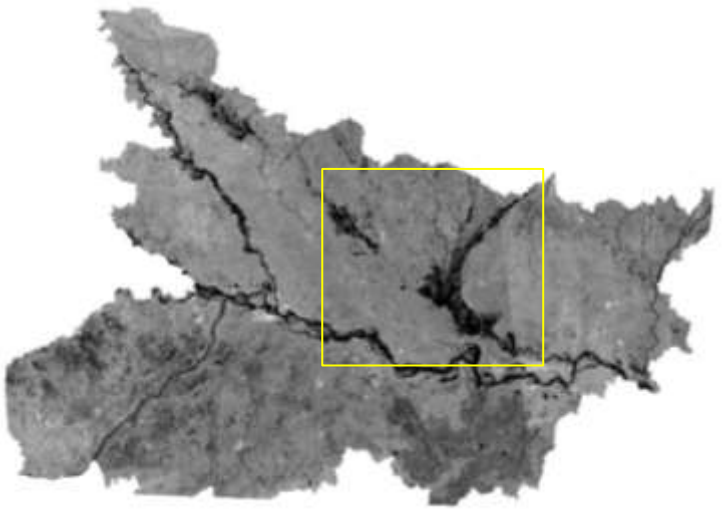


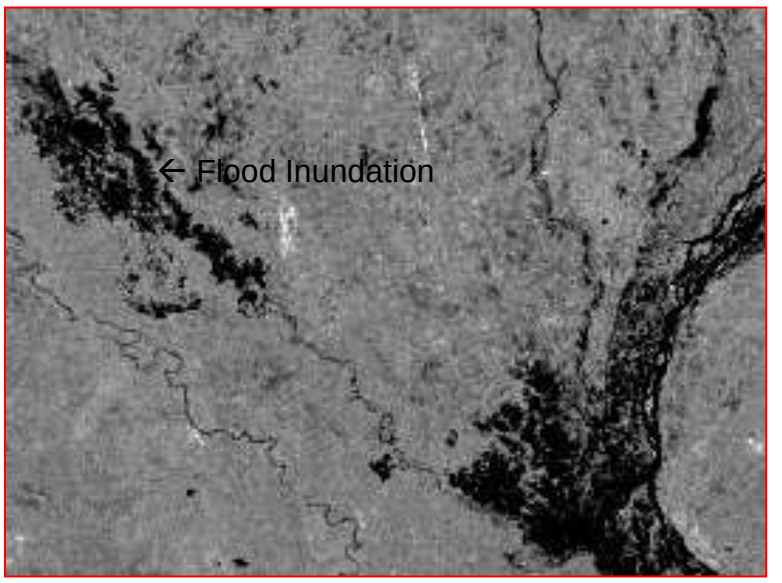
2013



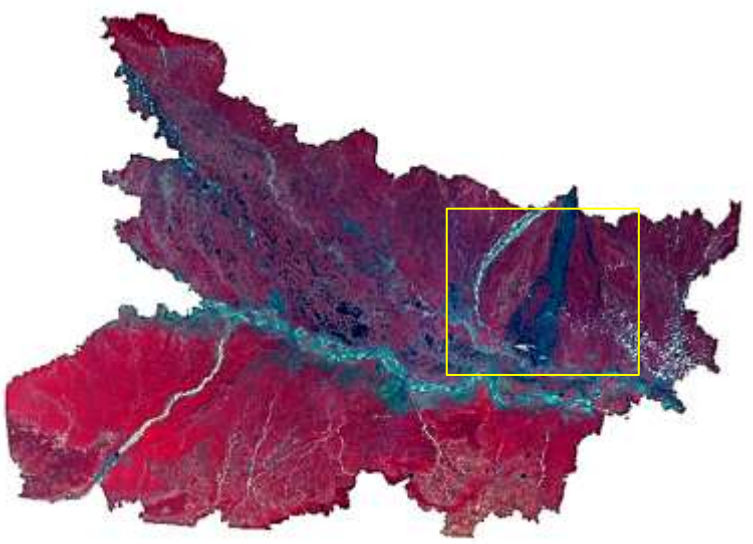


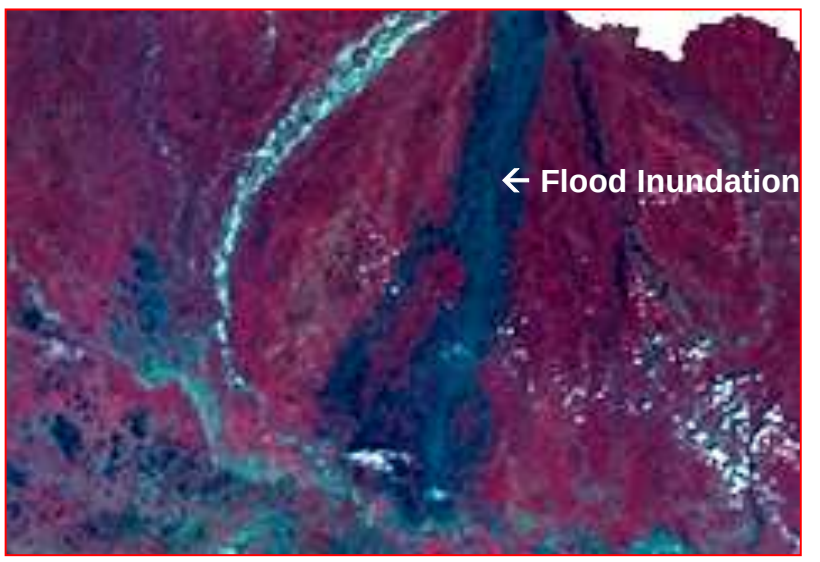
2010



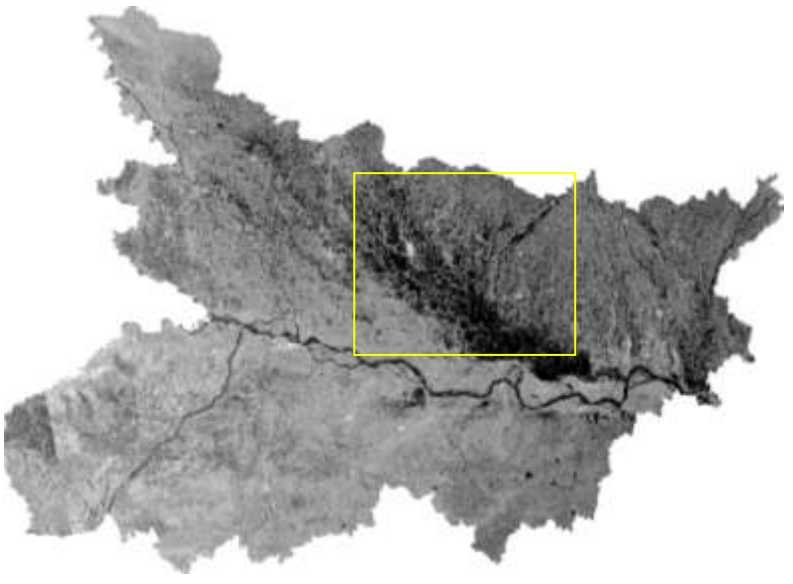


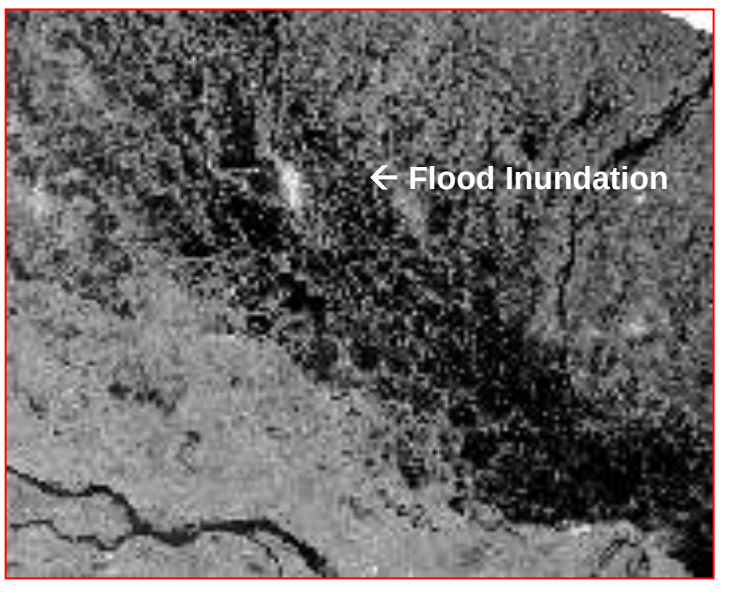
2008





2004





Chhattisgarh

10. Chhattisgarh

Chhattisgarh is a state located in central India, bordered by Madhya Pradesh to the northwest, Maharashtra to the southwest, Andhra Pradesh to the south, Telangana to the southeast, Odisha to the east, and Jharkhand to the northeast. Agriculture is the primary source of livelihood for the majority of the population in Chhattisgarh, with rice, wheat, and pulses being the major crops. The state is also rich in mineral resources, that include coal, iron ore, limestone, and bauxite. Mining is an essential economic activity in this state. Chhattisgarh is a state located in central India, and it is prone to floods during the monsoon season. The floods in Chhattisgarh are mainly caused by heavy rainfall, which leads to overflowing rivers, and the state has witnessed several few floods in the past. The floods in Chhattisgarh cause significant damage to infrastructure, property, and crops, leading to displacement and loss of human lives and livestock. It is crucial to develop effective flood management plans, build resilient infrastructure, promote climate-resilient agricultural practices, and improve disaster preparedness and response capabilities. These measures can help Chhattisgarh to mitigate the risks of floods and build resilience to future flooding events.

Major rivers in Chhattisgarh are (i) Mahanadi River: The Mahanadi is the largest river in Chhattisgarh and originates from the Dhamtari district. The river flows through the state before joining the Bay of Bengal in Odisha. The Mahanadi is one of the most important rivers in the region and is used for irrigation, transportation, and hydropower generation. (ii) Indravati River: The Indravati is a major river in Chhattisgarh, and it originates in the hills of the eastern Ghats. The river flows through the state before joining the Godavari River in Telangana. The Indravati is known for its scenic beauty and is an important source of water for the surrounding areas. (iii) Shivnath River: The Shivnath is another important river in Chhattisgarh, and it originates in the Durg district. The river flows through the state before joining the Mahanadi near the city of Dhamtari. The Shivnath is used for irrigation and is an important source of water for the surrounding areas. (iv) Arpa River: The Arpa is a tributary of the Mahanadi and originates in the Kanker district. The river flows through the state before joining the Mahanadi near the city of Bilaspur. The Arpa is used for irrigation and is an important source of water for the surrounding areas. (v) Hasdeo River: The Hasdeo is a major tributary of the Mahanadi and originates in the Surguja district. The river flows through the state before joining the Mahanadi near the city of Bilaspur. The Hasdeo is an important source of water for the surrounding areas and is used for irrigation and hydropower generation.

These rivers are crucial to the state's economy and provide water for irrigation, transportation, and other economic activities. However, they also pose a risk of flooding during the monsoon season. The state government has taken several measures to manage the risks associated with these rivers, including the construction of embankments and the dredging of river beds.

10.1. Flood Problem in Chhattisgarh

Major floods that have affected in the State are listed here in Table.10.1 for which satellite derived spatial flood inundation maps were generated and disseminated to State / Central Government Disaster Support Management Organisations by NRSC, ISRO.

Table. 10. 1 . Major flood events in Chhattisgarh state

	Year	Description of the flood event	Districts affected
1	2005	Floods occurred in 3rd week of Sep 2005 due to heavy rains which has affected low lying areas	2
2	2006	Floods occurred in 7-14th Aug 2006 due to rise in water level in Indravati, Sabri and Sankhani rivers which has affected low lying areas .	2
3	2010	Floods occurred during 1st week of Jul 2010 due to rise in water level in Narangi river	1
4	2020	Floods occurred during last week of August, 2020 under influence of South West Monsoon. Severe water logging was observed at many places in Mahanadi flood plain and inundation of low lying areas.	5

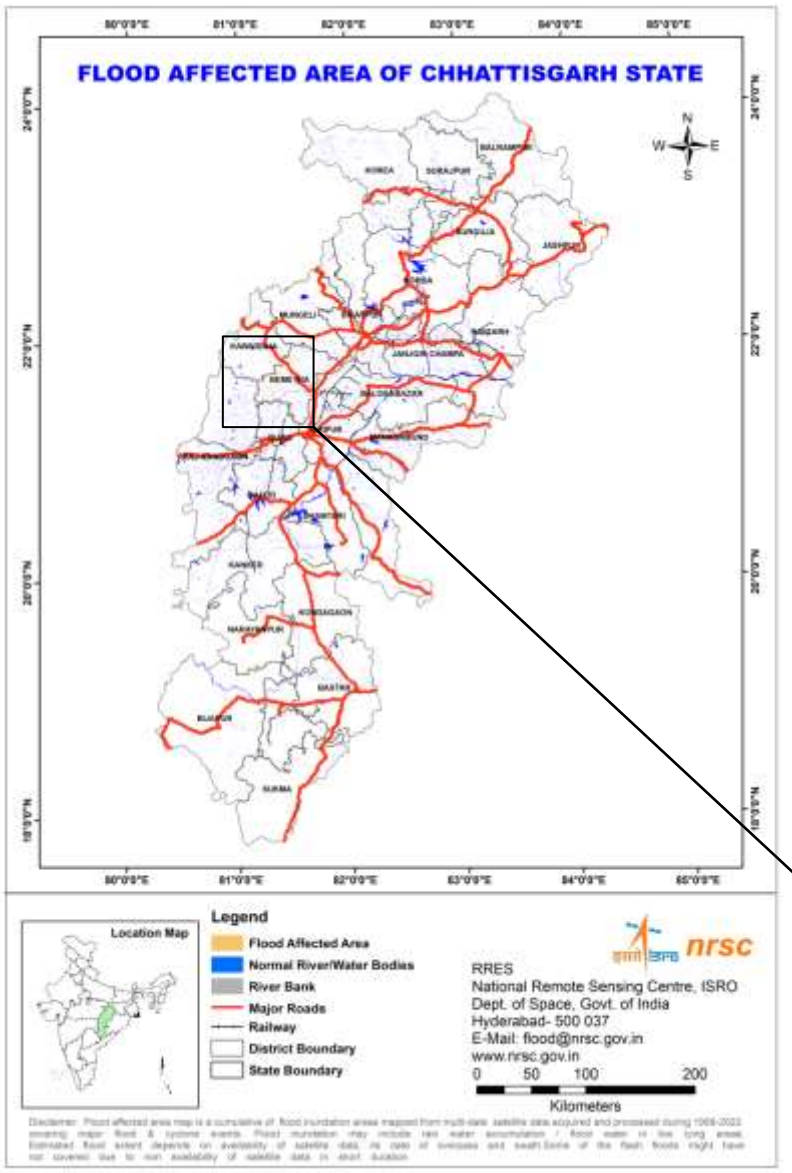
10.2. Flood Affected Area in Chhattisgarh

Cumulative flood inundation maps were utilised for generation of map of total flood affected area in Chhattisgarh and is estimated as 12,029 ha. Flood affected area map is shown in Figure.10.1 and District wise flood affected area statistics are given in Table. 10.2. Chhattisgarh has 12 districts where flood affected area is less than 10,000 ha.

Table.10.2 District wise statistics of Flood affected area in Chhattisgarh

S. No.	District	Flood Affected Area (Ha)
1	Bemetra	7328
2	Mungeli	930
3	Raj nandgaon	605
4	Kawardha	555
5	Bilaspur	527
6	Bastar	490
7	Raipur	414
8	Balodabazar	368
9	Durg	296
10	Kondagaon	213
11	Janjgir champa	199
12	Balod	103
TOTAL		**12029**

Glimpses of satellite images / flood inundation over the time period are depicted in this section.



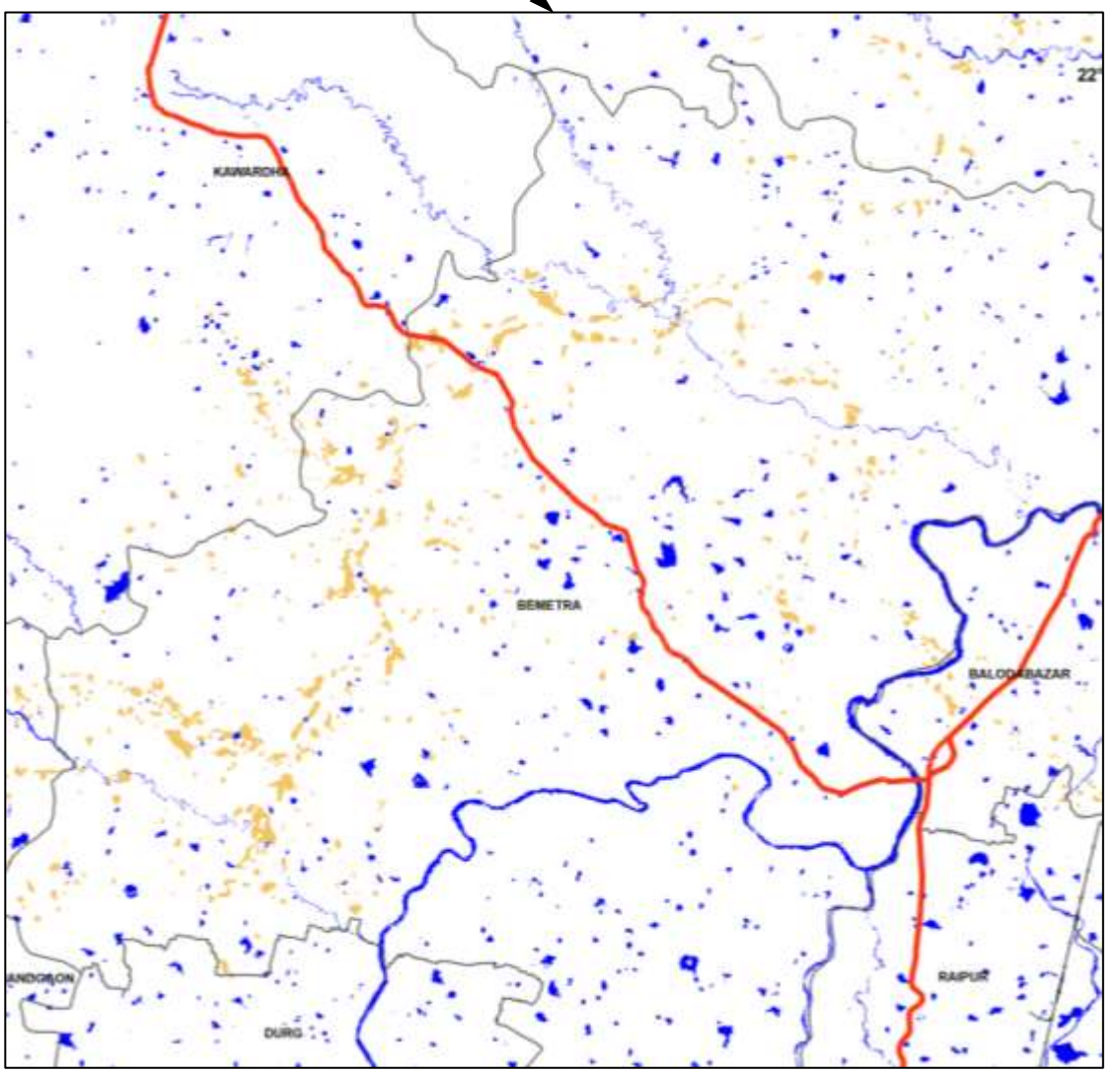
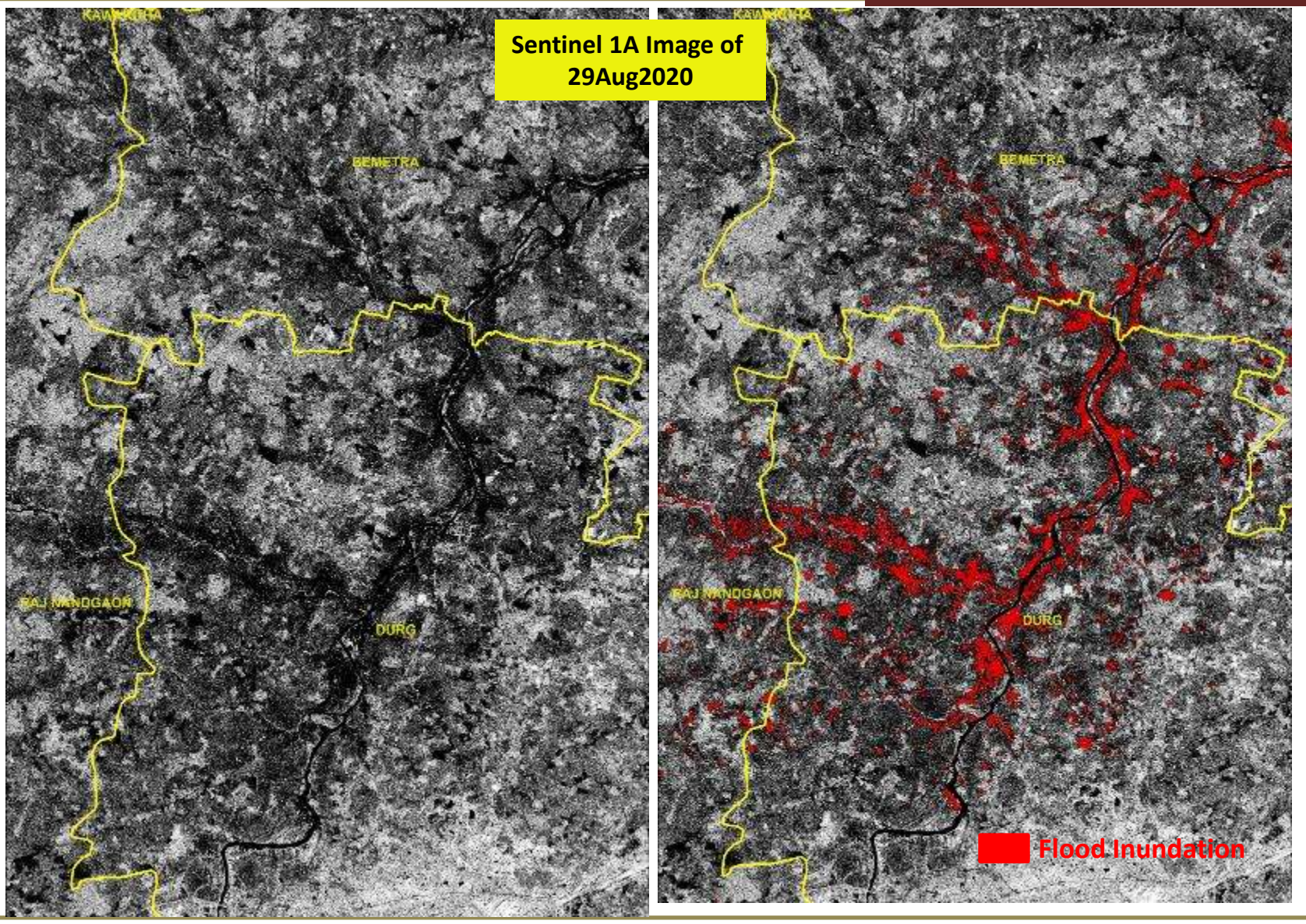
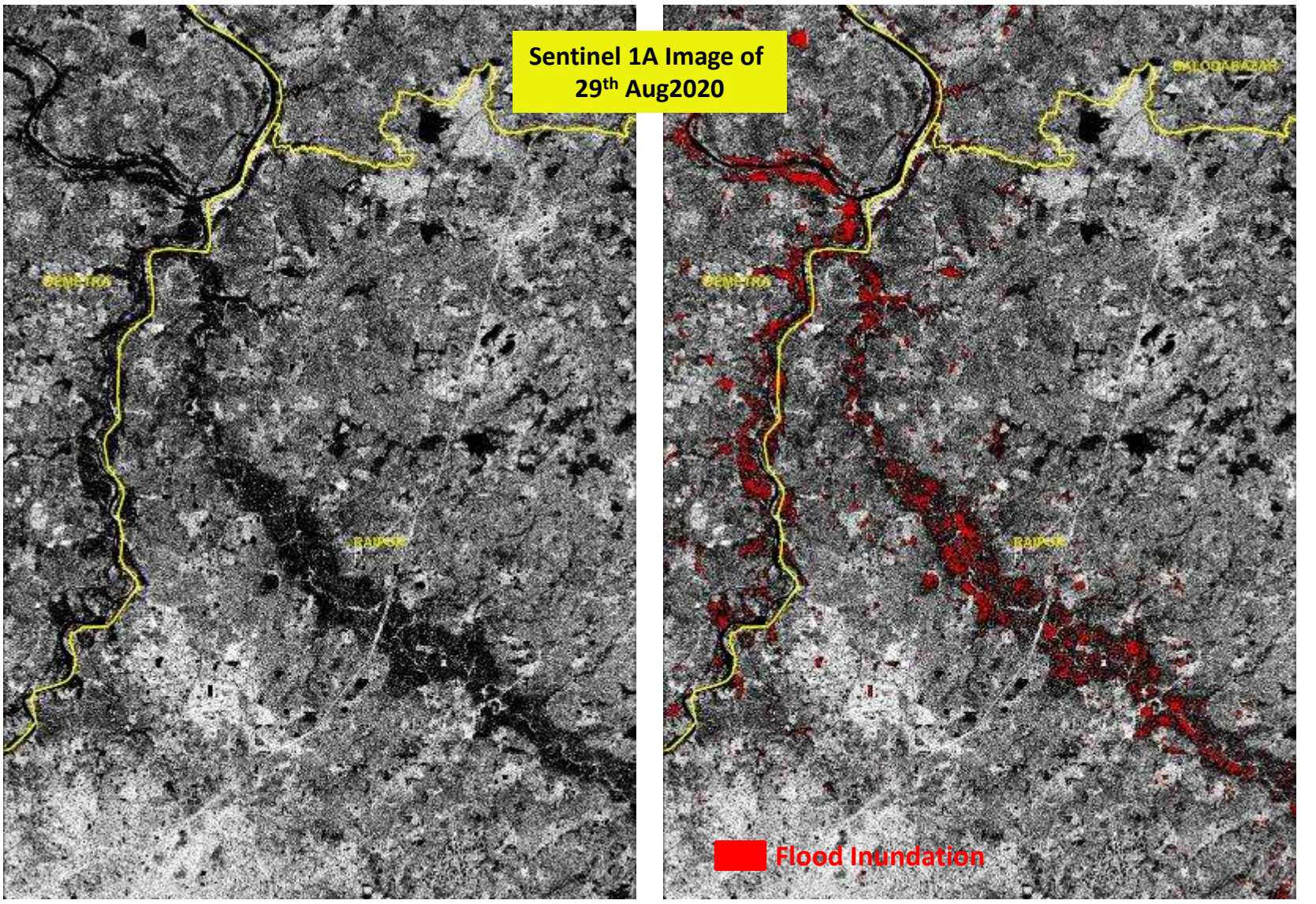


Fig.10.1 Flood affected area of Chhattisgarh State


Sentinel 1A Image of
29Aug2020
BEMETRA
RAJ NANDGAON
DURG
Flood Inundation


Sentinel 1A Image of
29th Aug2020
Flood Inundation

11. Delhi

Delhi

Delhi is the capital city of India and is situated on the banks of the Yamuna River. The Yamuna is the largest river in Delhi and it originates in the Himalayas and flows through several northern Indian states before finally joining the Ganges River in Allahabad. The following are the main river which get affected by flood inundation in low lying areas of Delhi during the peak flows. Concern for floods in delhi are due the rivers viz. Yamuna Flood Plains - The Yamuna flood plains are a vast area of land along the banks of the Yamuna River, Hindon River - The Hindon is a tributary of the Yamuna and flows through the states of Uttar Pradesh and Delhi, Sahibi River - The Sahibi is a small river that originates in the Aravalli Range in Rajasthan and flows through Haryana before entering Delhi, Najafgarh Drain - is a seasonal river that originates in Haryana and flows through the western part of Delhi before joining the Yamuna.

The average annual rainfall in Delhi is 714 mm with three-fourths of it falling in the months of July, August and September. Heavy rainfall in the catchment area of the Yamuna can result in a dangerous flood situation for the city. The causes of flood in Delhi is due to overflow of the Yamuna River, which is prone to flooding during the monsoon season located near by. Rapid urbanization and inadequate drainage systems in Delhi also might make the city vulnerable to urban floods. Delhi has also experienced flash floods in the past, particularly in the low-lying areas of the city. Government of Delhi has taken several measures, such as the construction of flood protection walls and the dredging of the Yamuna River to mitigate the impact of floods, and also implemented a flood management plan, which includes early warning systems, evacuation plans, and emergency response measures.

11.1. Flood Problem in Delhi

Major floods that have affected in the State are listed here in Table.11.1 for which satellite derived spatial flood inundation maps were generated and disseminated to State / Central Government Disaster Support Management Organisations by NRSC, ISRO.

11.2. Flood affected area in Delhi

Cumulative flood inundation maps were utilised for generation of map of total flood affected area in Delhi and is estimated as 5,848ha. Flood Affected Area Map is shown in Figure.11.2 and district wise flood affected area statistics are shown in Table. 11.2. Delhi has 7 districts where flood affected area is less than 10,000 ha.

Table. 11. 1 . Major flood events in Delhi

	Year	Description of the flood event	Districts affected
1	2010	Floods were reported during second week of September, 2010 in Delhi due to release of water from Hathnikund barrage resulting in increase of water level in Yamuna river	Delhi
2	2013	Floods were reported during third week of June 2013 in Delhi due to rising water level in River Yamuna.	Delhi
3	2018	Floods were reported in Delhi due to heavy torrential rainsduring last week of July,2018	Delhi
4	2019	Floods were reported in Delhi due to heavy torrential rains during third week of August, 2019. The river Yamuna has crossed the danger mark at many areas.	Delhi

Table.11.2 District wise statistics of Flood affected area in Delhi

S. No.	District	Flood Affected Area (Ha)
1	North Delhi	2387
2	South East Delhi	1362
3	East Delhi	808
4	Central Delhi	523
5	North East Delhi	335
6	Shahdara	273
7	North West Delhi	159
TOTAL		**5848**

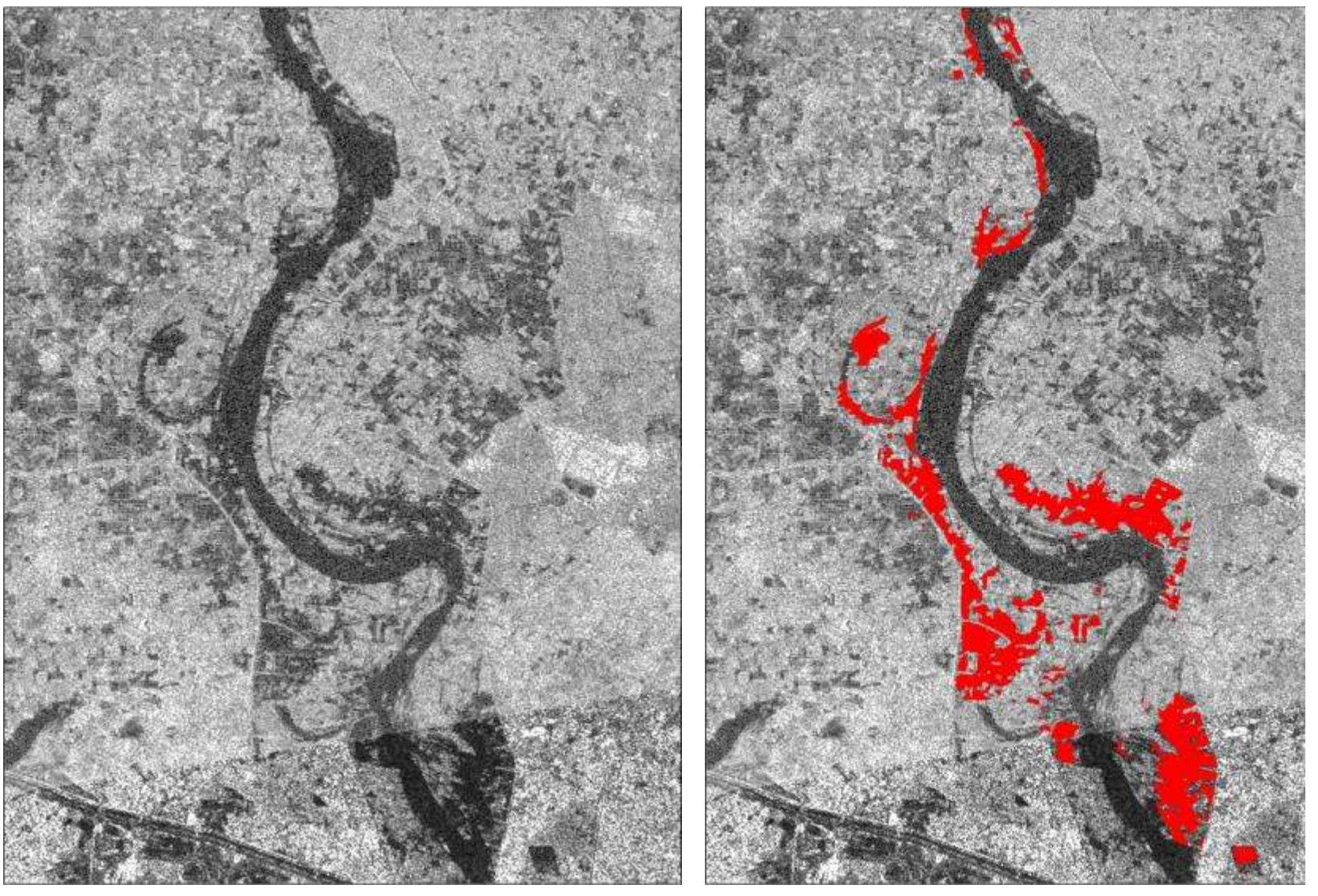


Fig.11.1 Flood Inundation observed in Delhi as on 30-Jul-2018 (Sentinel-1 SAR data)

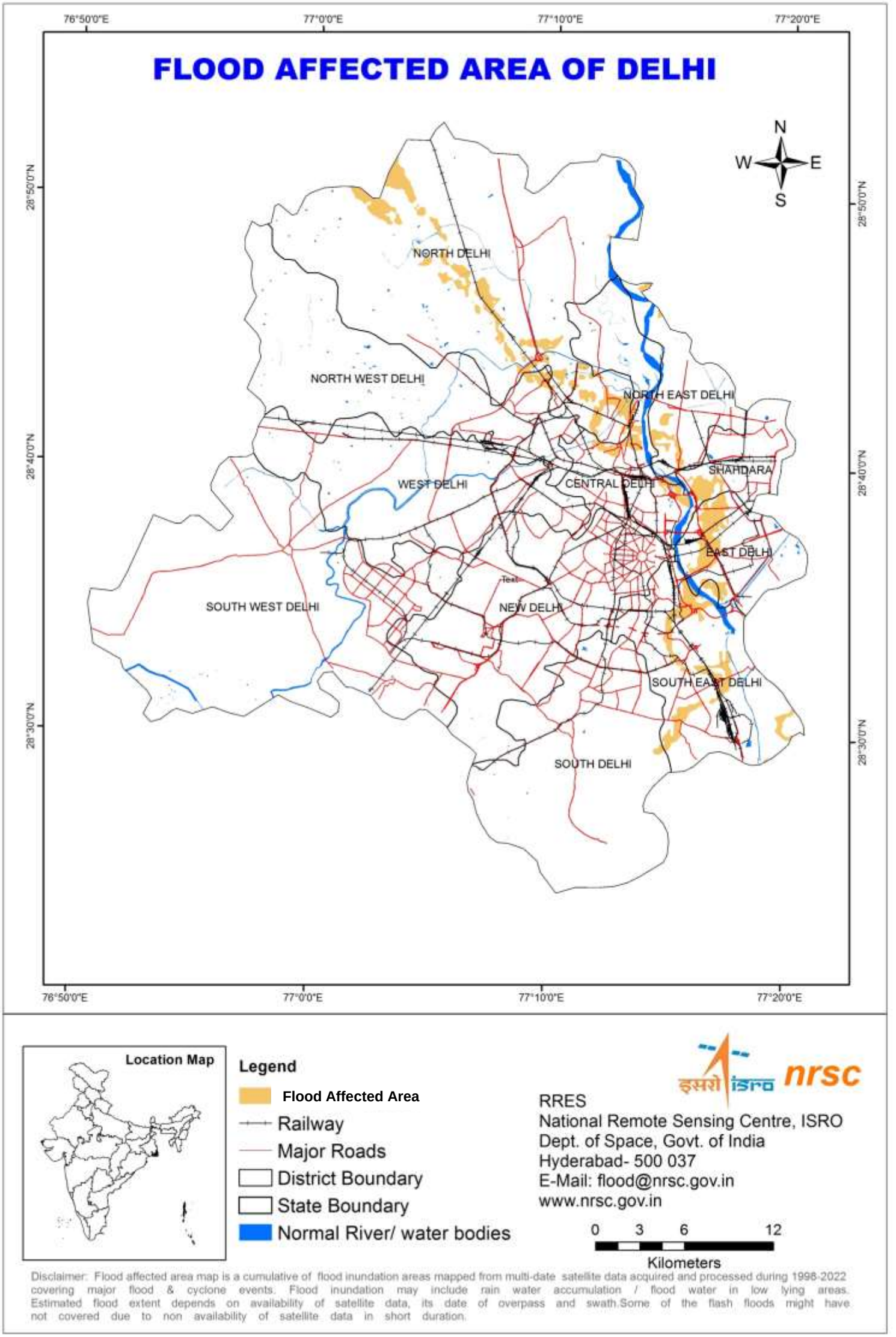


Fig.11.2 Flood Affected Area of Delhi

12. Gujarat

Gujarat is a state along the western coast of India. Its coastline is nearly 1,600 km and is the longest in the country, most of which lies on the Kathiawar peninsula. The State falls in the sub-tropical climate zone and experiences sub-humid climate in southern Gujarat (South of River Narmada), moderately humid climate in central Gujarat (between Narmada and Sabarmati rivers), humid and sultry climate in the coastal region (south facing coastal region of Saurashtra), dry climate in regions of central Gujarat (north of Ahmedabad and part of central Saurashtra) and arid and semi-arid climate in north Gujarat and Kutch.

Physiography of Gujarat state can be divided it into five parts namely (i) Plains: The major part of Gujarat consists of plains. These plains are made up of alluvial soil and are so very fertile. The plains of south Gujarat and central Gujarat are more fertile. The population is also very dense here. (ii) Hilly and Mountainous Areas: The hills and mountains are divided into three regions: Tal Gujarat Hills, Saurashtra Hills and Kutch Hills. (iii) Plateaus: Plateaus are landforms which are higher than the sea level and are flat like plains in the upper part. The middle part of Kutch and Saurashtra are plateaus. The plateau of Saurashtra is high in the middle while sloping and low towards the sea shore. (iv) Deserts: The deserts of Kutch are not sandy but full of salt. Coastal Plains: Gujarat state has a coastline of 1,600 km which is very useful for international trade.

Gujarat is a state in western India, and it is a home to several rivers and some of the major rivers in this state are given below : Sabarmati River: It originates in the Aravalli Range and flows through the city of Ahmedabad before emptying into the Gulf of Khambhat., Narmada River: It is one of the longest rivers in India, and it flows through Gujarat before emptying into the Arabian Sea. The Narmada is considered a sacred river in Hinduism, and many temples and shrines are located on its banks., Mahi River: It originates in Madhya Pradesh and flows through Gujarat before emptying into the Arabian Sea. The Mahi is known for its scenic beauty and is a popular destination for river rafting., Tapi River: It originates in the Satpura Range and flows through Gujarat before emptying into the Arabian Sea. The Tapi is also known as the Tapti River and is one of the major rivers in western India., Damanganga River: It originates in the Western Ghats and flows through Gujarat before emptying into the Arabian Sea. The Damanganga is also known as the Daman Ganga River and is a major source of water for the region.

12.1 Flood Problem in Gujarat

Major floods that have affected in the State are listed in Table.12.1 for which satellite derived spatial flood inundation maps were generated and disseminated to State / Central Government Disaster Support Management Organizations by NRSC, ISRO.

11.2. Flood Affected Area in Gujarat

Cumulative flood inundation maps were utilised for generation of map of total flood affected area in Gujarat and is estimated as 5,17,770 ha. Flood Affected Area Map is shown in Figure.12.1. and District wise flood affected area statistics are shown in Table. 12.2. Ahmedabad district has flood affected area greater than 1,00,000 ha, 2 districts in between 50000-100000 ha, 3 districts in between 25000-50000 ha, 3 districts in between 10000- 25000 ha and 7 districts <10000 ha in Gujarat State

Table.12.1 . Major flood events in Gujarat state

	Year	Description of the flood event	Districts affected
1	2005	Floods occurred during 2nd -11th July 2005 due to rise in water levels in Vishwamitri and Narmada rivers	11
2	2006	Floods occurred during 2nd -24th August 2006 due to heavy rains	7
3	2007	Floods occurred during 2nd week of July , 2nd week of Ag 2007 due to heavy rains	6
4	2008	Floods were reported in Gujarat in 3rd week September 2008 due to heavy rains	6
5	2009	Floods were reported in Gujarat in the last week of July 2009 due to heavy rains during 24-27th, Sep 2009 and also due to high tide scenario.	2
6	2013	Floods were reported in Gujarat in the last week of September 2013 due to sudden rise in the water levels of the Vishwamitri river	1
7	2017	Floods were reported due to heavy rains during 25-26th Jul 2017	4
8	2018	Floods were reported due to heavy rains during 1st week of August 2019 with many rivers in Central and South Gujarat flowing near danger mark.	6
9	2020	Heavy rains lashed Gujarat during 4th week of August 2020. According to reports inundation due to heavy rains was reported in Ahmedabad, Gandhinagar, Patan, and Sarkhej districts in Gujarat	4
10	2021	Heavy rains lashed Gujarat during 17-22nd May 21 under the influence of Cyclone Tauktae. It was an Extremely Severe Cyclonic storm and became the strongest tropical cyclone	9

Table.12.2 District wise statistics of Flood affected area in Gujarat

Sl No.	District	Flood Affected Area (Ha)
1	Ahmadabad	233388
2	Patan	73062
3	Surendranagar	54671
4	Anand	36385
5	Bharuch	29173
6	Bhavnagar	28264
7	Amreli	21910
8	Botad	17254
9	Kheda	17161

S. No.	District	Flood Affected Area (Ha)
10	Mahesana	2544
11	Banas Kantha	1242
12	Kachchh	1029
13	Gir Somnath	1027
14	Junagadh	311
15	Surat	212
16	Gandhinagar	139
TOTAL		**517770**

Glimpses of satellite images / flood inundation over the time period are depicted in this section.

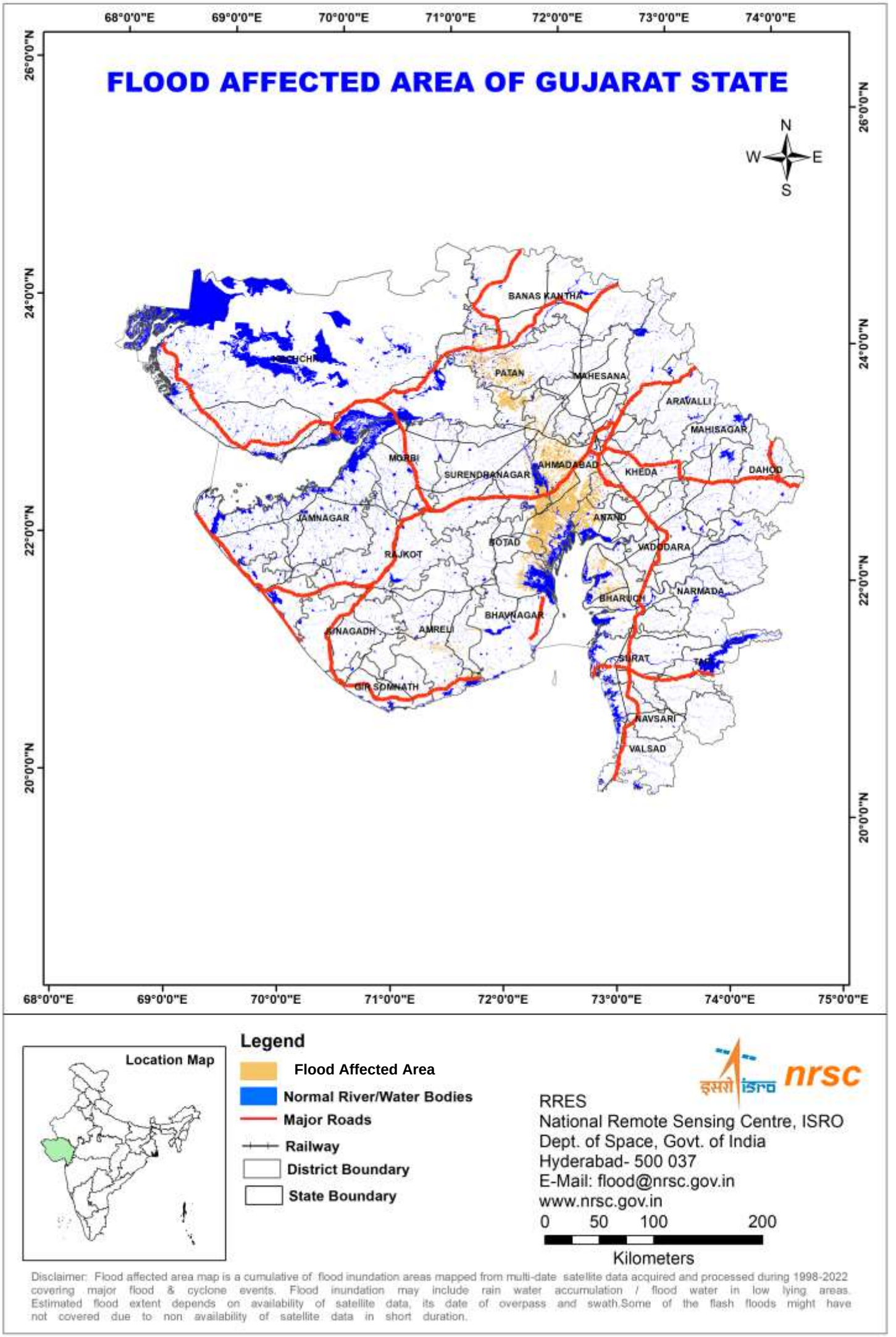
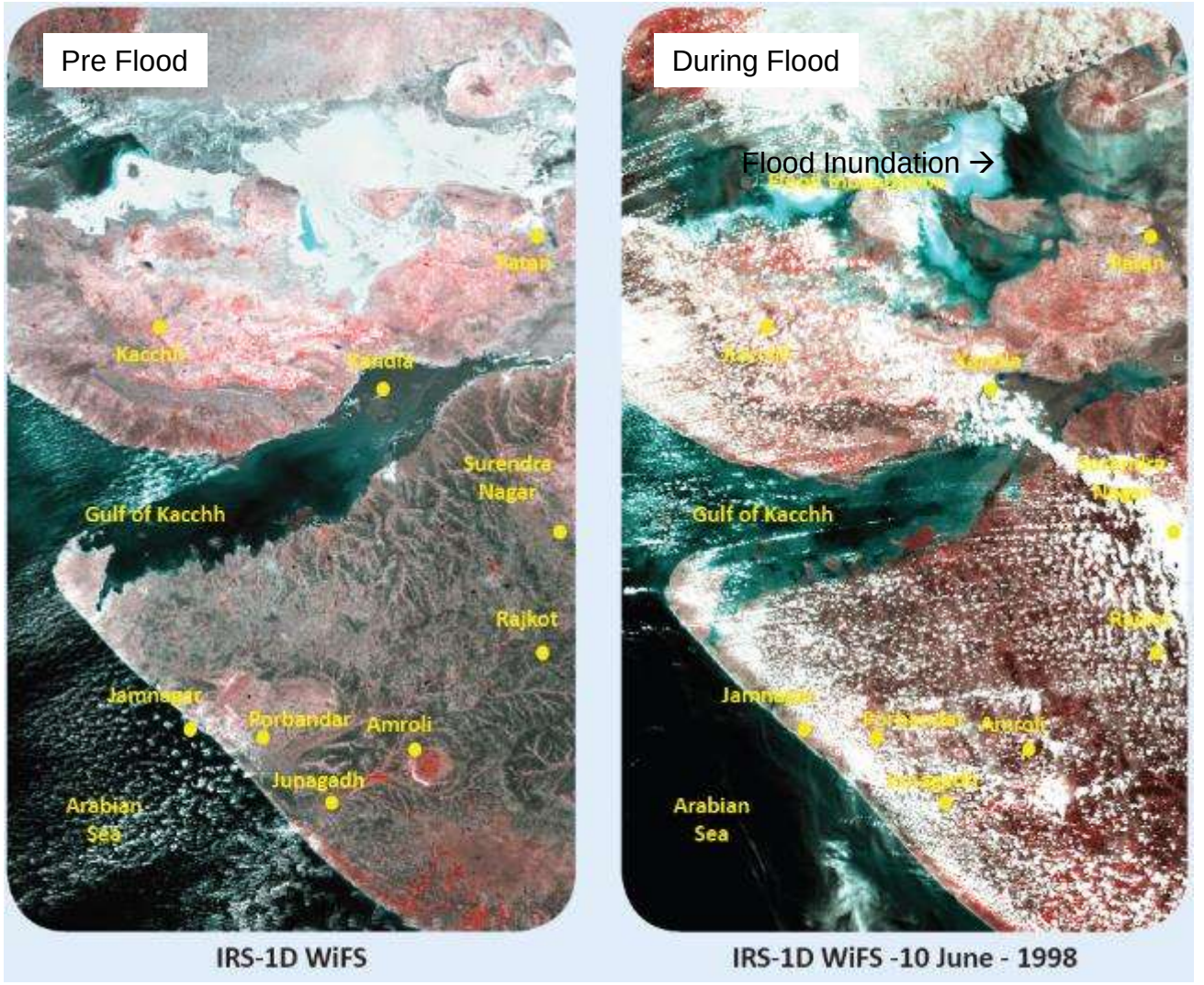
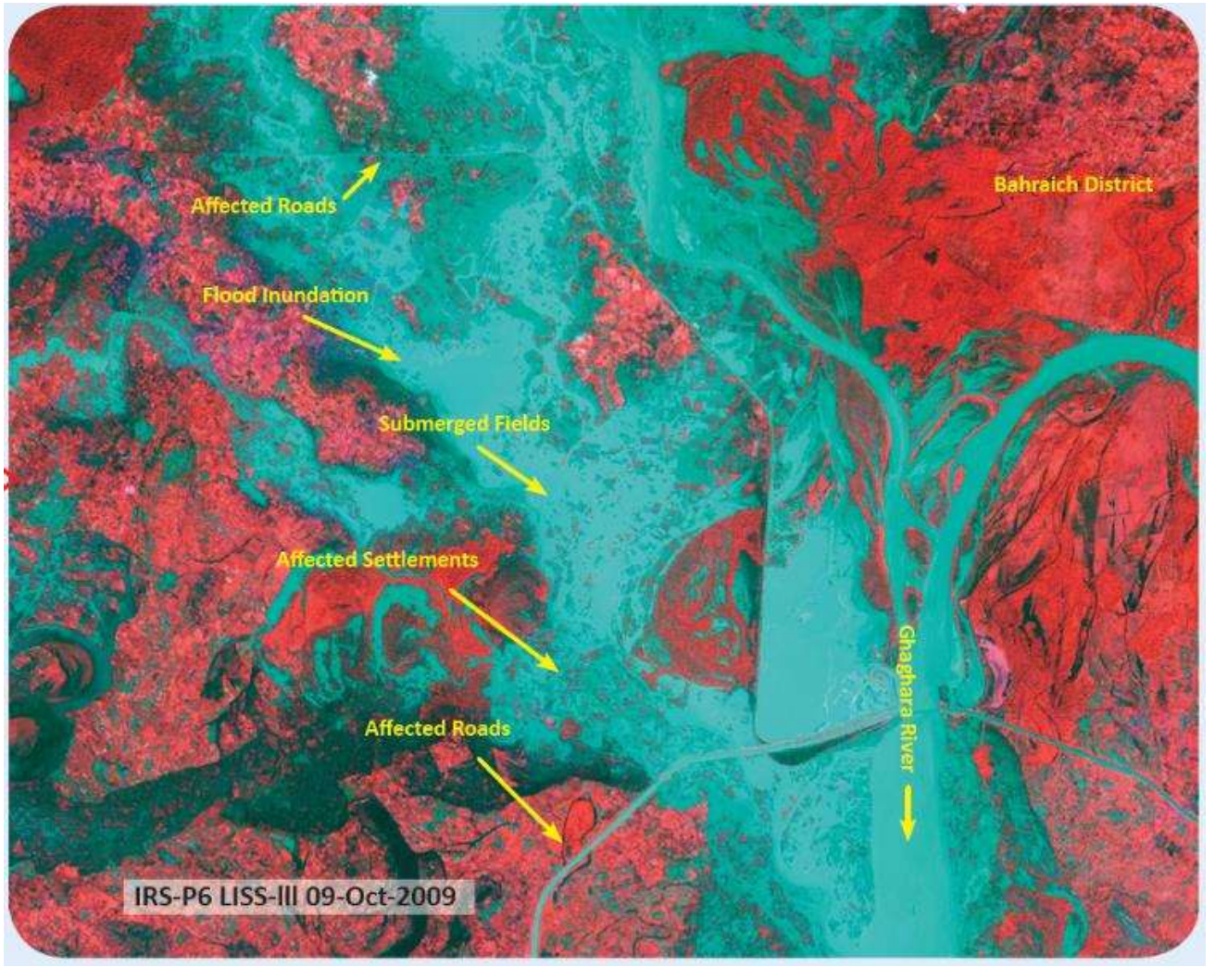


Fig.12.1 Flood affected area in Gujarat State


Pre Flood
During Flood
Flood Inundation →
Kacchh
Kandla
Surendra Nagar
Gulf of Kacchh
Rajkot
Jamnagar
Porbandar
Amroli
Jupagadh
Arabian Sea
IRS-1D WiFS
IRS-1D WiFS -10 June - 1998


Affected Roads
Flood Inundation
Submerged Fields
Affected Settlements
Affected Roads
Bahraich District
Ghaghara River
IRS-P6 LISS-III 09-Oct-2009

13. Haryana

Haryana is a state in northern India, and it is not directly located on any major river. However, it is situated in the northern plains of India and is surrounded by several states that are home to some of the country's most significant rivers. Some of the major rivers that flow near Haryana or through neighboring states include: Yamuna River - The Yamuna is one of the largest rivers in India and flows through the neighboring state of Uttar Pradesh. Ghaggar River - The Ghaggar is a seasonal river that flows through the states of Haryana, Punjab, and Rajasthan. Markanda River - The Markanda is a tributary of the Ghaggar River and flows through the states of Haryana and Punjab. Sahibi River - The Sahibi is a small river that originates in the Aravalli Range in Rajasthan and flows through Haryana before joining the Yamuna River. The rainfall in the region is low and erratic except in parts of Karnal, Kurukshetra and Ambala Districts. The climate is arid to semi-arid with an average rainfall of 354.5 mm. Around 29% of rainfall is received during the months from July to September as a result of the monsoon.

13.1 Flood Problem in Haryana

Floods have been a recurrent phenomenon in Haryana from time immemorial. Many parts of Haryana state are prone to flooding and experiance devastating floods in the years 1977, 1978, 1980, 1983, 1988, 1993, 1995 and 1996. Floods have been causing extensive damage not only to standing crops but also loss of lives and cattle. The floods in Haryana occur because of some natural reasons such as its physiographic situation that makes a depressional saucer shape zone around the Delhi-Rohtak-Hisar-Sirsa axis and poor natural drainage system sometimes heavy precipitation becomes a major contributing factor in causing flood as such in case of Rohtak flood, 1995. The state receives an average annual rainfall of about 650 mm. The average annual rainfall varies from less than 300mm in the western and south western parts of Sirsa, Hisar and Bhiwani districts along the Rajasthan border to over 1100mm in the north-eastern Shivalik hilly tracts of Panchkula and Yamunanagar districts along Himachal Pradesh border. The problem of floods is further accentuated by the existence of human-made barriers such as road and canal networks, which obstruct the natural flow of water.

Major floods that have affected in the State are listed here in Table.13.1 for which satellite derived spatial flood inundation maps were generated and disseminated to State / Central Government Disaster Support Management Organisations by NRSC, ISRO.

Table.13.1 . Major flood events in Haryana state

	Year	Description of the flood event	Districts affected
1	2004	Floods hit Haryana due to continuous rains during the 6th -09th August 2004.	4
2	2010	Floods hit Haryana due to continuous rains du ring 9-19^{th,} Jul, 4-9th Aug , 12-26th Sep 2010	12
3	2018	Floods were reported in the state of Haryana due to heavy torrential rains during last week of July, 2018 .	2
4	2019	Floods were reported in the state of Haryana due to incessant rains during third week of August, 2019.	5

13.2 Flood Affected Area in Haryana

Cumulative flood inundation maps were utilised for generation of map of total flood affected area in Haryana and is estimated as 67,852 ha. Flood Affected Area Map is shown in Figure.13.1 and district wise flood affected area statistics are given in Table. 13.2. Six districts in Haryana has flood affected area <10000 ha.

Table.13.2 District wise statistics of Flood affected area in Haryana

S. No.	District	Flood Affected Area (ha)
1	Kaithal	27185
2	Palwal	10474
3	Kurukshetra	10271
4	Sonipat	8885
5	Faridabad	7085
6	Ambala	2271
7	Panipat	901
8	Karnal	575
9	Yamunanagar	205
TOTAL		**67852**

Glimpses of satellite images / flood inundation over the time period are depicted in this section.

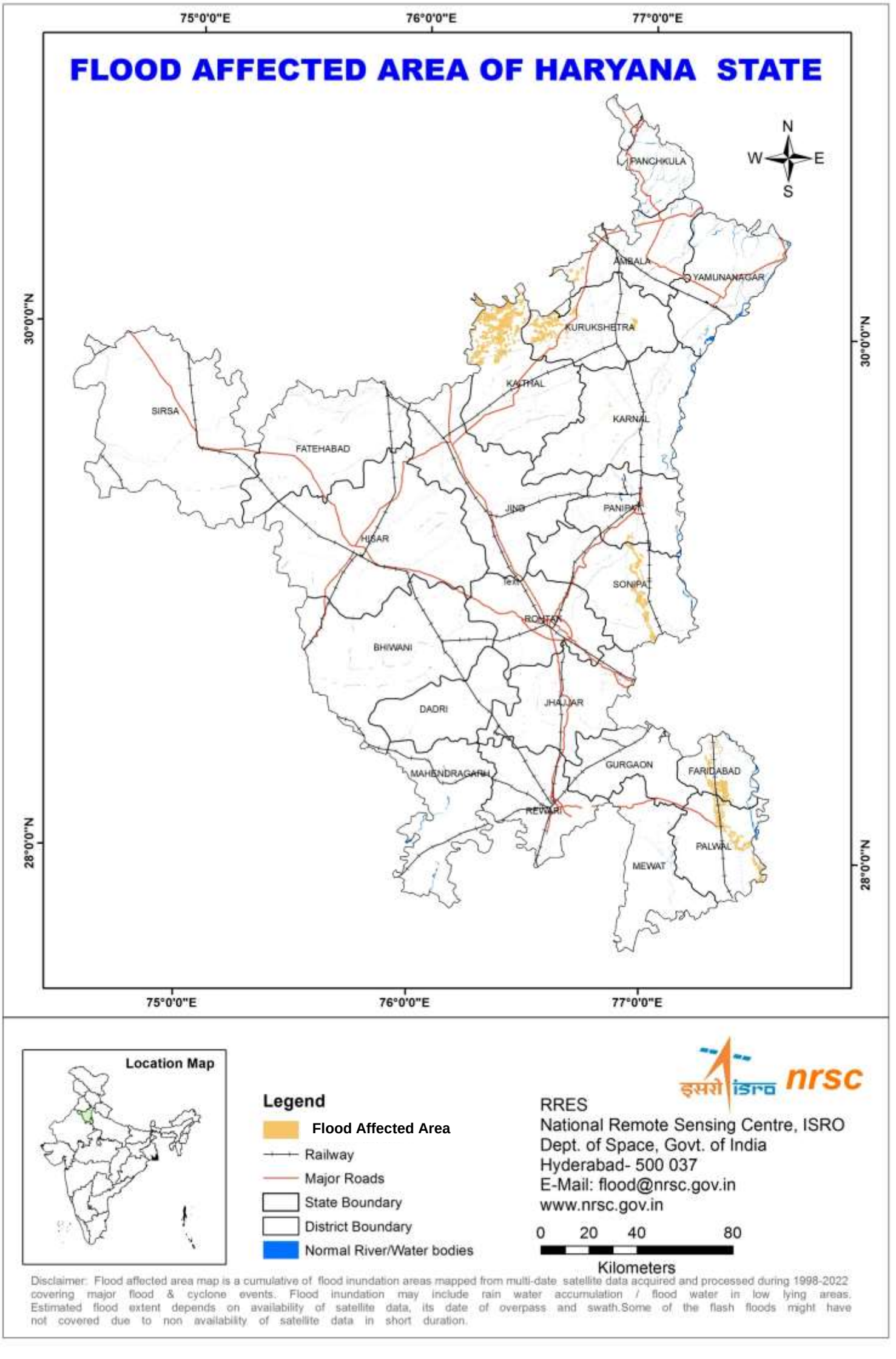
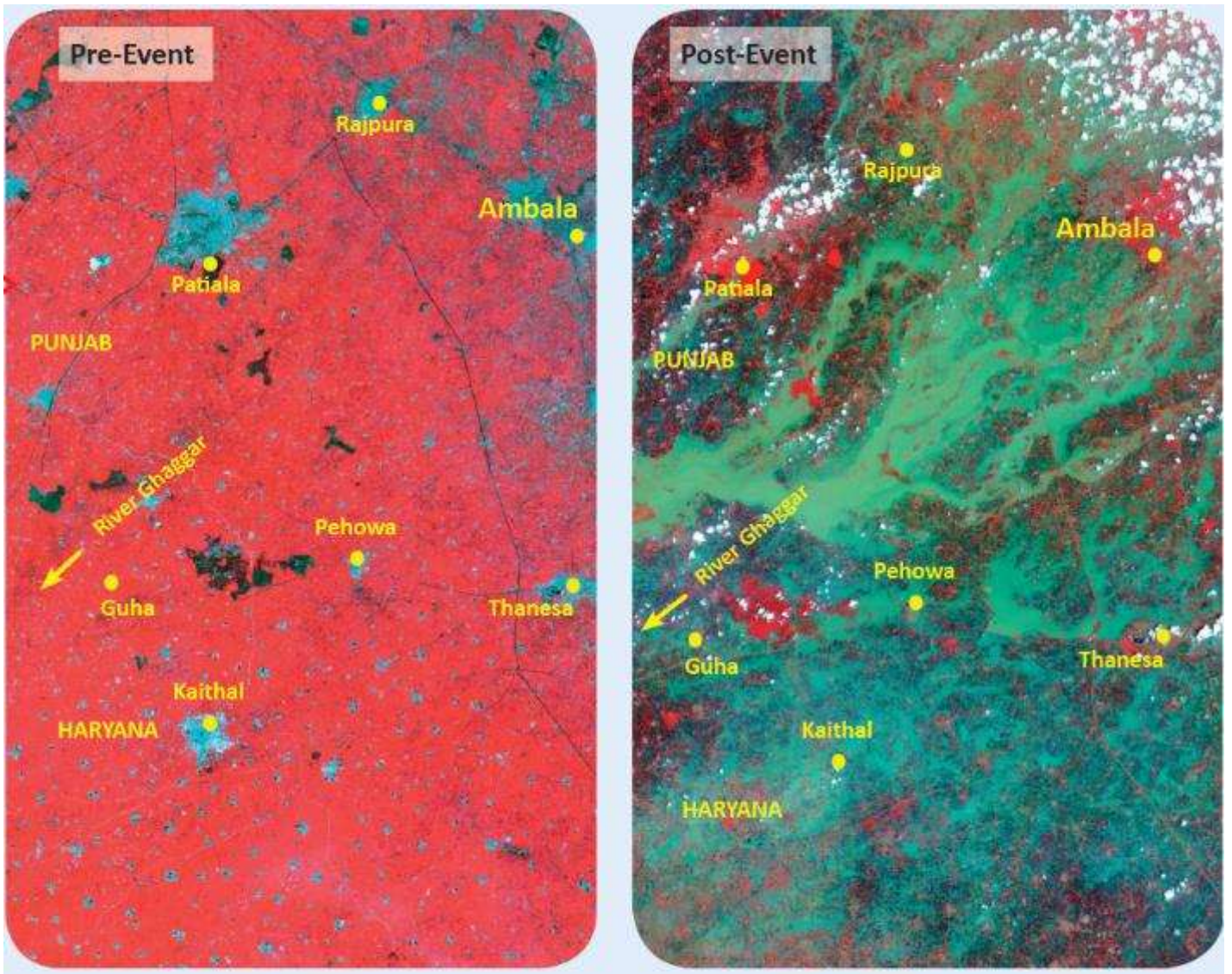
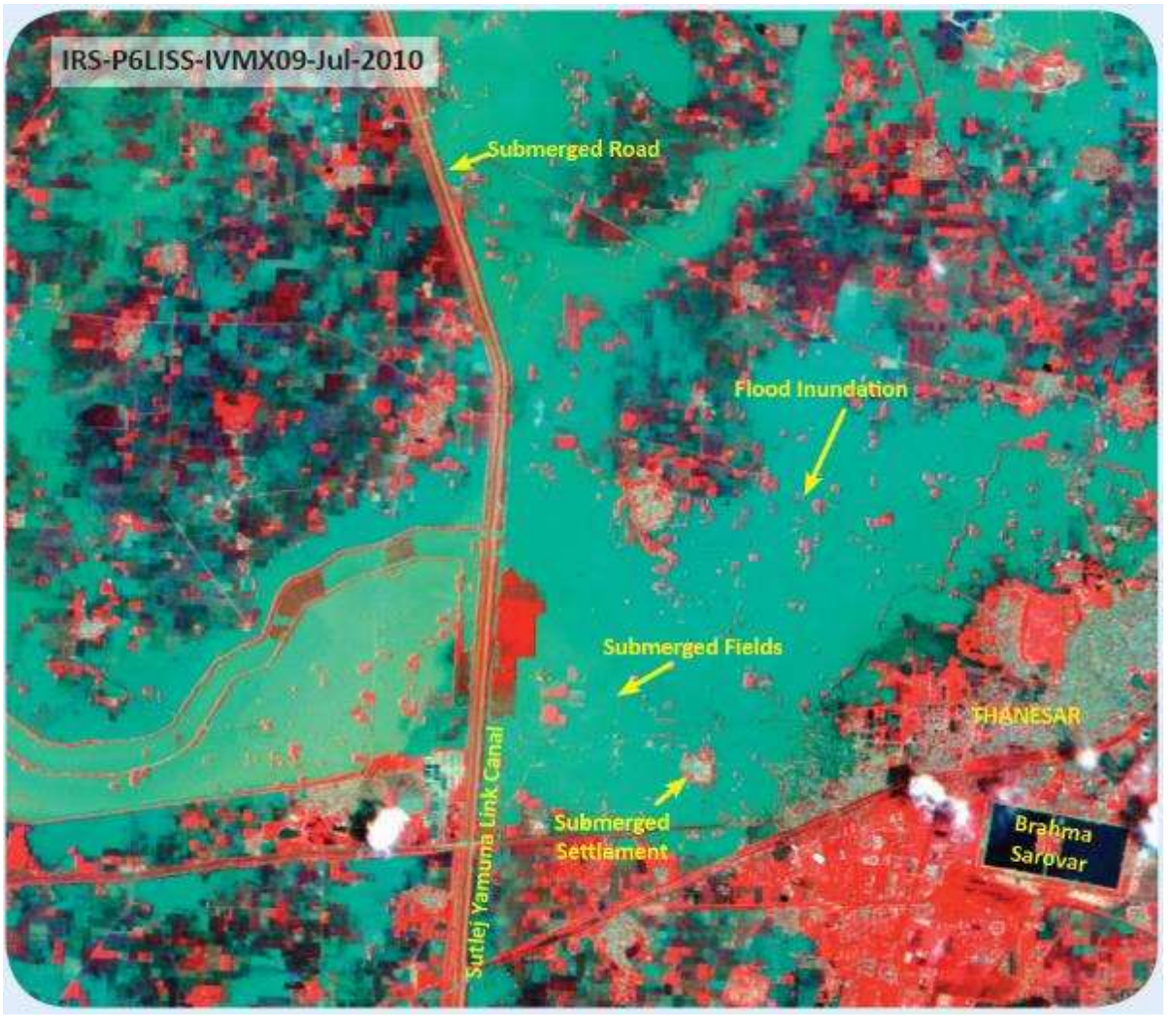


Fig.13.1 Flood affected area in Haryana State



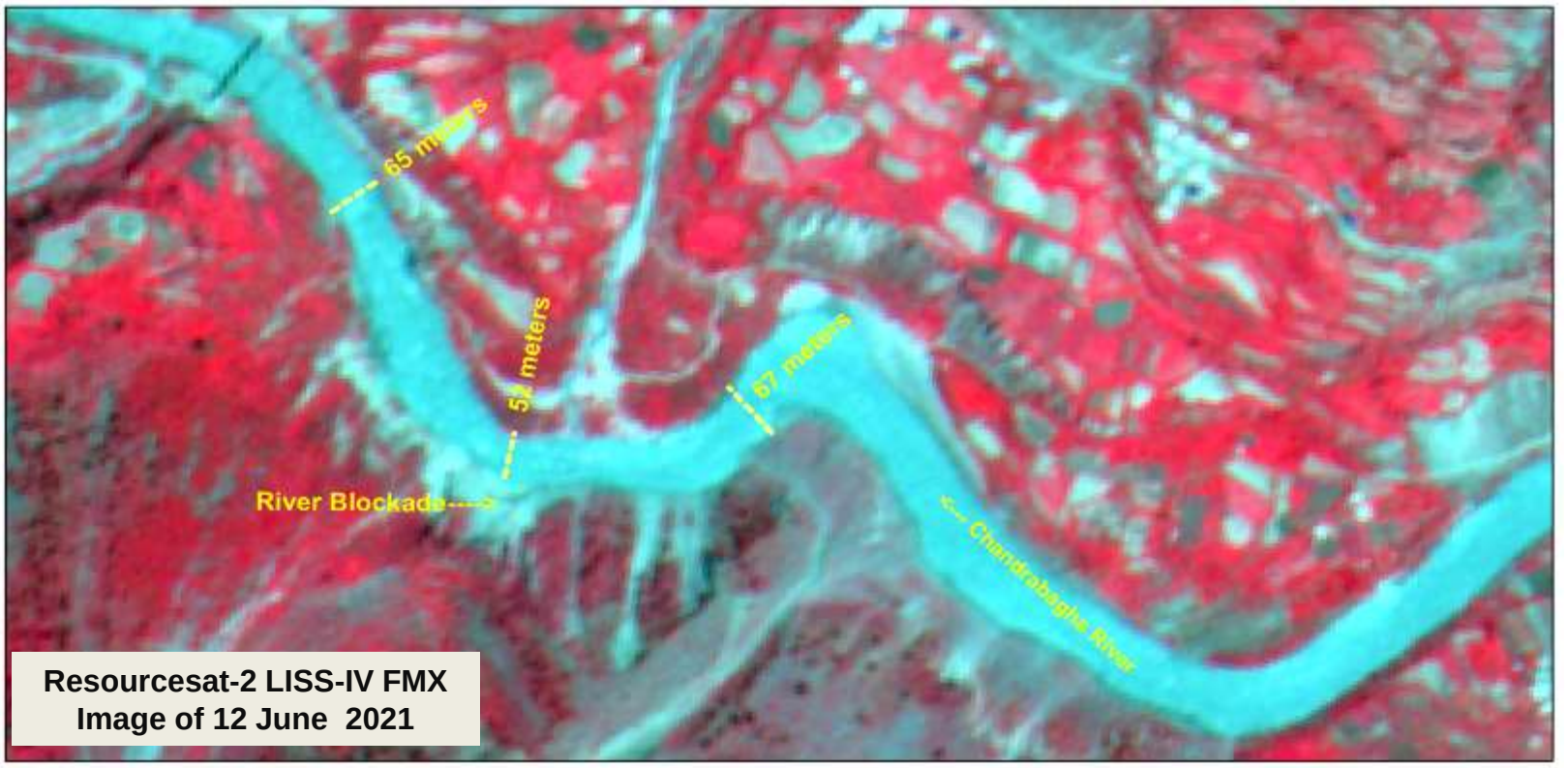
IRS-P6 AWiFS | IRS-P6 AWiFS 14 Jul-2010



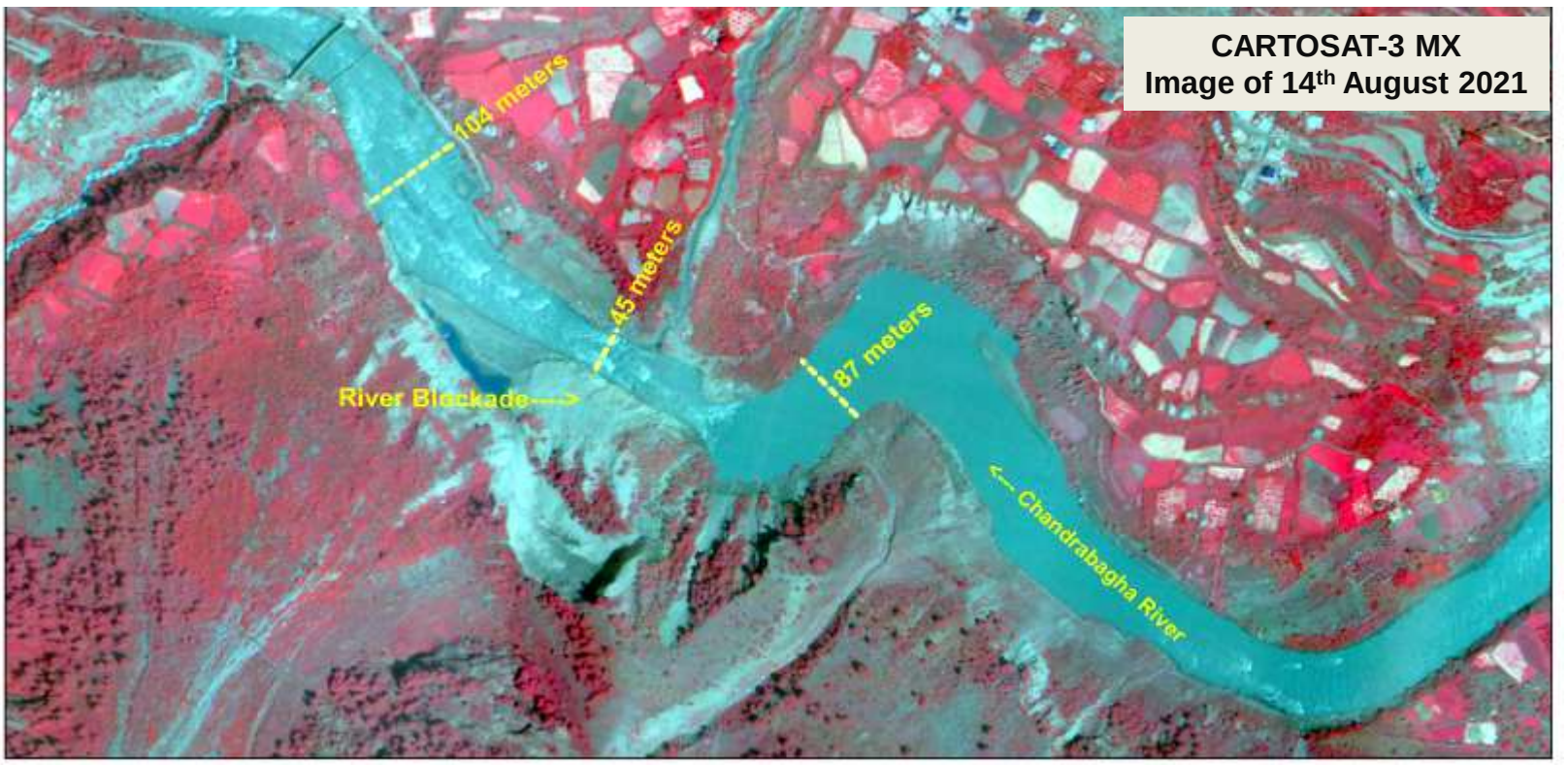
Himachal Pradesh

14. Himachal Pradesh

Himachal Pradesh is a north Indian state situated in the Western Himalayas. It is one of the thirteen mountain states and is characterized by an extreme landscape featuring several peaks and extensive river systems. Himachal Pradesh is the northern most state of India and shares borders with the union territories of Jammu and Kashmir and Ladakh to the north, and the states of Punjab to the west, Haryana to the southwest, Uttarakhand to the southeast and a very narrow border with Uttar Pradesh to the south. The state also shares an international border to the east with the Tibet Autonomous Region in China. Himachal Pradesh is spread across valleys with many perennial rivers flowing through them. Around 90% of the state's population lives in rural areas. Agriculture, horticulture, hydropower, and tourism are important constituents of the state's economy. The hilly state is almost universally electrified, with 99.5% of households having electricity as of 2016.



Resourcesat-2 LISS-IV FMX
Image of 12 June 2021



CARTOSAT-3 MX
Image of 14th August 2021

15. Jammu & Kashmir

Jammu and Kashmir is home to several valleys such as the Kashmir Valley, Tawi Valley, Chenab Valley, Poonch Valley, Sind Valley, and Lidder Valley. The Himalayas divide the Kashmir valley from the Tibetan plateau while the PirPanjal range, which encloses the valley from the west and the south, separates it from the Punjab Plain of the Indo-Gangetic Plain. Along the northeastern flank of the Valley runs the main range of the Himalayas. This valley has an average height of 1,850 metres above sea-level, but the surrounding PirPanjal range has an average elevation of 3,000 m. The southern Jammu region is mostly mountainous, with the Shivaliks, the middle and the great Himalayas running parallel to each other in a southeast-northwest direction. A narrow southwestern strip constitutes fertile plains.

The climate of Jammu and Kashmir varies with altitude and across regions. Southern and southwestern areas have a sub-tropical climate, with hot summers and cool winters. This region receives most of its rainfall during the monsoon season. In the east and north, summers are usually pleasant. The effect of the monsoon diminishes in areas lying to the leeward side of the PirPanjal, such as the Kashmir valley, and much of the rainfall happens in the spring season due to western disturbances. Winters are cold, with temperatures reaching sub-zero levels. Snowfall is common in the valley and the mountain areas. The average annual precipitation of the region is noted at 1100 mm.

Major rivers in Jammu & Kashmir are : Indus River: It is a Trans Himalayan river. It originates from the Mansarovar Lake in Tibet. It starts its itinerary at the meeting point of the Gar and Sengge rivers and penetrates the famous mountain range in southeast Ladakh, close to its meeting point with the Gurtang River. The altitude of the meeting point is 4,200 meters. The overall length of the river is 3,180 km. Jhelum River: It runs for an extensive stint across the Jammu region and ultimately pours into the Indus River. The water of the river contains a lot of mud.

15.1 Flood Problem in Jammu and Kashmir

In September 2014, the Kashmir region suffered disastrous floods across many of its districts caused by torrential rainfall. The Jammu and Kashmir union territory and adjoining areas received heavy rainfall from 2 September 2014, during the last stage of the monsoon in India. On 5 September, the Jhelum River in Srinagar was reported to be flowing at 6.83 m which was 1.34 m above the danger mark and at 10 m at Sangam in Anantnag district above the danger mark. The discharge rate in the river was recorded as 70,000 cusecs against the normal discharge of 25,000 cusecs. Jammu and Kashmir also experienced floods in 2015 due to heavy incessant rains causing rise in the water levels of Jhelum River. Major flood events in Jammu & Kashmir is listed in Table 15.1 for which satellite derived spatial flood inundation maps were generated and disseminated to state / central government disaster support management organizations by NRSC, ISRO.

Table.15.1 . Major flood events in Jammu & Kashmir

	Year	Description of the flood event	District Affected
1	2005	Floods occurred during 2nd week of July 2005 due to heavy rains and rise in water levels in Tawi, Chenab	4
2	2006	Floods occurred during 2nd week of September 2006 due to rise in water levels in Jhelum River, rivulets and streams of the vally	1
3	2007	Floods were reported in the state due to heavy rainfall and cloudburst during last week of March, 2007	1
4	2010	A cloudburst was reported near Leh on August 6th, 2010 leading to flash flood and mud slides	2
5	2014	Jammu & Kashmir experienced the worst floods in the past 60 years during 1st week of September 2014 due to unprecedented and intense rains. The Jhelum River and its trubutaries.	5

15.2 Flood Affected Area in Jammu and Kashmir

Cumulative flood inundation maps were utilised for generation of map of total flood affected area in Jammu and Kashmir and is estimated as 43,022ha. Flood Affected Area Map is shown in Figure.15.1. and District wise flood affected area statistics are shown in Table. 15.2.

Table.15.2 District wise statistics of Flood affected area in Jammu & Kashmir

S. No.	District	Flood Affected Area (Ha)
1	Badgam	9989
2	Bandipore	9475
3	Baramula	8058
4	Pulwama	6791
5	Srinagar	3415
6	Anantnag	2146
7	Ganderbal	1833
8	Kupwara	801
9	Kulgam	395
10	Shupiyan	119
TOTAL		**43022**

Glimpses of satellite images / flood inundation over the time period are depicted in this section.

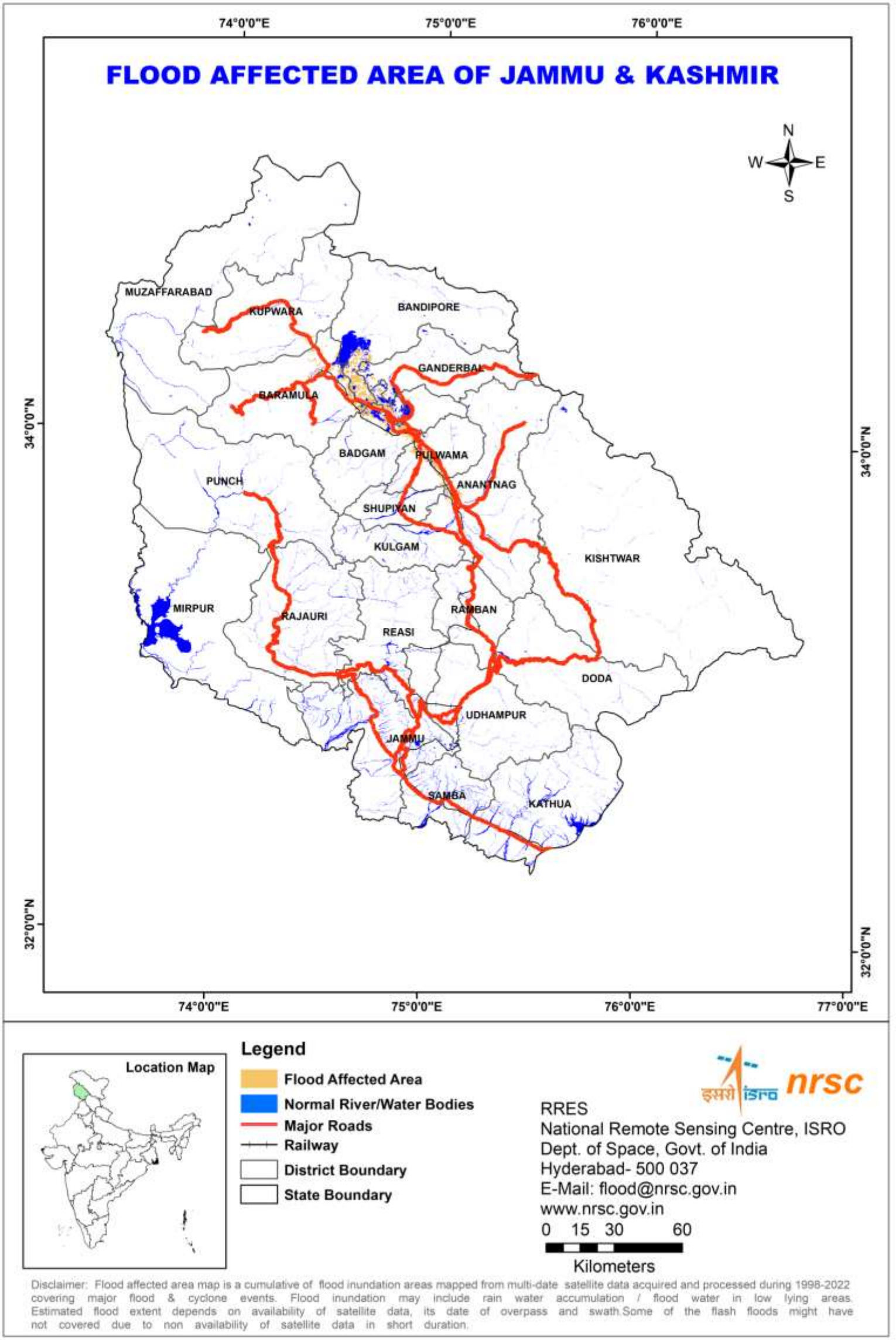
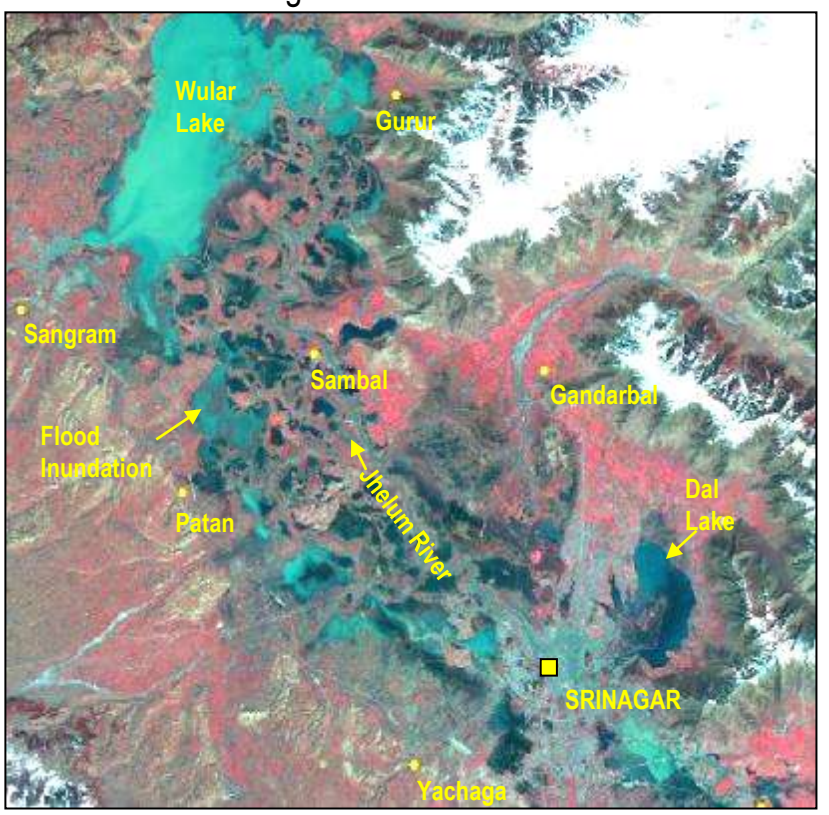
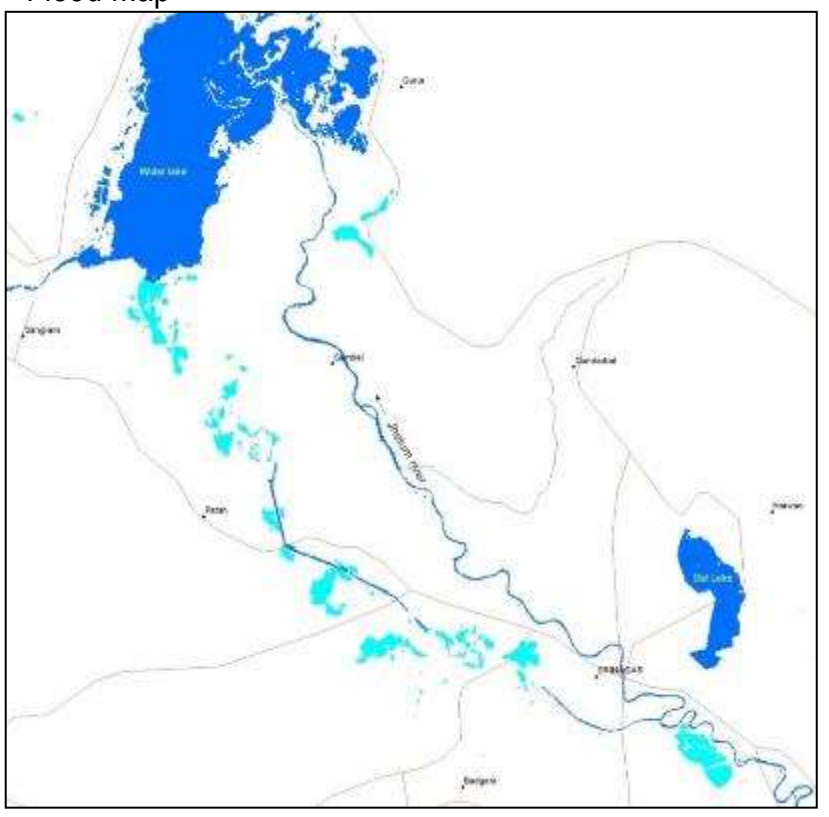


Fig.15.1 Flood Affected Area of Jammu & Kashmir

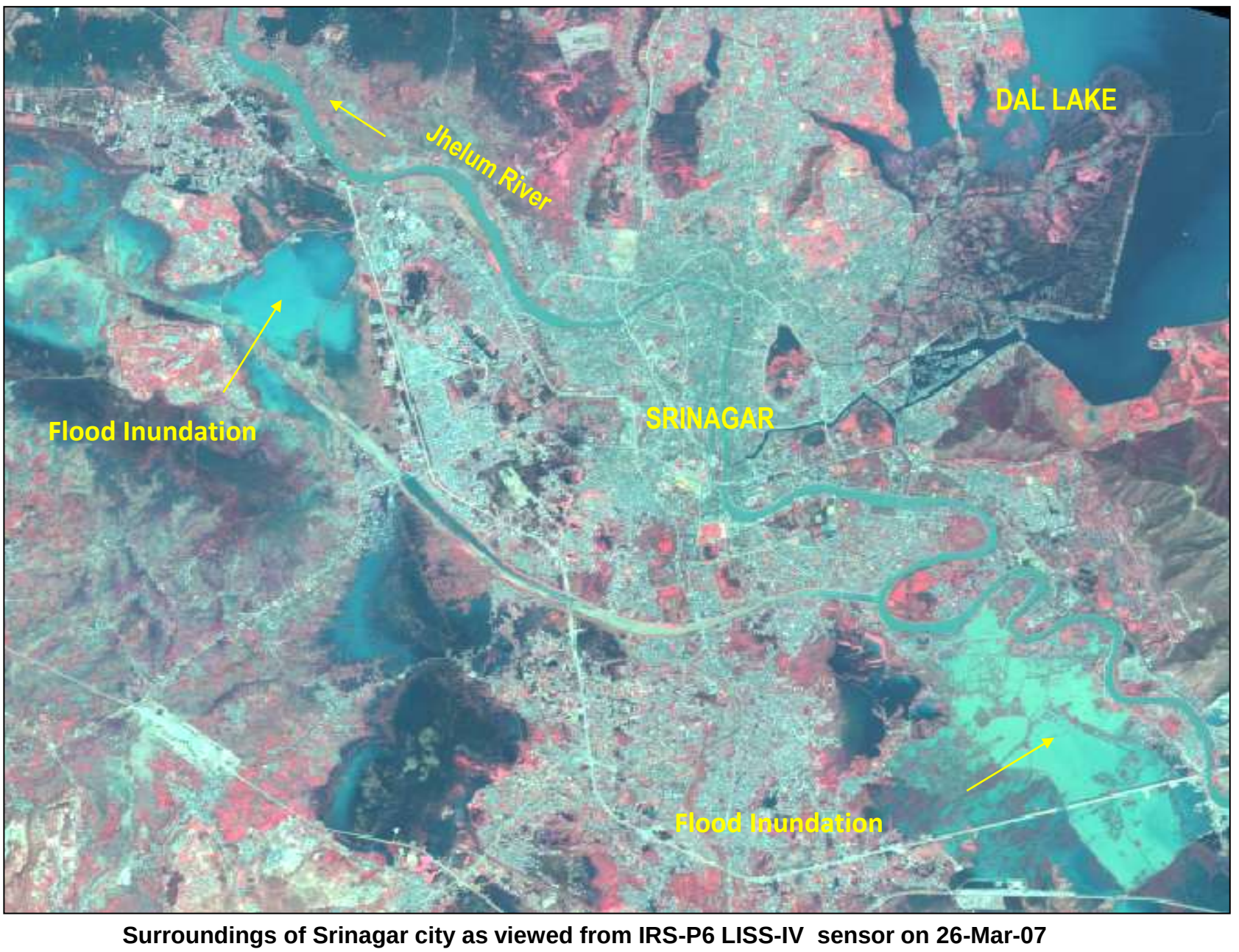
IRS-P6 AWiFS Image of 26-Mar-07



Flood Map



Flood situation as on 26-Mar-2007

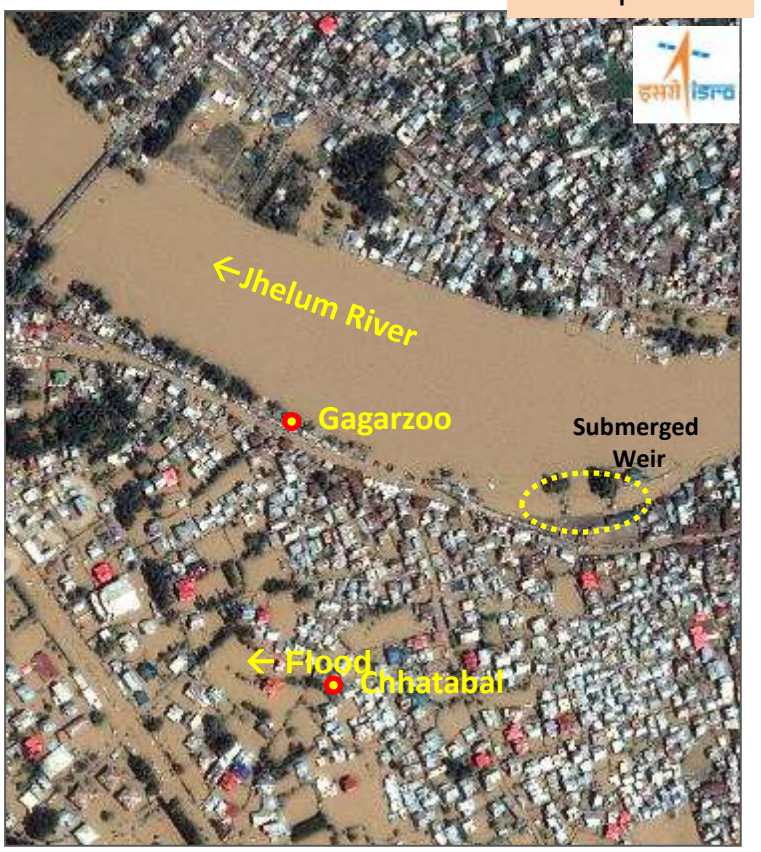


Surroundings of Srinagar city as viewed from IRS-P6 LISS-IV sensor on 26-Mar-07

Flooding Around Chhatabal Area, Srinagar, J&K : Submerged Weir

25-May-2014

10-Sep-2014



Scale

Flood Inundation 0 100 m

Flooding Around Assembly Area, Srinagar, J&K

25-May-2014

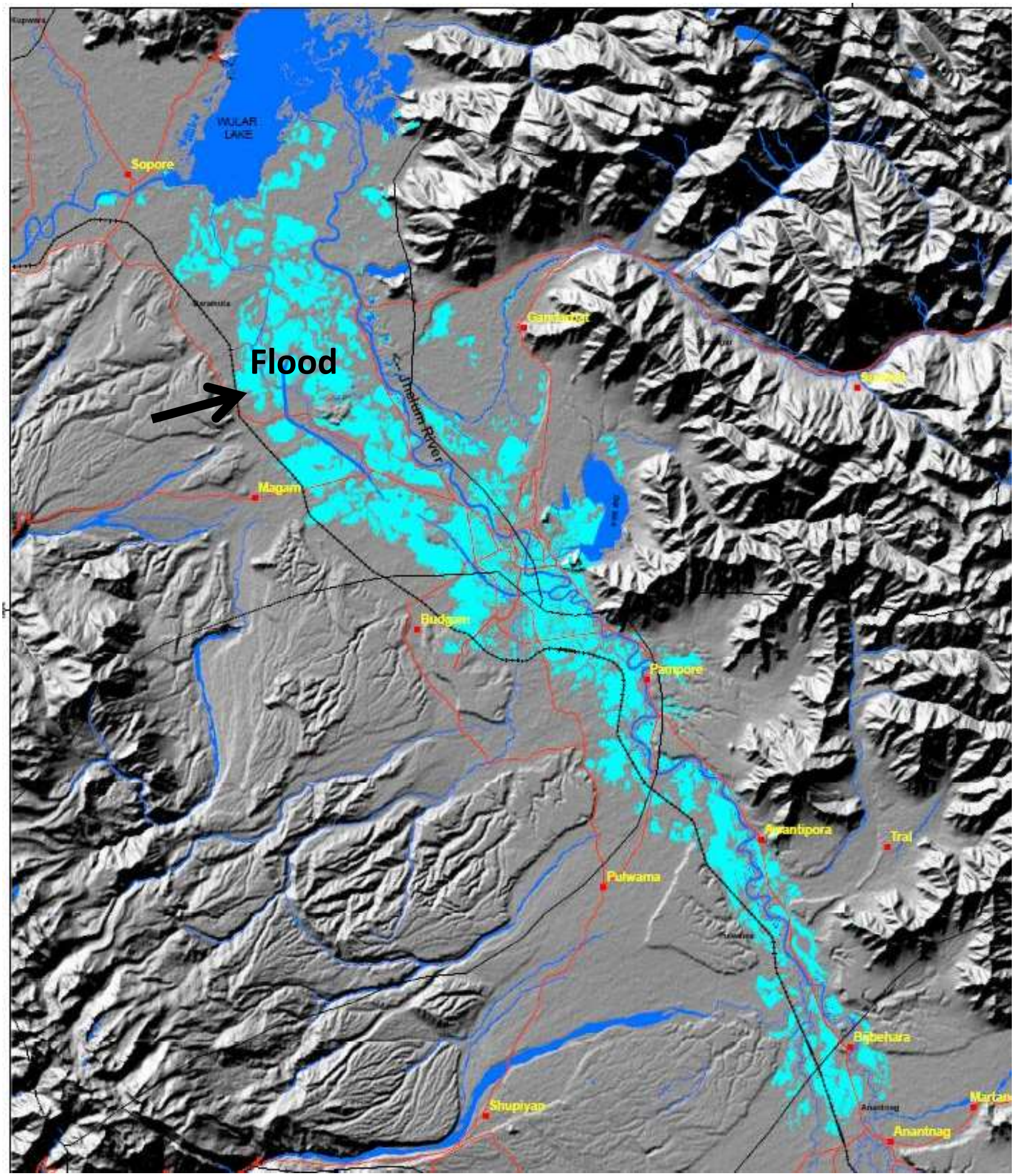
10-Sep-2014

Scale

Flood Inundation 0 100 m

Cumulative Flood Inundated Area in part of Jammu & Kashmir

Based on the analysis of RISAT, Cartosat-1, Resourcesat & Radarsat data of 08, 09, 10, 12, 15, 17, 19, 20 & 21 – September, 2014



Flood inundation

16. Jharkhand

Jharkhand is a state in eastern India and shares its border with the states of West Bengal to the east, Chhattisgarh to the west, Uttar Pradesh to the northwest, Bihar to the north and Odisha to the south. Climate of Jharkhand varies from Humid subtropical in the north to tropical wet and dry in the south-east. The main seasons are summer, rainy, autumn, winter and spring. The southwest monsoon, from mid-June to October, brings nearly all the state's annual rainfall, which ranges from about 1,000 mm in the west-central part of the state to more than 1,500 mm in the southwest. Nearly half of the annual precipitation falls in July and August.

Some of the major rivers that flow through Jharkhand are: Damodar River: It is the most important river in Jharkhand, originating from Chota Nagpur Plateau and flowing through the state before finally merging with the Hooghly River in West Bengal. Damodar River is also known as the "Sorrow of Bengal" due to its devastating nature.

Subarnarekha River: This river originates in the Chota Nagpur Plateau and flows through Jharkhand, West Bengal, and Odisha before finally merging with the Bay of Bengal. It is an important source of water for irrigation and domestic purposes. Brahmani River: This river originates from the Mahavir Pahar in Jharkhand and flows through Odisha before merging with the Bay of Bengal. It is an important source of water for irrigation and hydroelectric power generation. Kharkai River: It is a tributary of the Subarnarekha River and flows through the East Singhbhum and Seraikela Kharsawan districts of Jharkhand. South Koel River: This river originates from the Chota Nagpur Plateau and flows through Jharkhand and Odisha before finally merging with the Brahmani River. It is an important source of water for irrigation and hydroelectric power generation. North Koel River: It is also a tributary of the Brahmani River and flows through Jharkhand and Odisha. The river is known for its scenic beauty and is an important source of water for irrigation. Ganga River: Ganga passes through the north-eastern district of Sahebganj. Sahebganj and Pakur are the major cities on the banks of Ganga in Jharkhand. Son River : It originates in Amarkantak and the city of Sidhi is situated on its banks. North Koel River:It originates in Chota Nagpur plateau and flows through Daltonganj. Lilajan River:It is also known as Falgu River. It originates in Northern Chota Nagpur Plateau and flows through Gaya. Ajay River:It originates in Munger and flows through Purulia, Chittaranjan, Ilambazar and Jaydev Kenduli. Mayurakshi River:It originates in Trikut hill and the city of Suri is situated on its banks. Barakar River : It originates in Padma in Hazaribagh and flows through the districts of Koderma, Giridih, Hazaribagh, etc.

16.1 Flood Affected Area in Jharkhand

Cumulative flood inundation maps were utilised for generation of map of total flood affected area map in Jharkhand and is estimated as 2,966ha. Flood affected area map is shown in Figure.16.1. and district wise flood affected area statistics are given in Table. 16.1. Two districts in Jharkhand has flood affected area <10000 ha.

Table.16.1 District wise statistics of Flood affected area in Jharkhand

S. No.	District	Flood Affected Area (ha)
1	Sahibganj	2625
2	Pakur	341
	Total	**2966**

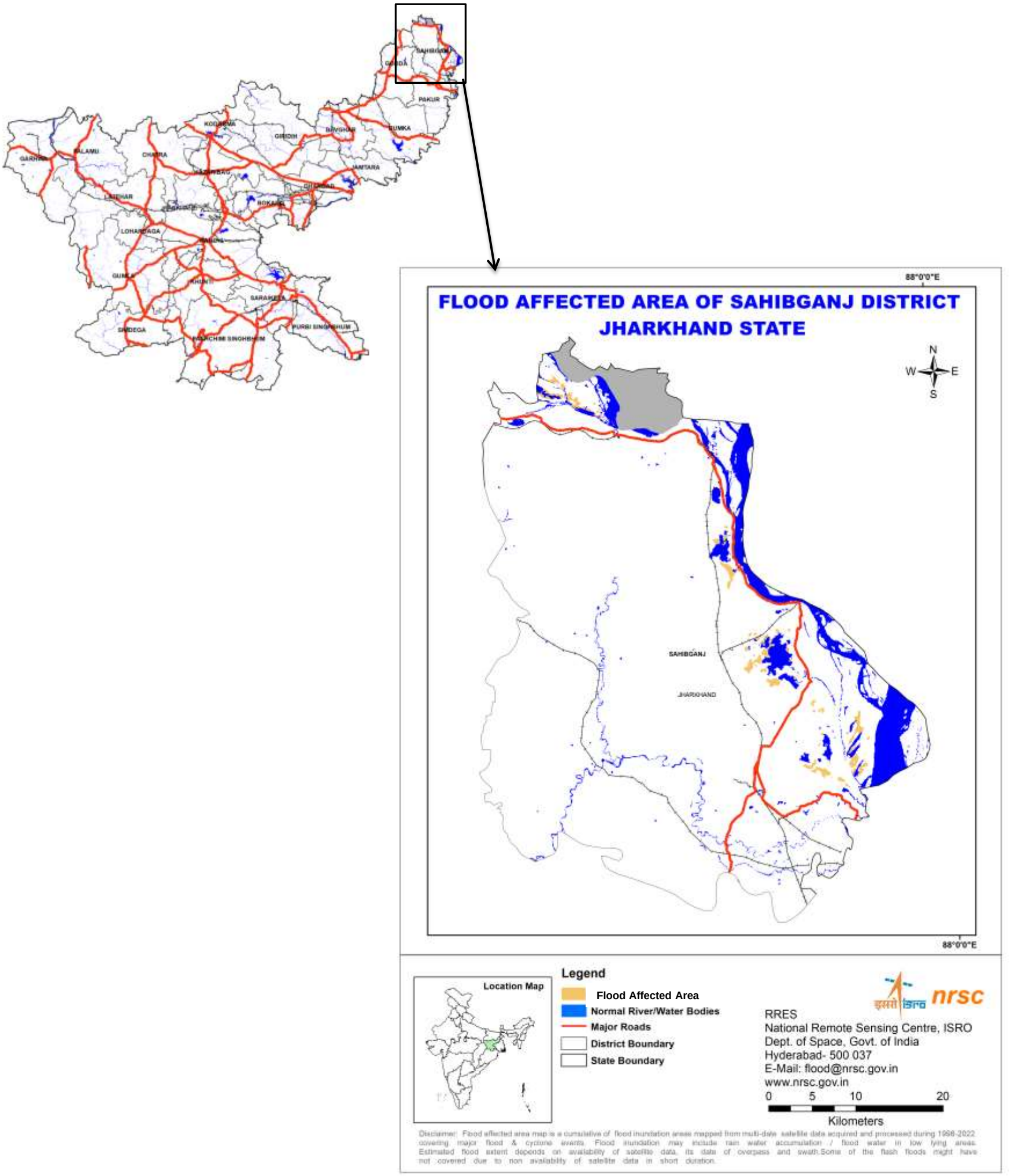


Fig.16.1 Flood affected area in Jharkhand State

17. Karnataka

Karnataka

Karnataka is a state in the southwestern region of India. Karnataka is bordered by the Lakshadweep Sea to the west, Goa to the northwest, Maharashtra to the north, Telangana to the northeast, Andhra Pradesh to the east, Tamil Nadu to the southeast, and Kerala to the southwest. The state can be divided into four physiographic landforms – the Northern Karnataka Plateau, the Central Karnataka Plateau, the Southern Karnataka Plateau and the Coastal Karnataka Region. The Northern Karnataka Plateau covers the districts of Belgaum, Bidar, Bijapur and Gulbarga. The area is mainly composed of the Deccan Trap. It represents an extensive deforested plateau landscape. The Northern Karnataka Plateau has an elevation of 300m to 600m from the sea level. The plateau slopes towards the east. The landscape is mainly covered with rich black cotton soils. The Central Karnataka Plateau is located between the Northern Karnataka Plateau and the Southern Karnataka Plateau. It consists of districts like Bellary, Chikmagalur, Chitradurga, Dharwad, Raichur and Shimoga. The elevation of the Central Karnataka Plateau varies between 450 metres and 700 metres. The general slope of this plateau is towards the east. The Southern Karnataka Plateau includes the districts of Bangalore Urban, Bangalore Rural, Hassan, Kodagu, Kolar, Mandya, Mysore and Tumkur. This plateau region is covered by a high degree of slope. It is encircled by the Western Ghats on the west and the south. The Southern Karnataka Plateau has a general elevation of 600m to 900m. But the Biligirirangan hills of Mysore district and the Brahmagiri range of Kodagu district have residual heights ranging between 1,500m to 1,750m.

Major rivers flowing through Karnataka are: Kaveri River: It is the largest river in the state and originates from the district of Coorg. Kabini River: It is a tributary of Kaveri, originates in Kerala and flows eastward. The river Kabini joins the Kaveri at Tirumakudal Narasipur. Krishna River: It is second largest river in peninsular India. It originates in Maharashtra and passes through Karnataka. Tungabhadra River: It is the chief tributary of Krishna River. Tungabhadra is formed in the district of Shimoga, by the union of the Tunga and the Bhadra rivers. The river Tungabhadra flows east across the Deccan Plateau, joining the Krishna in Andhra Pradesh state and then empties into the Bay of Bengal. Ghataprabha River: It begins in the Western Ghats and flows eastwards and joins the river Krishna. The river forms the well-known Gokak Falls in Belgaum District. Bhima River: It originates in the forest of Bhimashankar in Pune, and flows through the states of Maharashtra and Karnataka. It joins the Krishna near Kudlu in Raichur taluk. In addition to these, rivers such as Malaprabha, Manjra, Mandavi, Pennar, Sharavati etc. flow through Karnataka.

17.1 Flood Problem in Karnataka

Major flood events occurred in Karnataka states are listed in Table.17.1.

Table.17.1 . Major flood events in Karnataka state

	Year	Description of the flood event	Districts affected
1	2005	Floods occurred during 1st week of Aug 2005 due to heavy rainfall and subsequent water releases from Koyna and Ujjani dams	2
2	2009	Floods occurred during 1st week of October 2009 due to heavy rainfall and rise in water level in Krishna District	5
3	2013	Floods were reported in Karnataka state during last week of July, 2013 due to heavy rainfall. Krishna river at Alamatti Dam in Bijapur	2
4	2019	Heavy rains are reported in Karnataka during second week of August2019	16
5	2020	Floods due to heavy rains were reported thrice in Karnataka during 2020. 15-20th Aug ,3-20 th Sep,14-18th Oct	14
6	2022	Heavy rains were reported in Karnataka state during the last week of July 2022.	17

17.2 Flood Affected Area in Karnataka

Cumulative flood inundation maps were utilised for generation of map of total flood affected area in Karnataka and is estimated as 2,80,156 ha. Flood Affected Area Map is shown in Figure.17.1. and district wise flood affected area statistics are shown in Table. 17.2. One district in Karnataka has flood affected area between 50,000-1,00,000 ha, 2 districts between 25,000-50,000 ha, 5 districts between 10,000-25,000 ha and 18 districts <10000 ha.

Table.17.2 District wise statistics of Flood affected area in Karnataka

S. No.	District	Flood Affected Area (ha)
1	Belgaum	67033
2	Shimoga	37524
3	Bagalkot	33330
4	Davangere	20359
5	Haveri	18715
6	Mysore	17290
7	Bijapur / Vijayapura	13565
8	Bellary	11585
9	Yadgir	9224
10	Raichur	9174
11	Uttar Kannad	7236
12	Gulbarga	5609
13	Hassan	4303
14	Mandya	3900
15	Udupi	3674
16	Dharwad	3576
17	Gadag	3281
18	Chikmagalur	3150
19	Chamrajnagar	2020
20	Koppal	1926
21	Chitradurga	1248
22	Dakshin Kannad	920
23	Kodagu	695
24	Tumkur	301
25	Bidar	262
26	Bangalore Rural	257
TOTAL		**280156**

Glimpses of satellite images / flood inundation over the time period are depicted in this section.

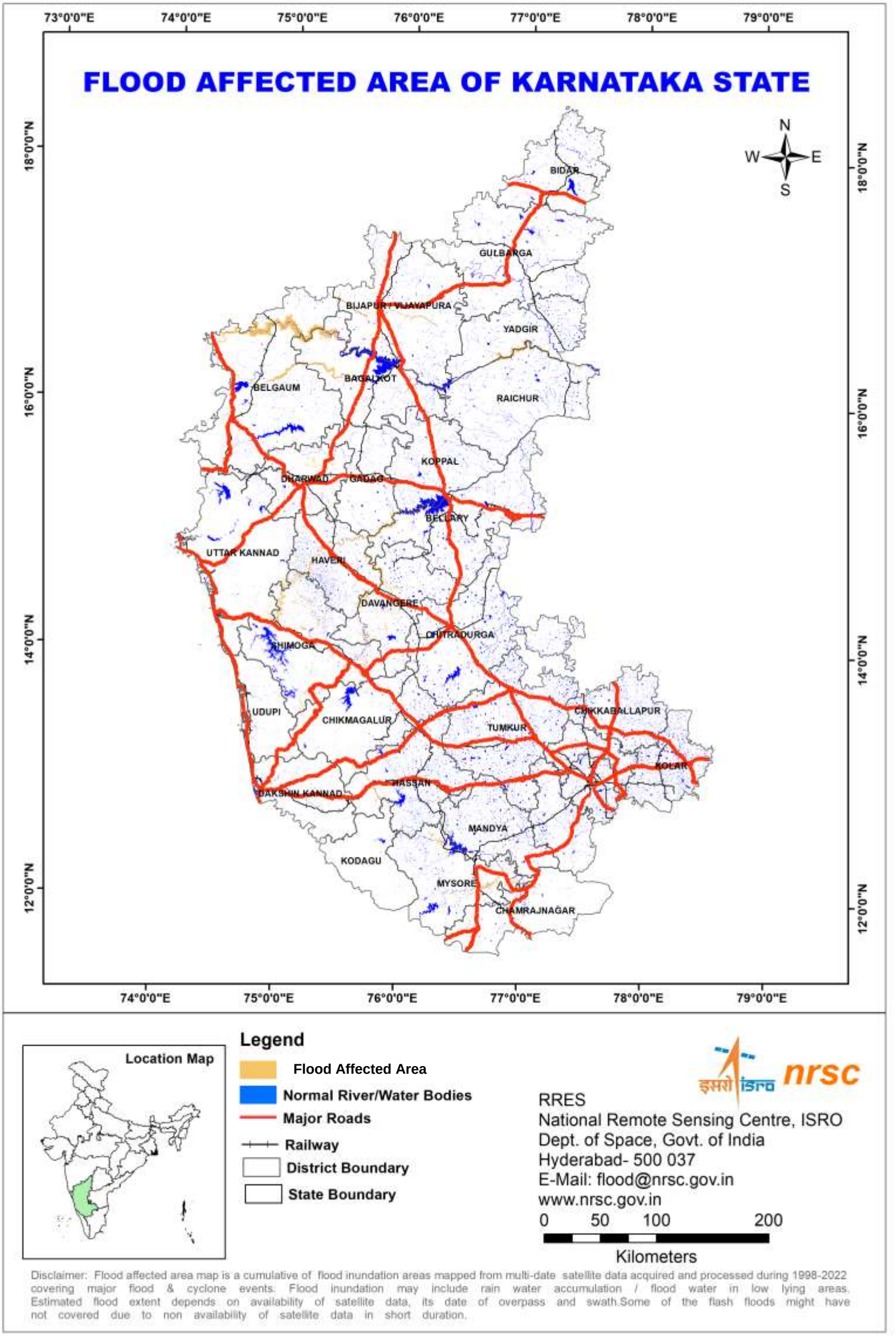
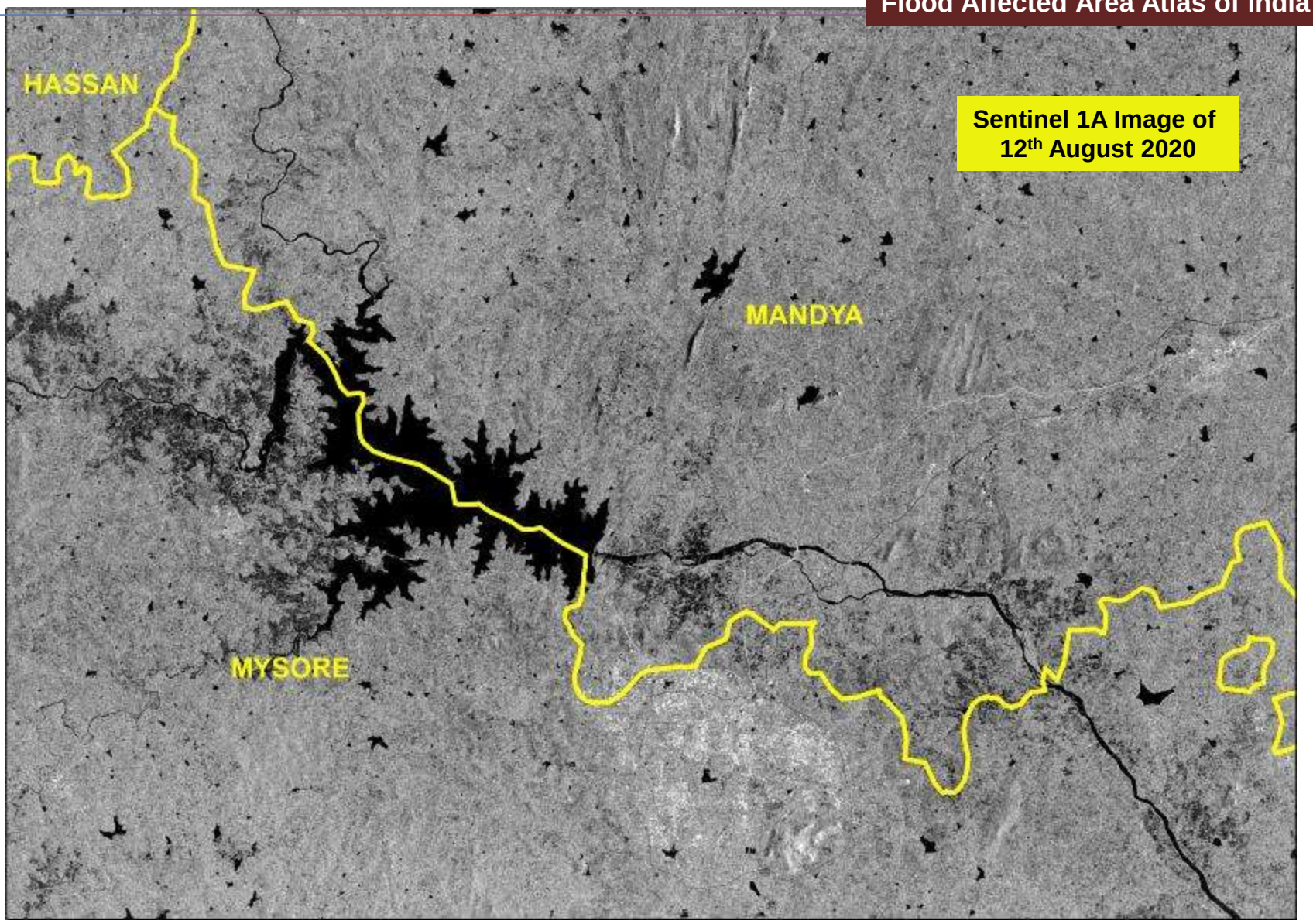
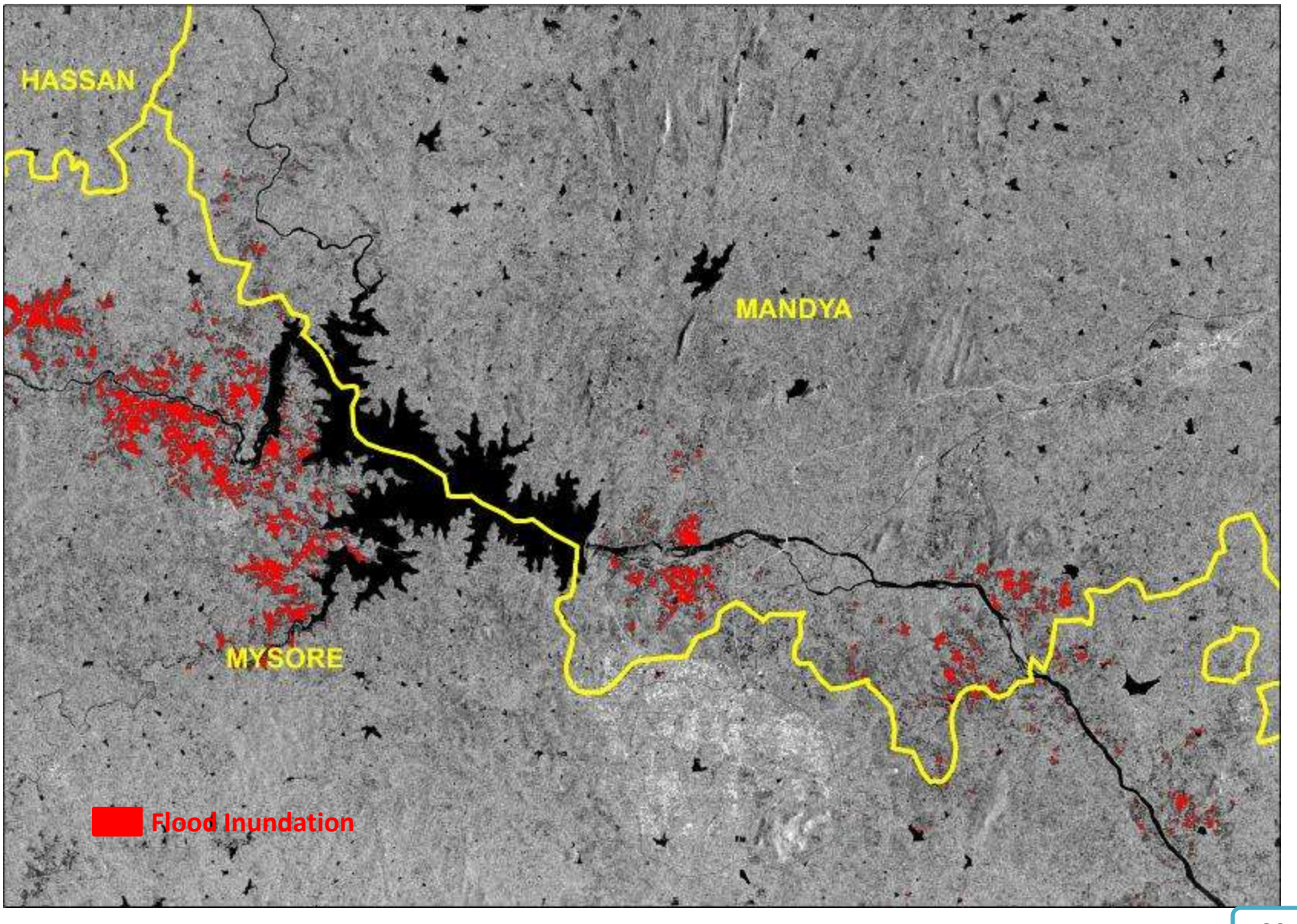
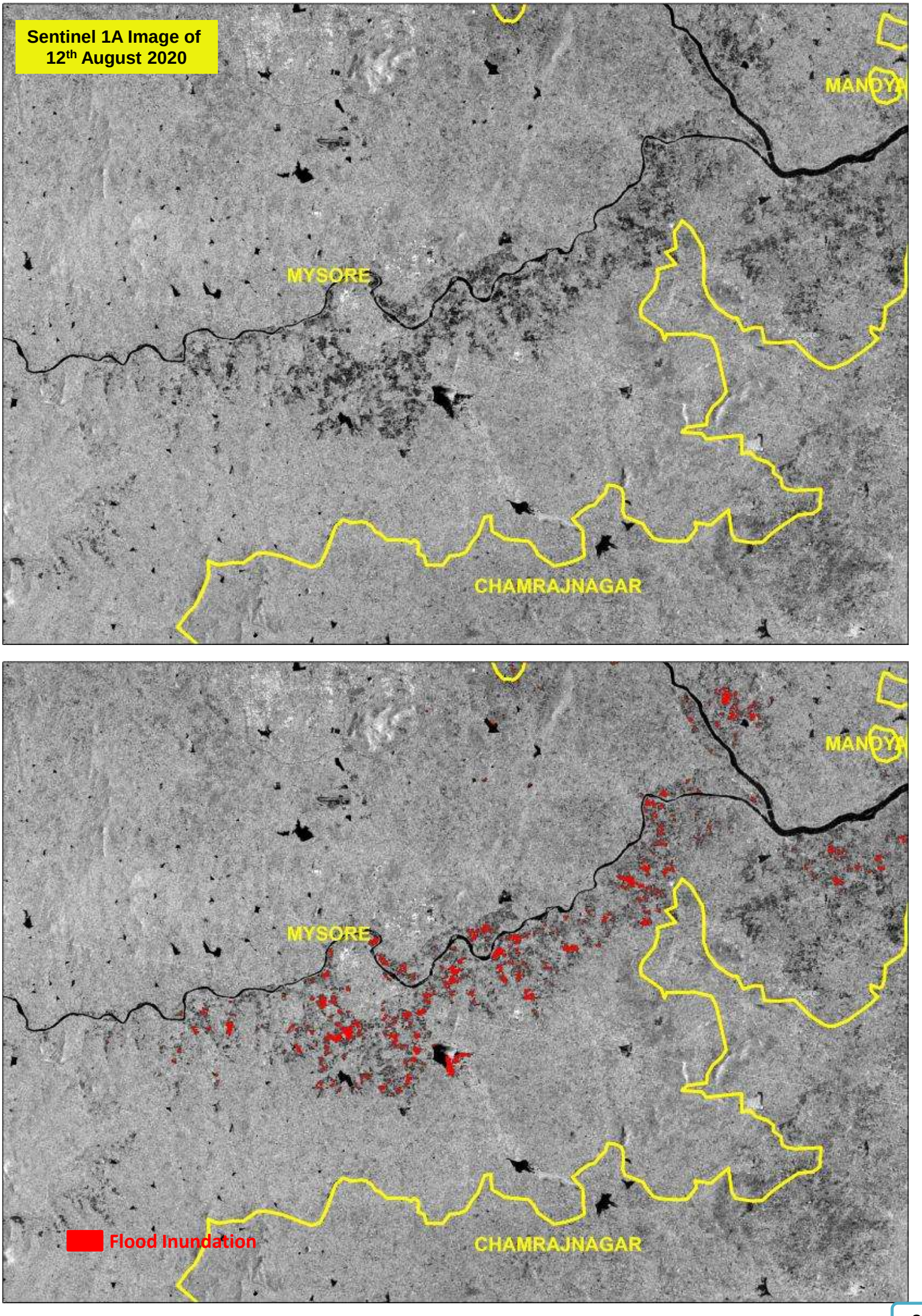


Fig.17.1 Flood affected area in Karnataka

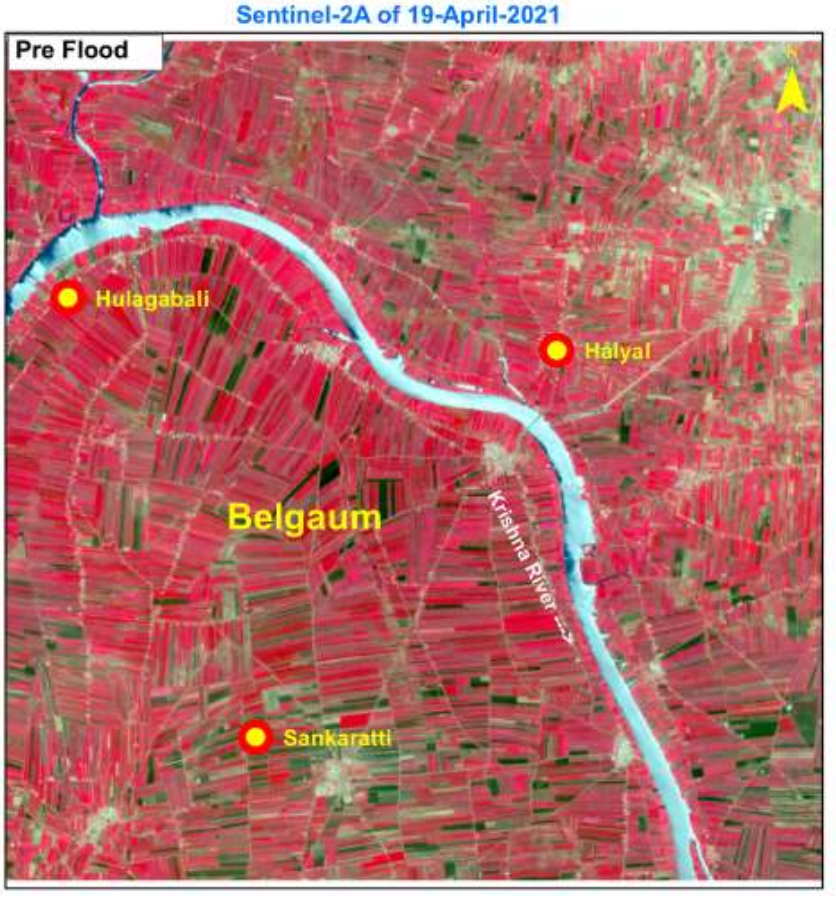

HASSAN
MANDYA
MYSORE
Sentinel 1A Image of
12th August 2020


HASSAN
MANDYA
MYSORE
Flood Inundation

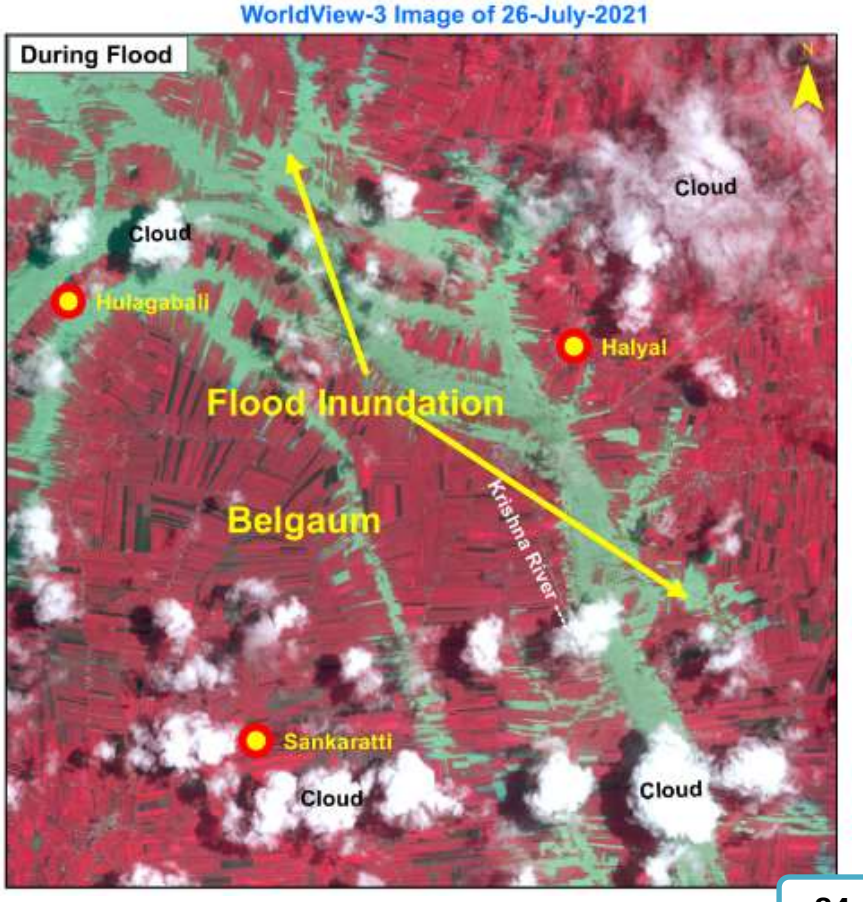

Sentinel 1A Image of
12th August 2020
MANDYA
MYSORE
CHAMRAJNAGAR
MANDYA
MYSORE
CHAMRAJNAGAR
Flood Inundation

Resourcesat-2 AWiFS

Sentinel-2A of 19-April-2021



WorldView-3 Image of 26-July-2021



Kerala

18. Kerala

Kerala state lies in the tropic region and is subject to the typical humid tropical wet climate experienced by most of rainforests. The state is the gateway to the onset of Southwest monsoon and experiences its first spell of rains during late May and June every year. The state receives an average normal annual rainfall of 3107mm with parts of Kerala's low lands experiencing as low as 1250 mm annually and the highlands of Idukki district experience a highest rainfall of 5000 mm due to Orographic precipitation. The state has about 120-140 rainy days on an average every year. The periyar river is the major river draining the state.

Geographically, Kerala can be divided into three climatically distinct regions: the eastern highlands; rugged and cool mountainous terrain, the central mid-lands; rolling hills, and the western lowlands; coastal plains. Pre-Cambrian and Pleistocene geological formations compose the bulk of Kerala's terrain. Kerala's western coastal belt is relatively flat compared to the eastern region, and is criss-crossed by a network of interconnected brackish canals, lakes, estuaries, and rivers known as the Kerala Backwaters. Kuttanad, also known as The Rice Bowl of Kerala, has the lowest altitude in India, and is also one of the few places in world where cultivation takes place below sea level. Kerala has a wet and maritime tropical climate influenced by the seasonal heavy rains of the southwest summer monsoon and northeast winter monsoon.

Around 65% of the rainfall occurs from June to August corresponding to the Southwest monsoon, and the rest from September to December corresponding to Northeast monsoon. The moisture-laden winds of the Southwest monsoon, on reaching the southernmost point of the Indian Peninsula, divides into two branches; namely the "Arabian Sea Branch" and the "Bay of Bengal Branch“ due to its topography. The "Arabian Sea Branch" of the Southwest monsoon first hits the Western Ghats, making Kerala the first state in India to receive rain from the Southwest monsoon. There are 44 major rivers in Kerala, all but three originating in the Western Ghats. 41 of them flow westward and 3 eastward. The rivers of Kerala are small, in terms of length, breadth and water discharge. The rivers flow faster, owing to the hilly terrain and as the short distance between the Western Ghats and the sea. All the rivers are entirely monsoon-fed and many of them shrink into rivulets or dry up completely during summer.

18. 1 Flood problem in Kerala

Kerala is to the west coast of the sub-continent and has an annual precipitation of more than 3000 mm. The short monsoon duration of June-September followed by smaller river stretches to the mouth of Arabian sea results in severe drainage congestion. This cumulative effect of drainage congestion and high precipitation leads to severe floods/flash floods in the state. Kerala has witnessed floods during 2010, 2018, 2019, 2020, 2021 and 2022. The devastating floods of 2018 have resulted severe loss to human lives and property. The floods of 1924 were the severe floods in the history prior to great floods of 2018.

During August, 2018 , the state received about 116 % more than usual rainfall and added to that the release of waters from dams has further exacerbated the situation and it has experienced one of the worst floods of this decade. The state also suffered losses due to recent cyclone "OCKHI", of 2017. During the last three years starting from 2017 – 2020
Major flood events in Kerala is listed in Table 18.1 for which satellite derived spatial flood inundation maps were generated and disseminated to state / central government disaster support management organizations by NRSC, ISRO.

Table.18.1 . Major flood events in Kerala state

	Year	Description of the flood event	Districts affected
1	2005	Floods occurred during 5 -12th , Aug 2005 due to heavy rains.	3
2	2010	Floods were reported in many parts of Kerala due to heavy rains during fourth week of November 2010.	2
3	2011	Heavy rains lashed many parts of Kerala during the first week of June 2011.	1
4	2012	Floods were reported in Kerala during first week of August 2013 due to torrential rains.	4
5	2018	Floods occurred during 16-21st July , 9- 27th aug due to heavy rains	8
6	2019	Floods were reported in due to heavy torrential rains during Second Week of August, 2019. 10-14th aug 2018	7
7	2020	Floods were reported ins during Second Week of August, 2020. 8-12th August 2020 due to heavy rains	5
8	2022	Floods occurred due to heavy rains were reported in Kerala state during the last week of July 2022,	7

18.2 Flood Affected Area in Kerala

Cumulative flood inundation maps were utilised for generation of map of total flood affected area in Kerala and is estimated as 79,377 ha. Flood Affected Area Map is shown in Figure.18.1. and district wise flood affected area statistics are shown in Table. 18.2. Three districts in Kerala has flood affected area between 10,000-25,000 ha and 7 districts <10000 ha.

Table.18.2 District wise statistics of Flood affected area in Kerala

S. No.	District	Flood Affected Area (ha)
1	Kottayam	21379
2	Thrissur	19562
3	Alappuzha	12187
4	Ernakulam	7663
5	Pattanamtitta	6052
6	Malappuram	5989
7	Palakkad	4137
8	Kollam	1829
9	Wayanad	469
10	Kozhikode	110
	TOTAL	**79377**

Glimpses of satellite images / flood inundation over the time period are depicted in this section.

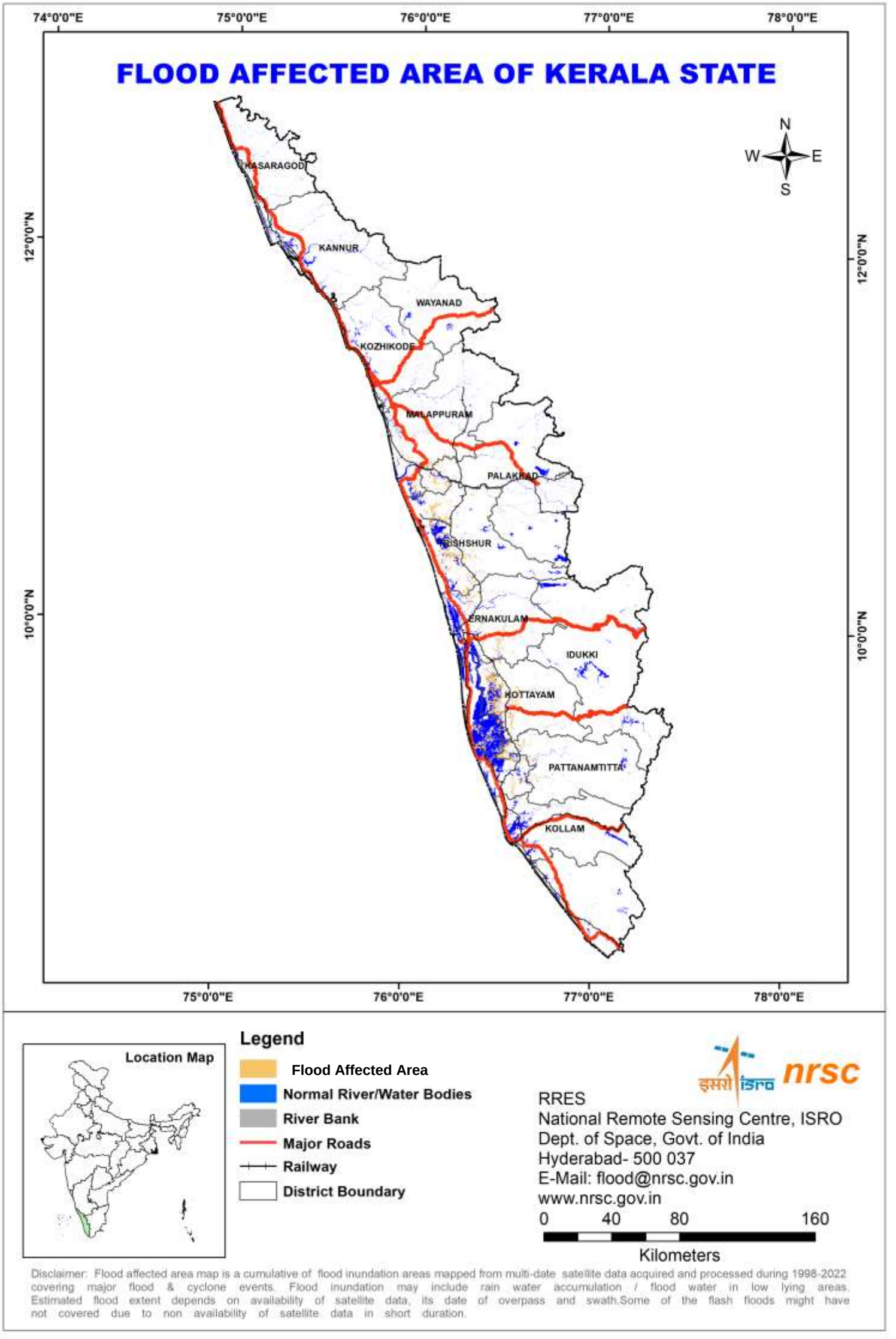
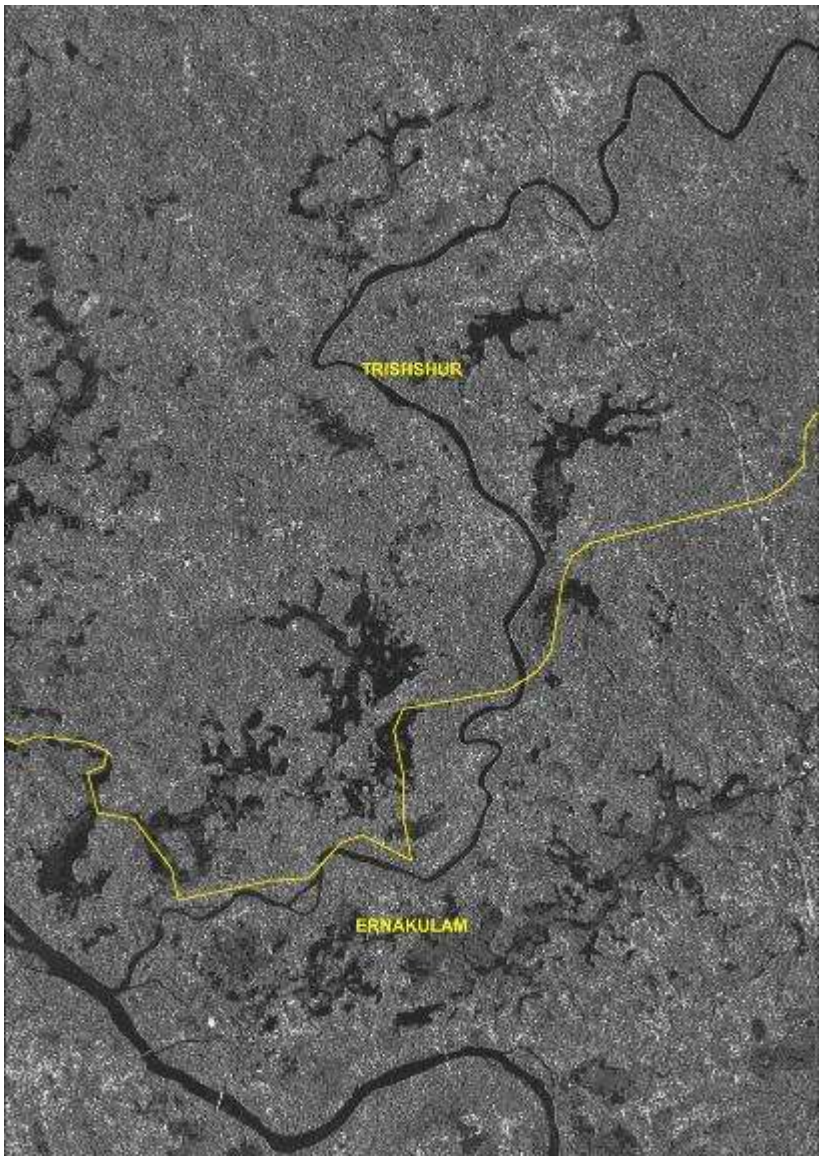
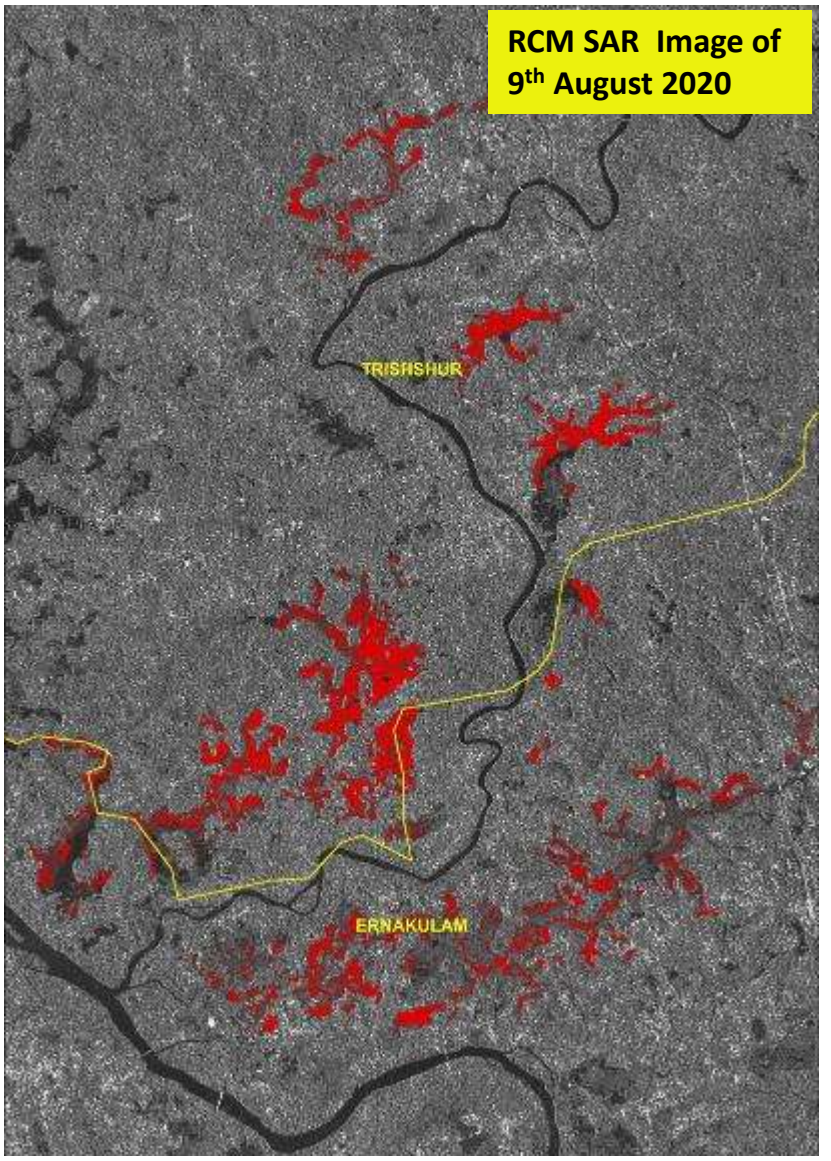
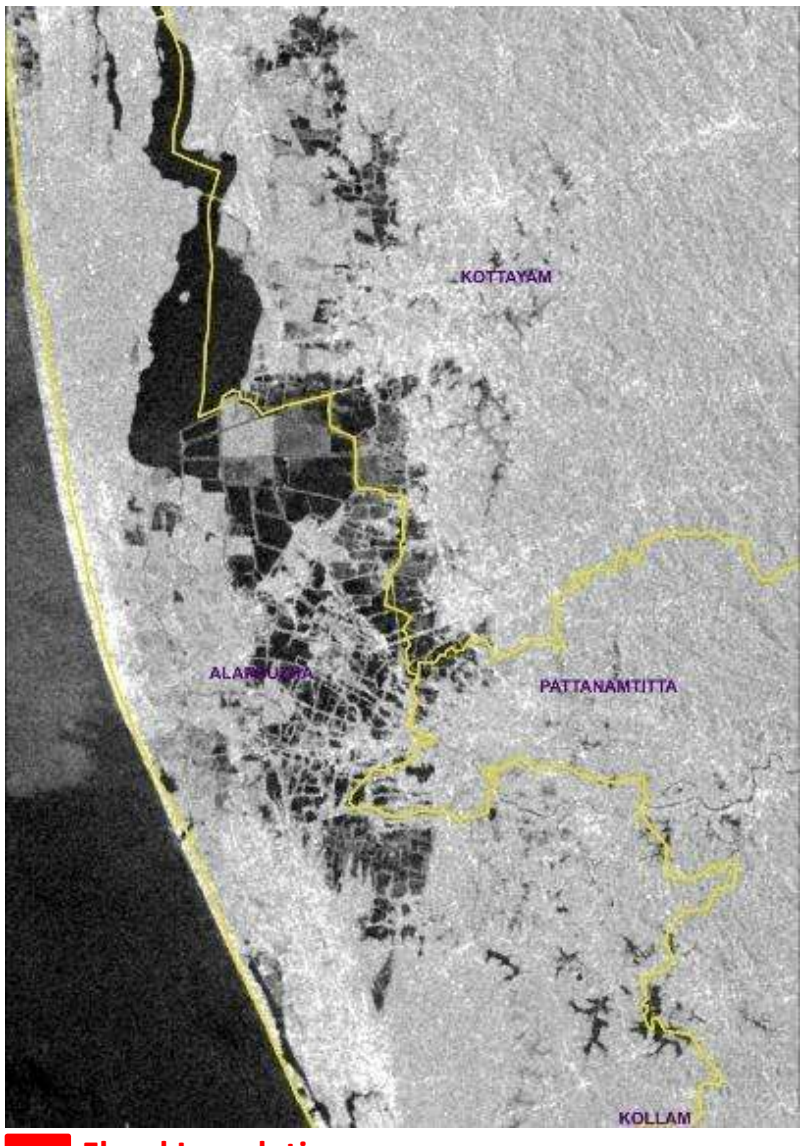
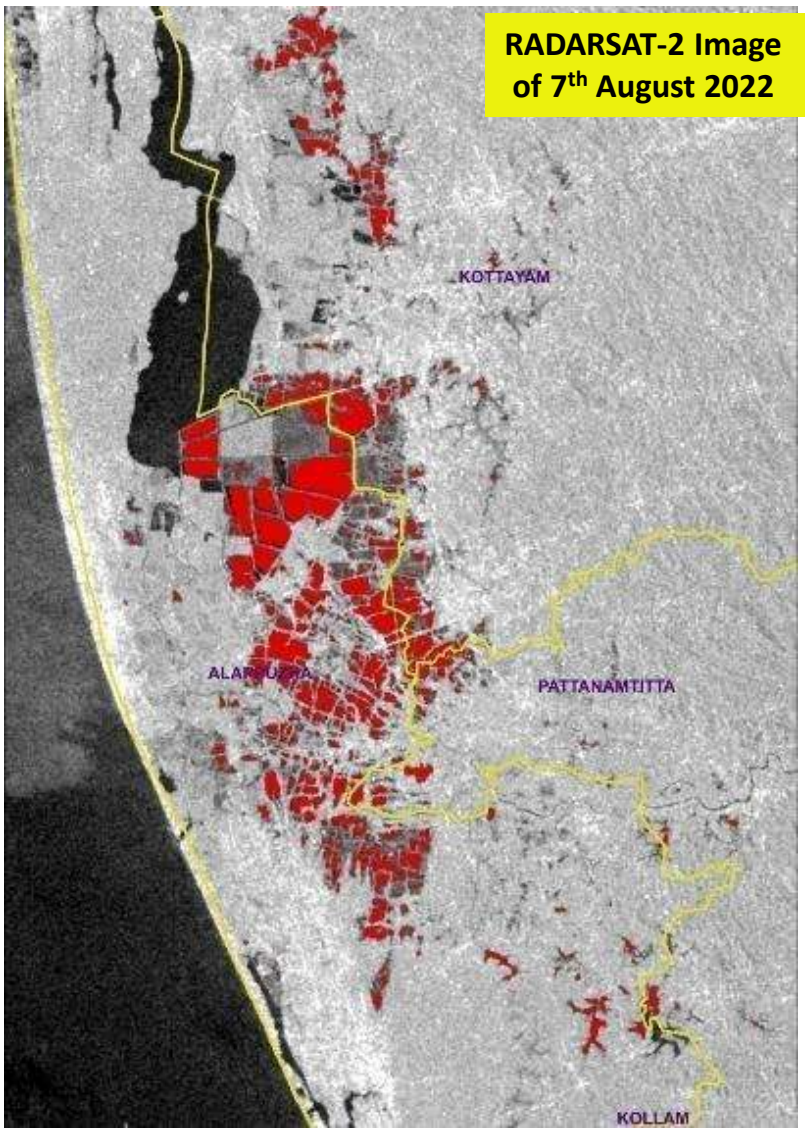


Fig.18.1 Flood affected area in Kerala State



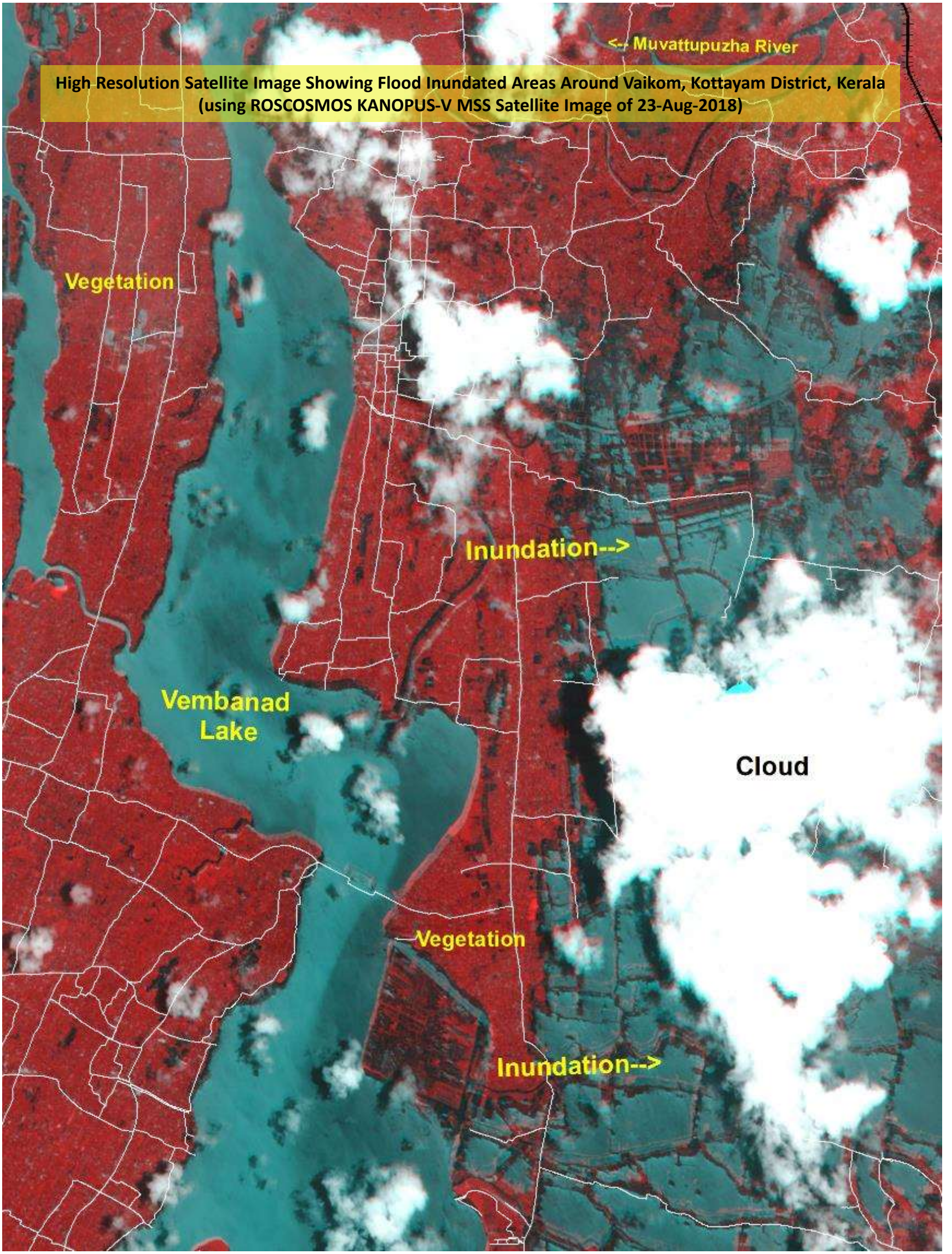






Flood Inundation

High Resolution Satellite Image Showing Flood Inundated Areas Around Vaikom, Kottayam District, Kerala
(using ROSCOSMOS KANOPUS-V MSS Satellite Image of 23-Aug-2018)



19. Madhya Pradesh

Madhya Pradesh is located in the geographic heart of India. Madhya Pradesh is divided into 52 districts for administrative purposes. The state straddles the Narmada River, which runs east and west between the Vindhya and Satpura ranges; these ranges and the Narmada are the traditional boundaries between the north and south of India. The highest point in Madhya Pradesh is Dhupgarh, with an elevation of 1,350 m. The state is bordered on the west by Gujarat, on the northwest by Rajasthan, on the northeast by Uttar Pradesh, on the east by Chhattisgarh, and on the south by Maharashtra. Five major rivers of the country have their sources in Madhya Pradesh. These are Narmada (Shahdol district), Tapti (Betul District), Mahi (Dhar district), Godawari (Wainganga - Balaghat District). Likewise, the State also provides water to Ganga and Yamuna through Chambal, Sindh, Betwa,Kuanwari-Sindh and Son, Rihand& Ken rivers and Godawari river basin through Wain Ganga (Pranhita) rivers.(source:http://mpwrd.gov.in).

19.1 Flood Problem in Madhya Pradesh

The riverine flooding is a common phenomena in Madhya Pradesh due to very heavy incessant rainfall followed by slow movement of depressions. The state accounts for 3.6% of flood prone areas in the country (Planning Commission, 2011). The decadal flood damage statistics indicated that 2003-2011 was the lowest flood affected period and years 1993-2002 account for the highest flood affected areas in the history and the population affected was highest in 1993-2002 time frame and lowest was in 1953-62.During 2011-2022, floods were mapped during 2016,2019,2020,2021 & 2022 using multi-mission satellite datasets.

Major flood events in Madhya Pradesh is listed in Table 19.1 for which satellite derived spatial flood inundation maps were generated and disseminated to state / central government disaster support management organizations by NRSC, ISRO.

Table.19.1 . Major flood events in Madhya Pradesh state

	Year	Description of the flood event	Districts affected
1	2005	Floods occurred during 8th -12th Jul 2005 due to heavy rains and rise in water levels in Tons, Kane rivers.	1
2	2006	Floods occurred during 3rd week of Aug 2006 due to rise in water levels of Naramada River	4
3	2013	Floods were reported in Madhya Pradesh state during fourth week of August 2013, Narmada and Betwa rivers were flowing above danger mark. Hosangabad and Vidisha were reported to be the worst hit.	2
4	2019	Heavy incessant rains were reported in various parts of Madhya Pradesh in the third week of September, 2019. River Chambal was reported to be flowing in sever flood situation at various locations in Madhya Pradesh	2
5	2020	Floods were reported during the last week of August and first week of September, 2020 under the influence of heavy incessant rains. Rivers Wainganga and Narmada were reported to be flowing in extreme flood situation at respective gauge sites in Madhya Pradesh	3
6	2022	Floods were mapped in the state of MP two times during the month of August and once during September, 2022	26

19.2 Flood Affected Area in Madhya Pradesh

Cumulative flood inundation maps were utilised for generation of total flood affected area map in Madhya Pradesh and is estimated as 2,10,809 ha. Flood Affected Area Map is shown in Figure.19.1. and District wise flood affected area statistics are shown in Table. 19.2. One district in Madhya Pradesh has flood affected area between 25,000-50,000 ha, 5 districts between 10,000-25,000 ha and 24 districts <10000 ha.

Table.19.2 District wise statistics of Flood affected area in Madhya Pradesh

S. No.	District	Inundated Area (ha)
1	Jabalpur	35696
2	Vidisha	23052
3	Raisen	18252
4	Hoshangabad	15132
5	Panna	12393
6	Ashoknagar	10773
7	Rewa	9864
8	Morena	9649
9	Sehore	6995
10	Bhind	6916
11	Narsimhapur	6597
12	Damoh	6474
13	East Nimar	6341
14	Shivpuri	5713
15	Satna	4538
16	Katni	4287
17	Guna	3842
18	Sagar	3644
19	Dhar	3374
20	Dewas	2850
21	Mandla	2524
22	Chhatarpur	2466
23	Barwani	2354
24	Seoni	2268
25	Harda	1893
26	Balaghat	1374
27	Bhopal	714
28	Rajgarh	491
29	Umaria	221
30	Alirajpur	122
	TOTAL	**210809**

Glimpses of satellite images / flood inundation over the time period are depicted in this section.

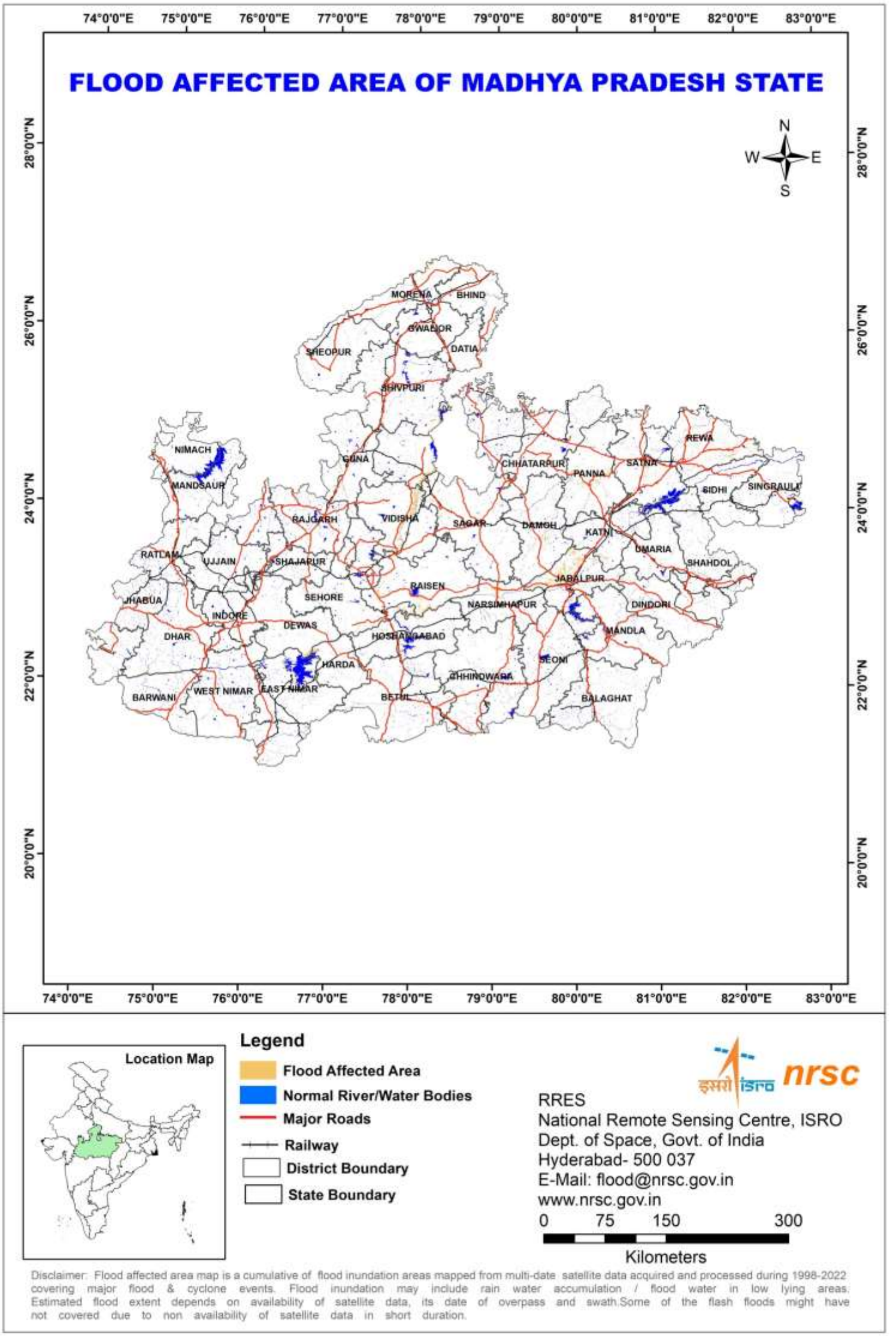
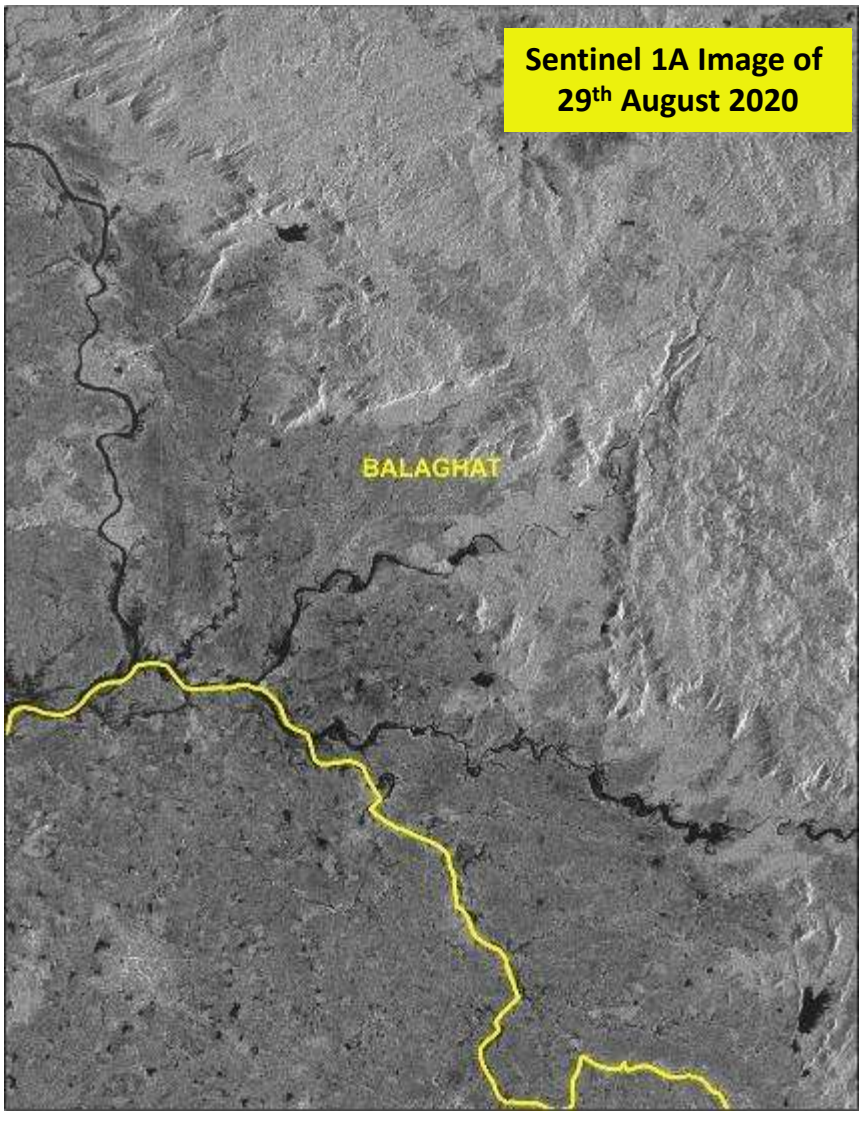
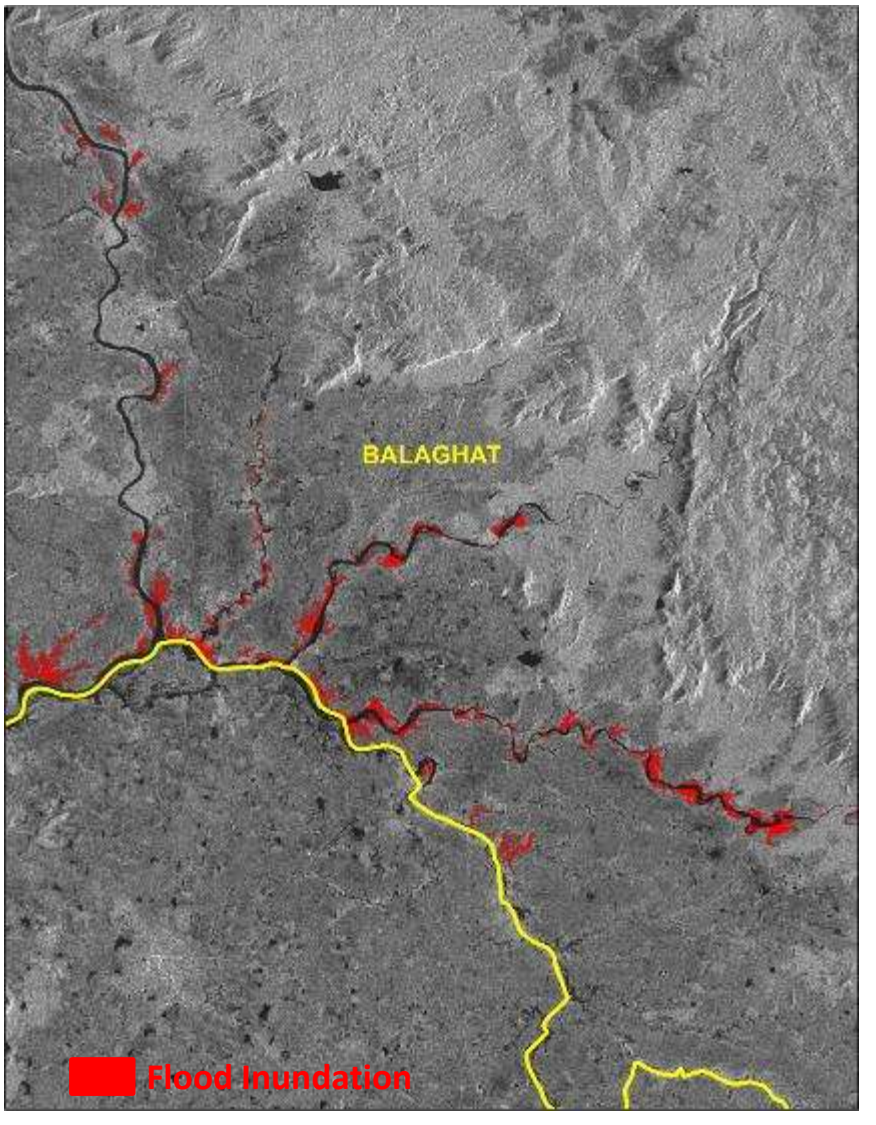
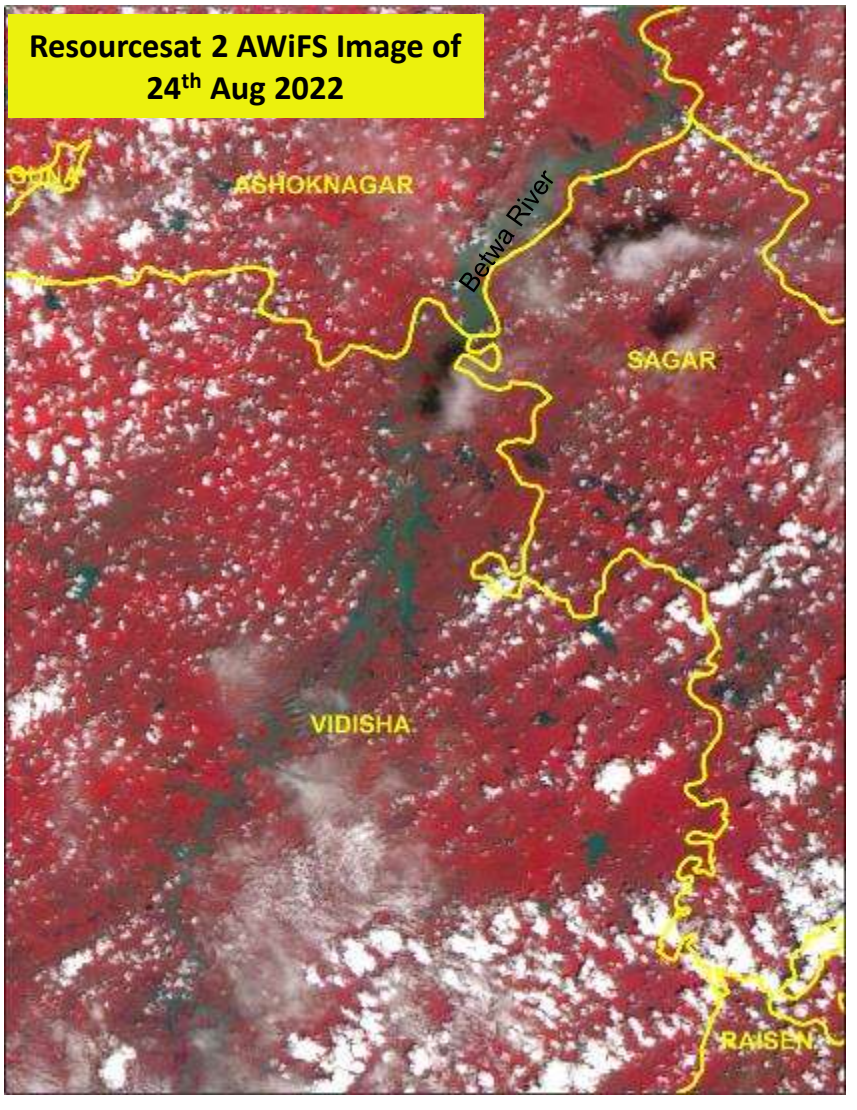
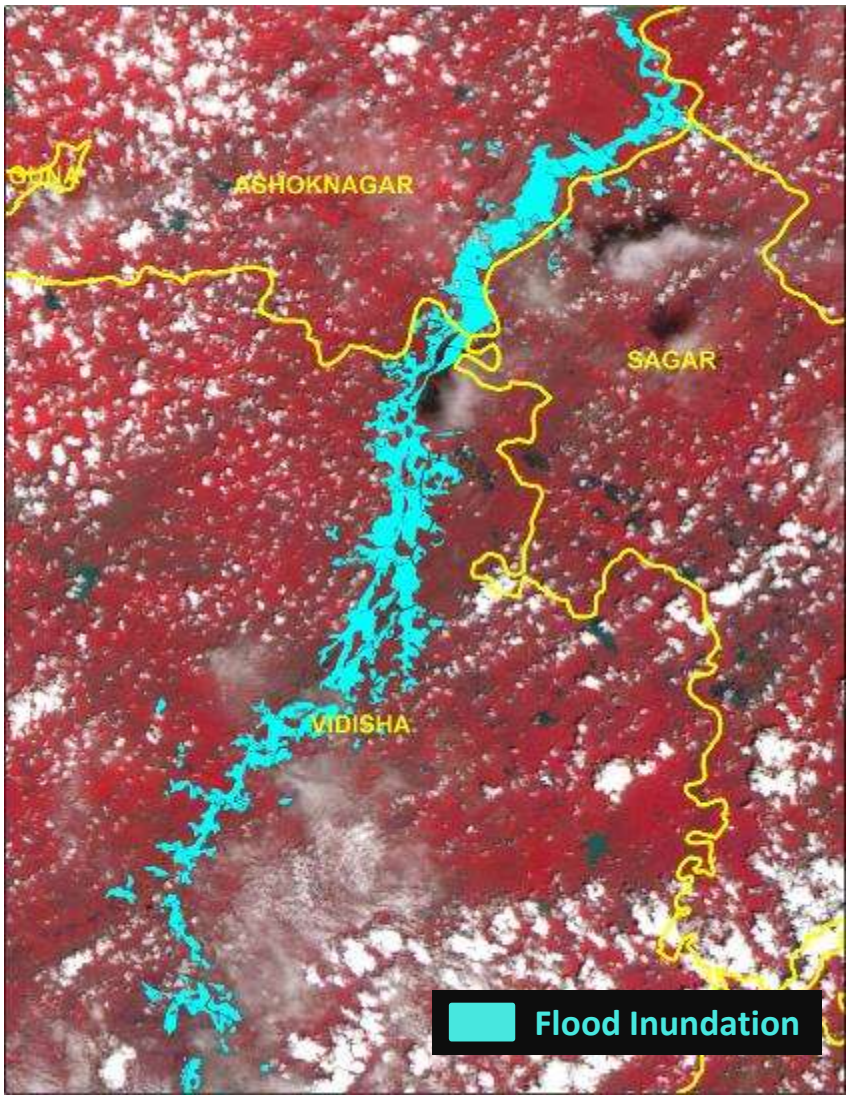


Fig.19.1 Flood affected area in Madhya Pradesh State


Sentinel 1A Image of
29th August 2020
BALAGHAT


BALAGHAT
Flood Inundation


Resourcesat 2 AWiFS Image of
24th Aug 2022
ASHOKNAGAR
Betwa River
SAGAR
VIDISHA
RAISEN


ASHOKNAGAR
SAGAR
VIDISHA
Flood Inundation

20. Maharashtra

Maharashtra state in western peninsular region of India occupies a substantial portion of the Deccan plateau. It has a coastline of 720 kms along the Arabian sea. It has a tropical climate with three distinct seasons and monsoon is usually experienced during June-September every year. The Sahyadri mountain ranges provide a physical backbone to the State on the west, while the Satpuda hills along the north and Bhamragad-Chiroli- Gaikhuri ranges on the east serve as it‘s natural borders. The State is surrounded by Gujarat to the north west, Madhya Pradesh to the north, Chattisgarh to the east, Andhra Pradesh to the south east, Karnataka to the south and Goa to the south west.

Major Rivers and Coastline: Godavari River: The Godavari River originates near Nashik in Maharashtra and flows nearly around 1,465 km before joining to the Bay of Bengal. Its principal tributaries are the Parvara, the Purna, the Manjra, the Penganga, the Wardha, the Wainganga, the Indravati and the Kolab. Asia's largest lift irrigation project is constructed on the river just 5 km away from Nanded city. Krishna River: The Krishna River rises from a place with an elevation of 1337m north of Mahabaleshwar. The Ghataprabha, the Malaprabha, the Bhima, the Tungabhadra and the Musik are the major tributaries joining Krishna. BhimaRiver:The river is prone to flooding due to heavy rainfall during the monsoon season. In 2005 there was severe flooding in Solapur, Bijapurand Gulbarga districts. Tapi River:Tapi River starts from a place with an elevation of 752m near Multai in the Betul district of Madhya Pradesh. It flows for about 724 km before out falling into the Arabian Sea through the Gulf of Cambay. The Purna, the Girna, the Panjhra, the Vaghur, the Bori and the Aner are the principal tributaries of Tapi. Rivers flowing from the Western Ghats : Maharashtra has more than 11 important west flowing rivers including Damanganga Surya, Vaitarna, Ulhas, Savitri, Kundalika, Patalganga, Vashisti, Shastri, Karli, and Terekhol.There are numerous smaller rivers joining the creeks. Coastline Maharashtra is bordered by the Arabian Sea to the west and has a long coastline stretching nearly 720 kilometers along the Arabian from Goa to Gujarat.

20.1 Flood Problem in Maharashtra

The state experiences floods and cyclones on a regular basis. The Mumbai floods of 2005, the Wainganga and Wardha river floods of 2013 and frequent episodes of Urban floods in Mumbai are annual features. During 2019 and 2020, the state experienced riverine floods due to Krishna and Godavari rivers. The state also witnessed the losses due to nes KYARR and NISARG.

20.2 Flood Affected Area in Maharashtra

Cumulative flood inundation maps were utilised for generation of total flood affected area map in Maharashtra and is estimated as 2,33,590 ha. Flood Affected Area Map is shown in Figure.20.1 and district wise flood affected area statistics are shown in Table. 20.2. One district in Maharashtra has flood affected area between 50,000-1,00,000 ha, 2 districts between 25,000-50,000 ha, 4 districts between 10,000-25,000 ha and 13 districts <10000 ha.

Major flood events in Maharashtra is listed in Table 20.1 for which satellite derived spatial flood inundation maps were generated and disseminated to state / central government disaster support management organizations by NRSC, ISRO.

Table.20.1 . Major flood events in Maharashtra state

	Year	Description of the flood event	Districts affected
1	2005	Floods occurred during 29th Jul -5th August and 17th Sep 2005 due to heavy rains	5
2	2006	Many low-lying areas in parts of Maharashtra`s Vidarbha region were inundated due to rains during 10-13th Aug 2006	4
3	2013	Floods were reported in Maharashtra state during last week of July, 2013	9
4	2016	Floods were reported in first week of August in the state of Maharashtra due to heavy torrential rains during 1st week of 2016	4
5	2019	Floods were reported in first week of August in the state of Maharashtra due to heavy torrential rains during 6-15th Aug 2018	6
6	2020	Heavy incessant rains lashed Maharashtra during the third week of August, 2020.	3
7	2022	Heavy incessant rains were reported in various parts of Maharashtra in July & August 2022.	8

Table.20.2 District wise statistics of Flood affected area in Maharashtra

S. No.	District	Flood Affected Area (ha)
1	Chandrapur	54009
2	Kolhapur	46304
3	Garhchiroli	38847
4	Bhandara	16915
5	Yavatmal	13930
6	Sangli	13925
7	Bid	11065
8	Jalna	9676
9	Wardha	6172
10	Nanded	5819
11	Solapur	3873
12	Akola	3184
13	Nashik	3075
14	Parbhani	1876
15	Ahmadnagar	1785
16	Raygad	1300
17	Gondiya	819
18	Hingoli	462
19	Amravati	399
20	Nagpur	155
TOTAL		**233590**

Glimpses of satellite images / flood inundation over the time period are depicted in this section.

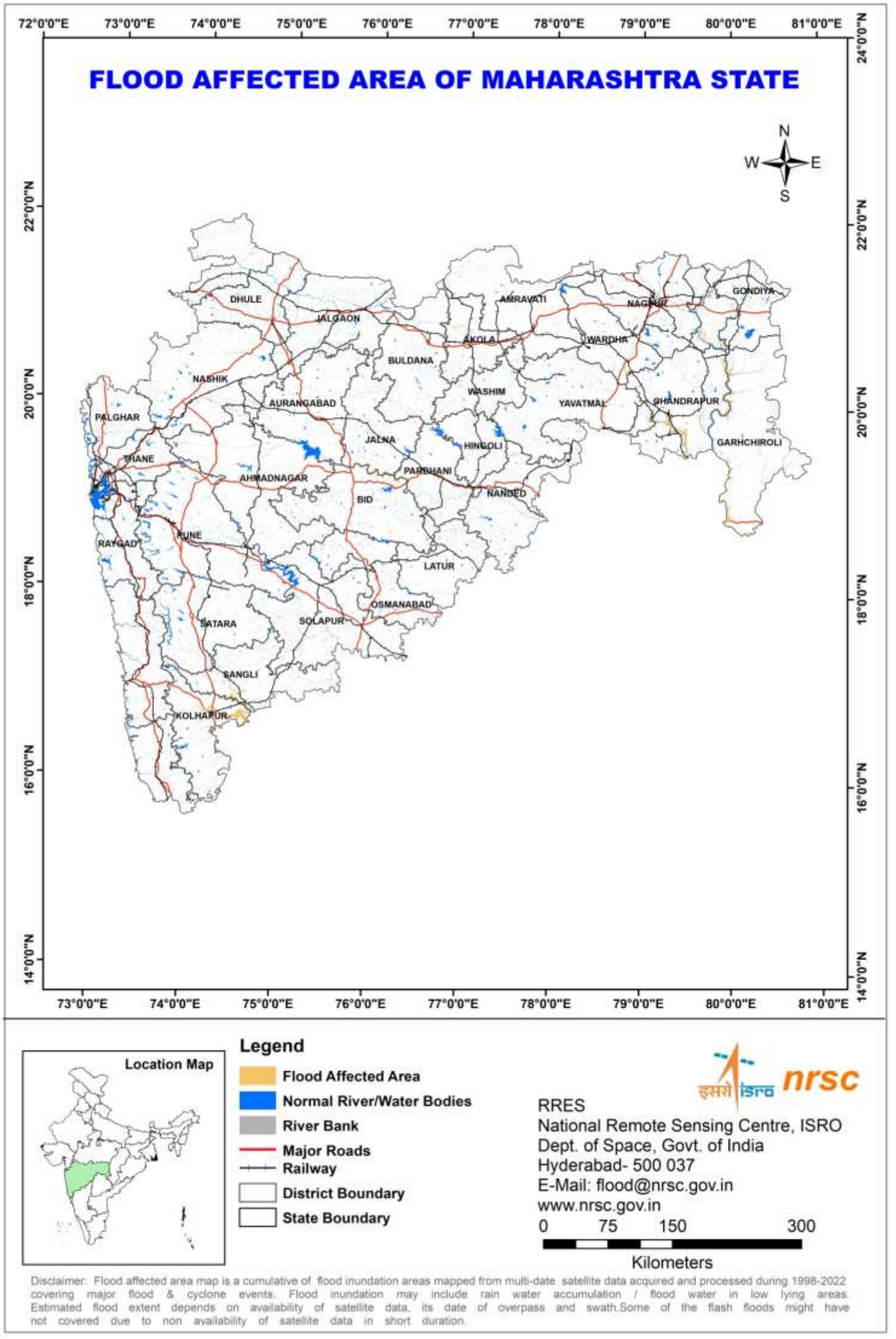
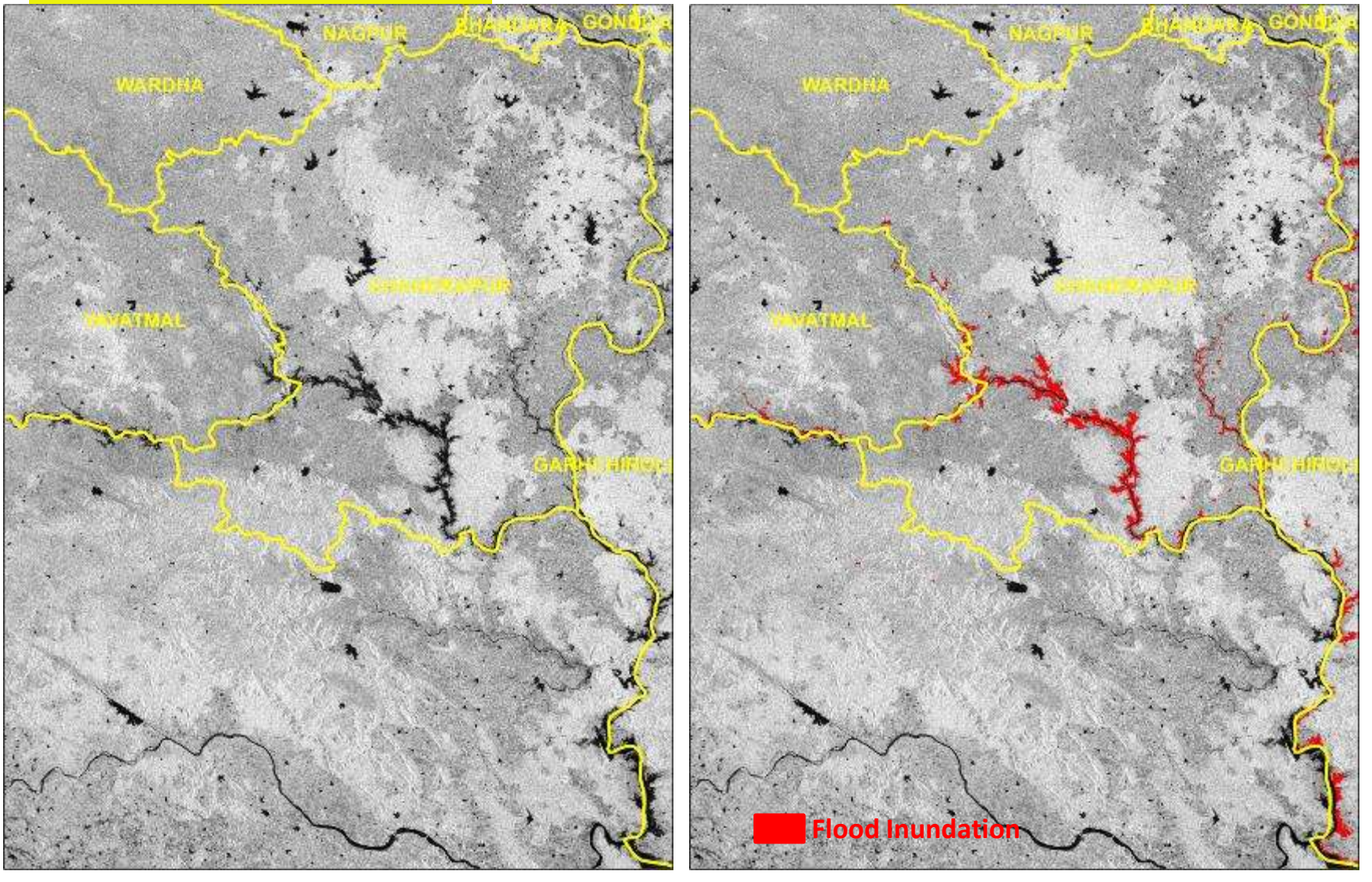
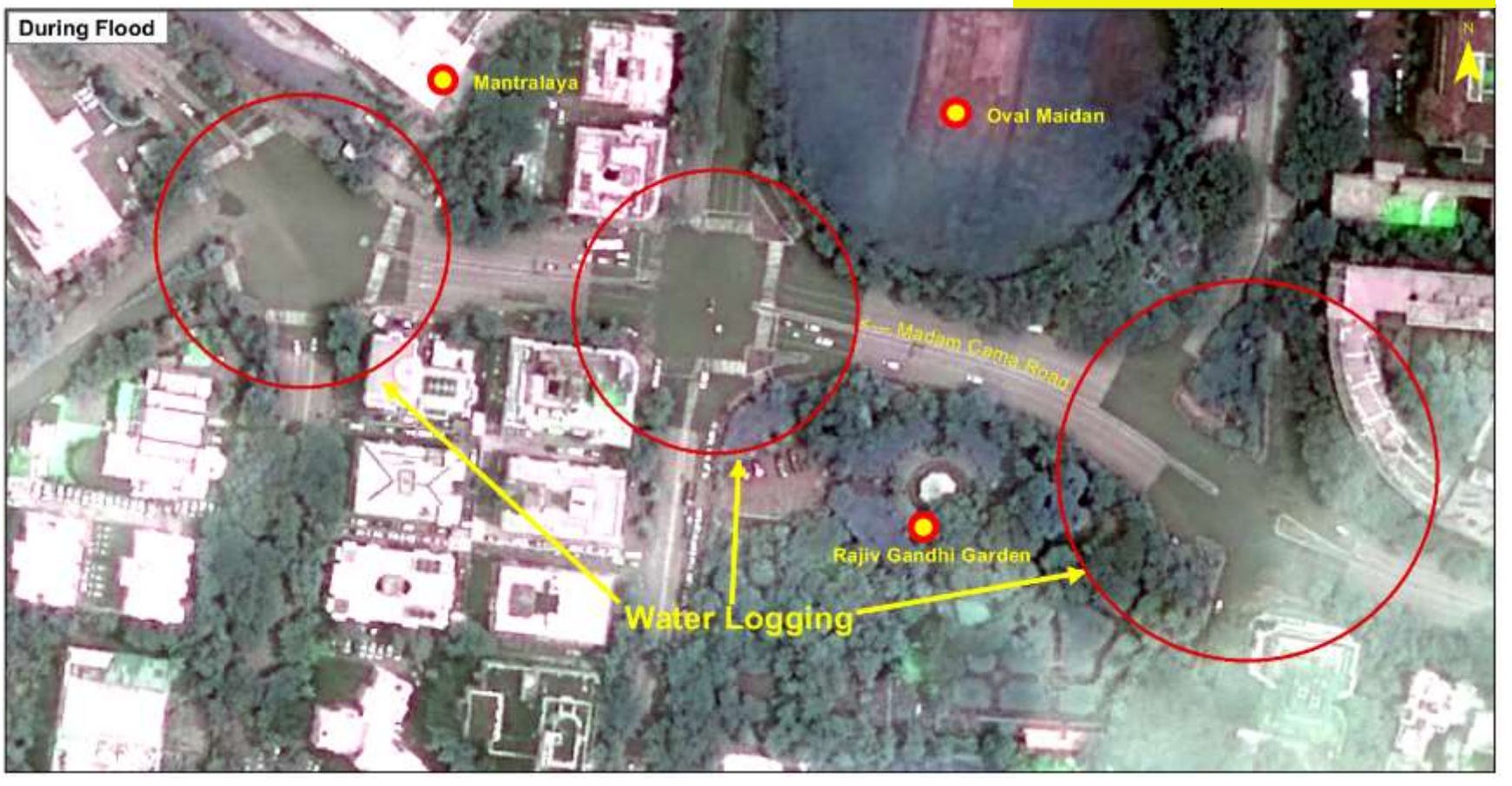


Fig.20.1 Flood affected area in Maharashtra State

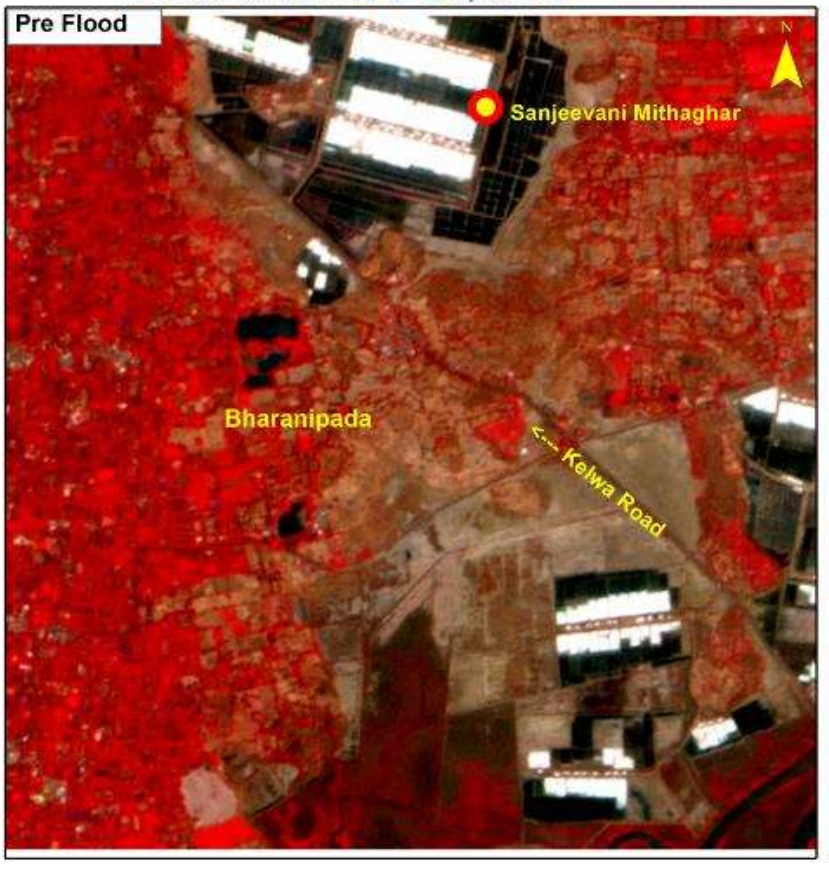
RADARSAT 2Image of 1st August 2013



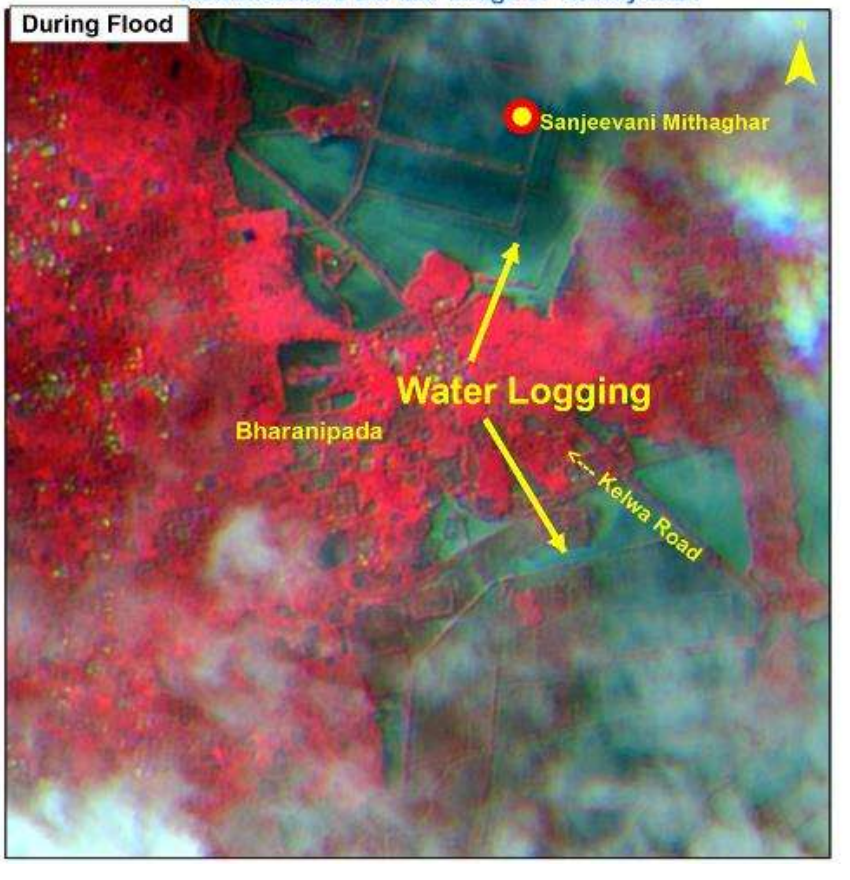
PLEIADES Image of 09August 2020

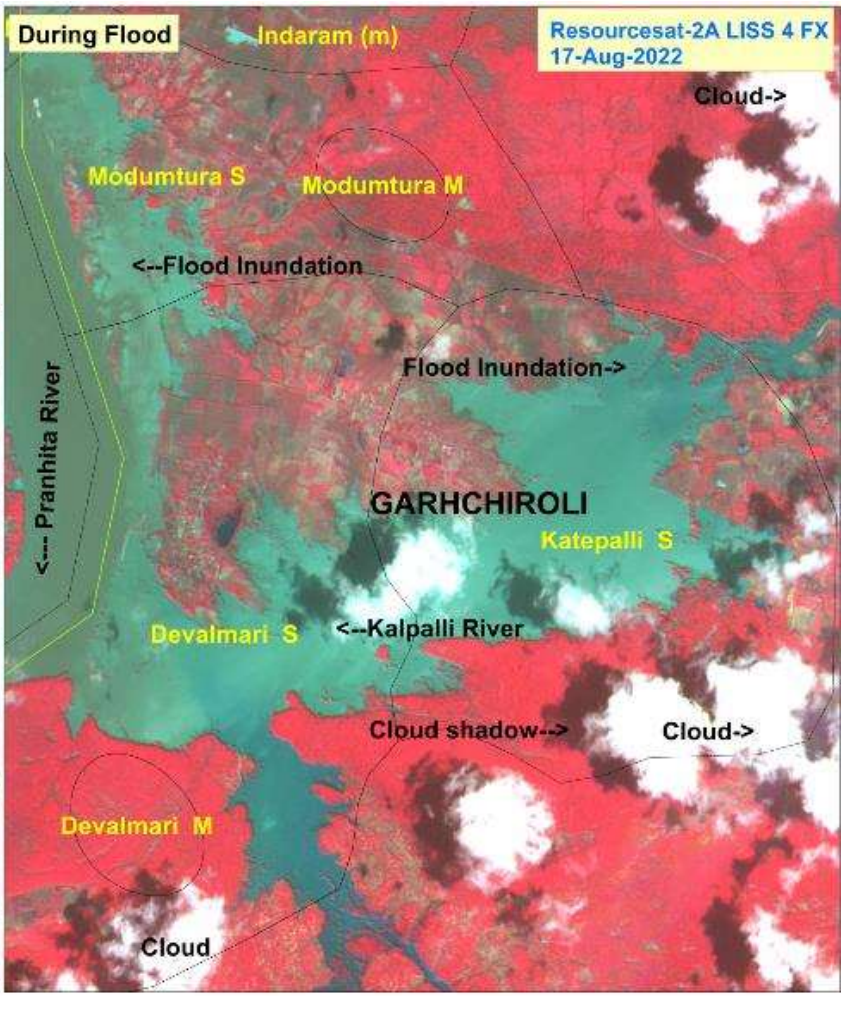


Resoucesat-2 L4FMx of 12-April-2019



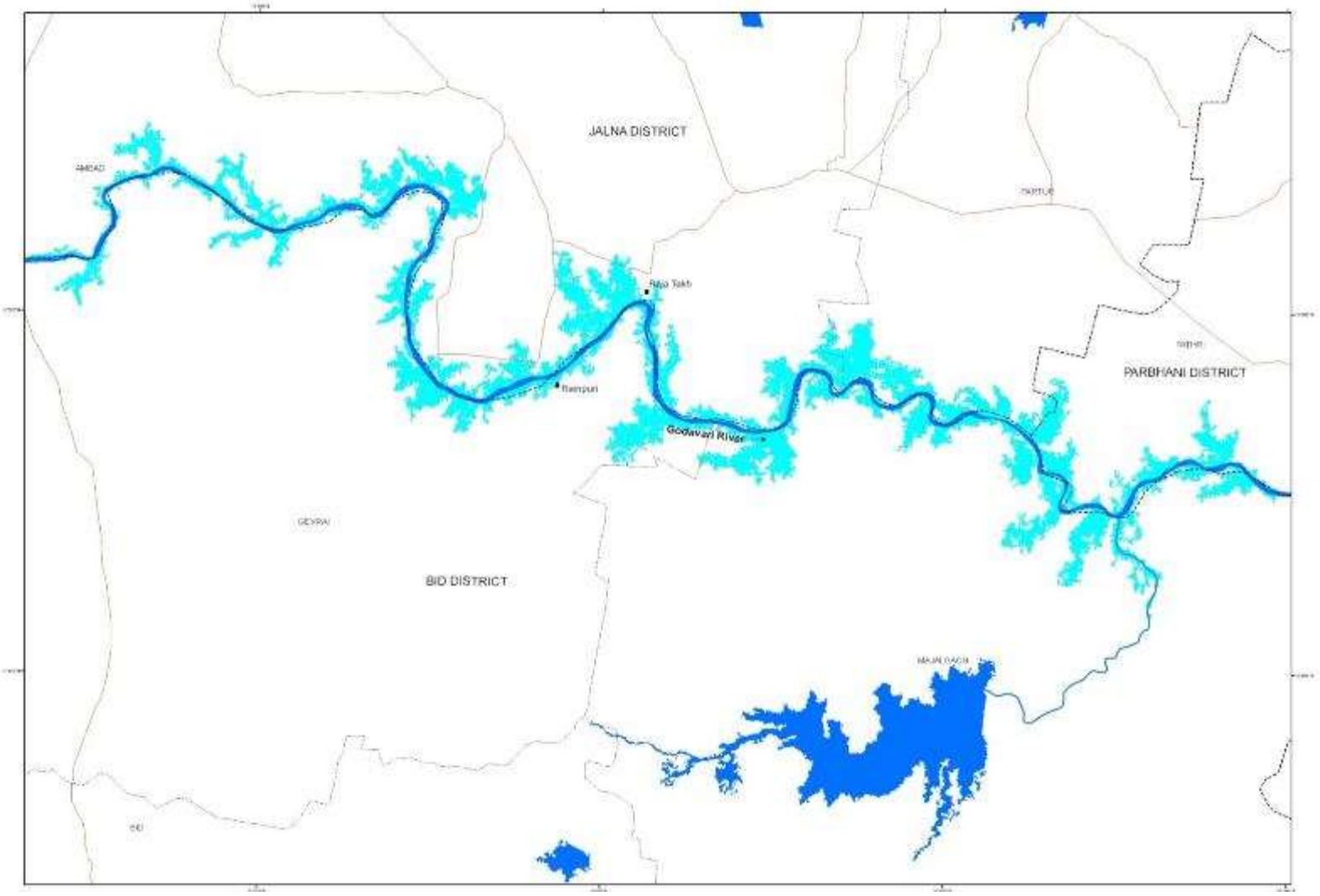
Resourcesat-2 L4FMX Image of 18-July-2021



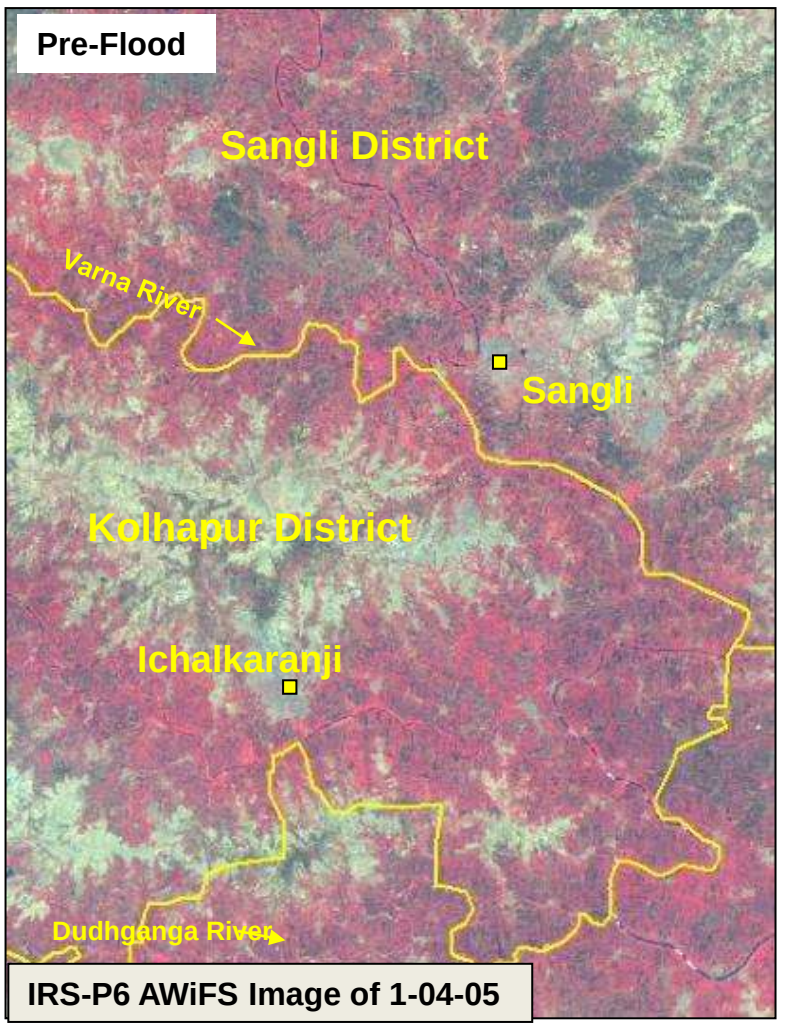


Flood Inundated Areas in parts of Jalna & Bid Districts, Maharastra State

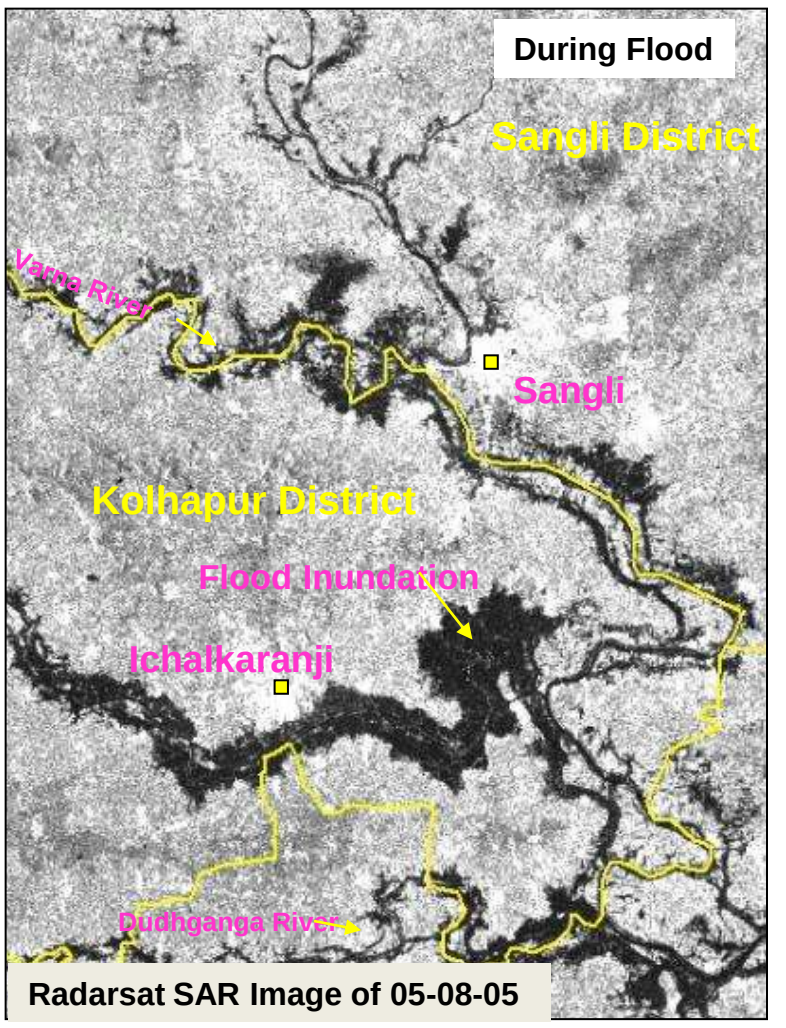
Based on the analysis of Radarsat data of 13-August-2006



Satellite Images of part of Sangli & Kolhapur Districts Maharashtra State



IRS-P6 AWiFS Image of 1-04-05



Radarsat SAR Image of 05-08-05

RADARSAT-2 as on 9th August 2019

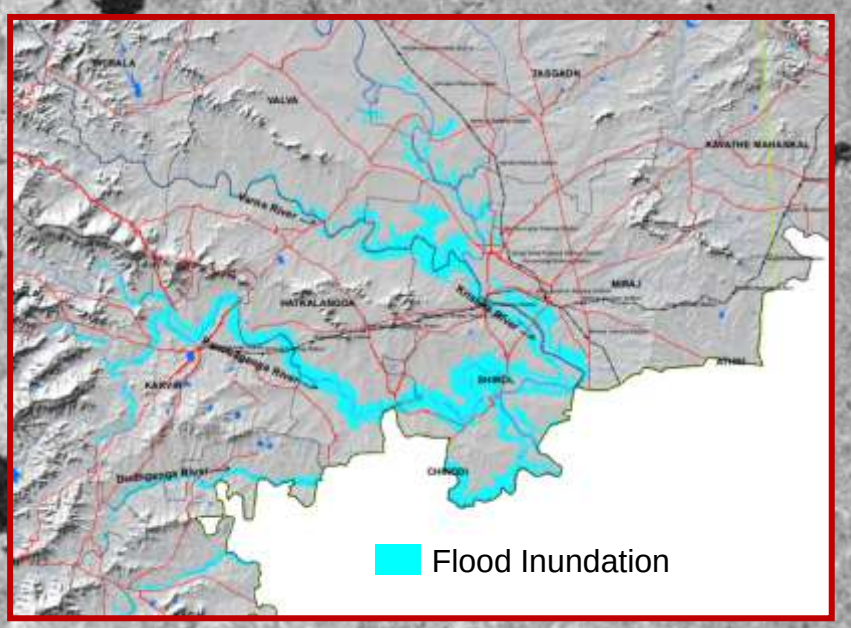
Krishna River

Flood Inundation

SHIROL

Panchaganga River

Dudhganga River



21. Manipur

Manipur

Manipur state is located in the north-eastern region of India. The economy of Manipur is primarily based on agriculture and allied activities, including horticulture, sericulture, and livestock rearing. The state is also known for its handloom and handicraft industries, which produce exquisite fabrics and handicrafts. The state is bordered by the Indian states of Nagaland to its north, Mizoram to its south, Assam to its west, and shares an international border with Myanmar to its east. Manipur may be characterised as two distinct physical regions: an outlying area of rugged hills and narrow valleys, and the inner area of flat plain, with all associated landforms. These two areas are distinct in physical features and are conspicuous in flora and fauna. The valley region has hills and mounds rising above the flat surface. The Loktak lake is an important feature of the central plain. The total area occupied by all the lakes is about 600 km^2. The altitude ranges from 40 m at Jiribam to 2,994 m at Mount Tempü peak along the border with Nagaland.

Barak River: It is the longest river in Manipur and flows through the southern part of the state before merging with the Meghna River in Bangladesh. The Barak River is an important source of water for irrigation and hydroelectric power generation. Imphal River: It is a major river in Manipur, originating from the Manipur hills and flowing through the Imphal Valley before merging with the Barak River in Assam. The Imphal River is an important source of water for irrigation and domestic purposes. Iril River: It is a tributary of the Imphal River and originates from the Kangchup Hills in Manipur. The Iril River is an important source of water for irrigation and domestic purposes. Thoubal River: It is a major river in Manipur, originating from the Thoubal district and flowing through the Imphal Valley before merging with the Imphal River. The Thoubal River is an important source of water for irrigation and domestic purposes. Chindwin River: It is a major river in Myanmar, originating from the Hukawng Valley and flowing through the Sagaing Region before entering Manipur. The Chindwin River is an important source of water for irrigation and transportation.

21.1 Flood Problem in Manipur

During 2015, Manipur faced floods and landslides and caused severe loss to property and inundated many low lying areas along the Loktak lake. The floods were witnessed during 2015, 2016, 2017 & 2018. Major flood events in Manipur is listed in Table 21.1 for which satellite derived spatial flood inundation maps were generated and disseminated to state / central government disaster support management organizations by NRSC, ISRO.

Table.21.1 . Major flood events in Manipur state

S.No	Year	Description of the flood event	Districts affected
1	2010	Floods occurred due to heavy rains lashed Manipur during 2nd week of October 2010. Rise in water level was observed in Nambul, Iril, Imphal rivers and its tributaries	1
2	2017	Flood occurred due to heavy rains during 1st week of June which has lasted for 3 weeks	3
3	2018	Floods were reported in Manipur due to heavy torrential rains during Second week of June. Imphal, Thoubal and Bishnupur districts	3

21.2 Flood Affected Area in Manipur

Cumulative flood inundation maps were utilised for generation of map of total flood affected area in Manipur and is estimated as 88,352 ha. Flood Affected Area Map is shown in Figure.21.1 and district wise flood affected area statistics are shown in Table. 21.2. Four districts in Manipur has flood affected area between 10,000-25,000 ha and 5 districts <10000 ha.

Table.21.2 District wise statistics of Flood affected area in Manipur

Sl. No.	District	Flood Affected Area (Ha)
1	Imphal West	20043
2	Thoubal	19579
3	Bishnupur	17253
4	Imphal East	17000
5	Kakching	8777
6	Kangpokpi	4893
7	Tengnoupal	439
8	Jiribam	221
9	Senapati	146
	TOTAL	**88352**

Glimpses of satellite images / flood inundation over the time period are depicted in this section.

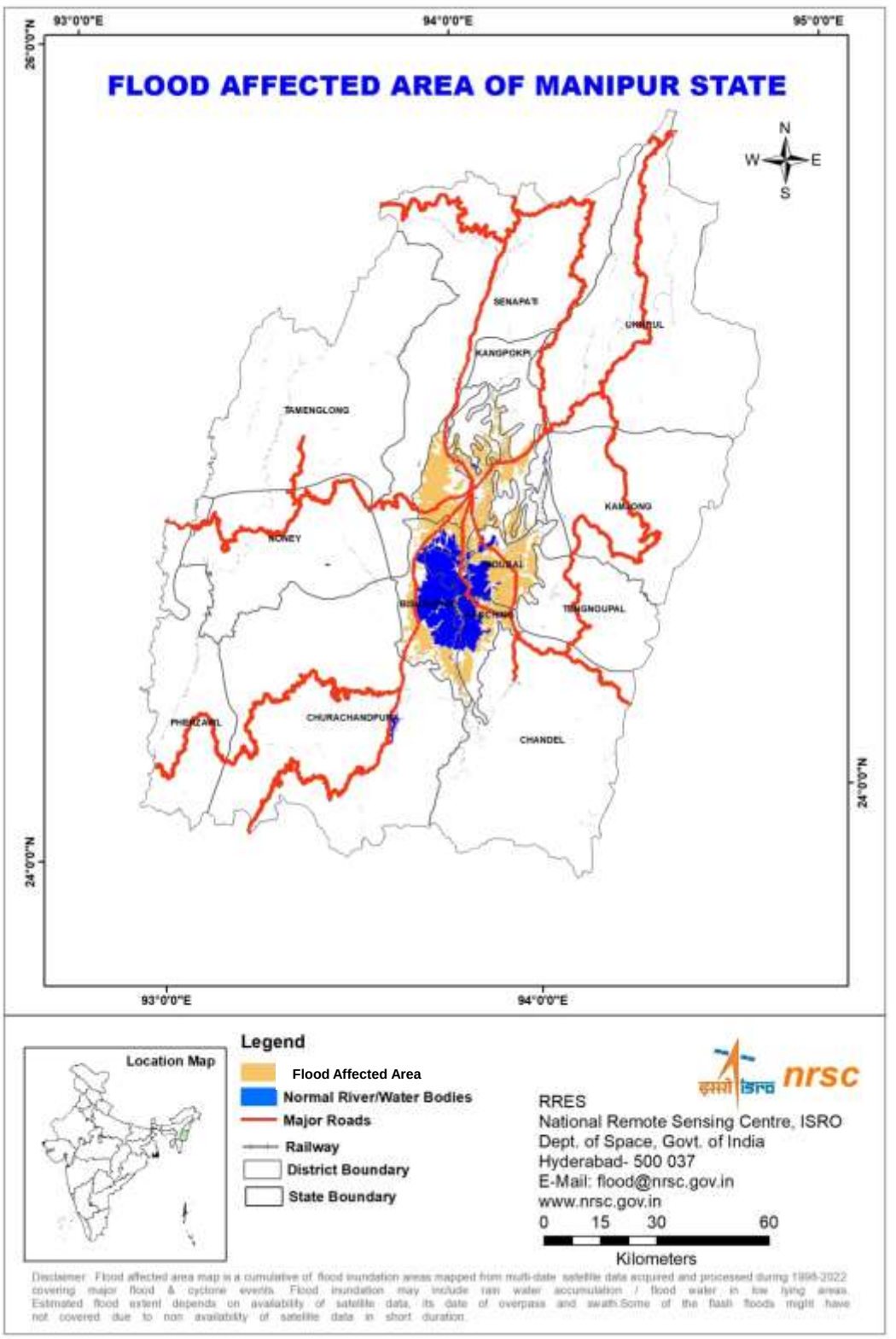
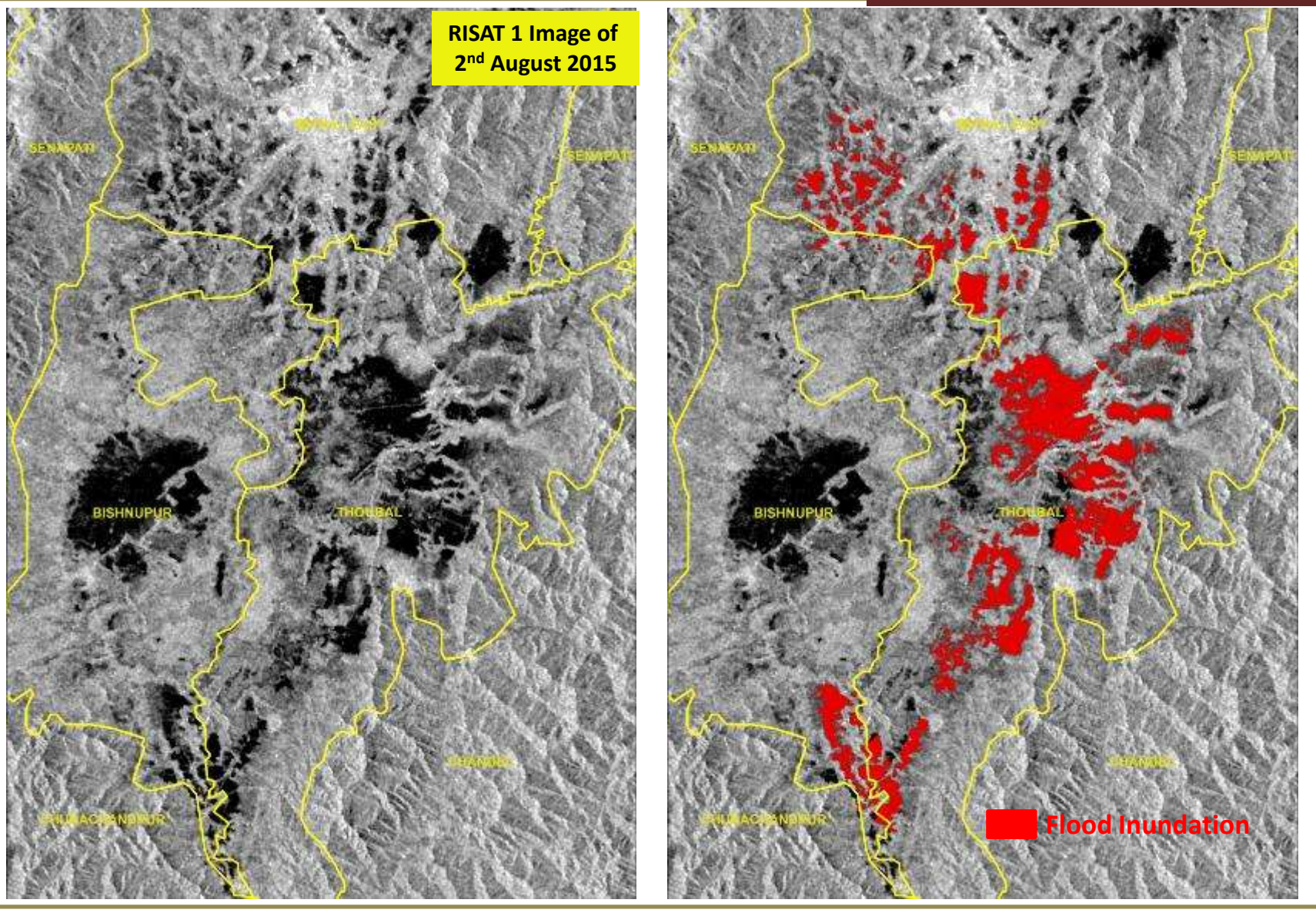
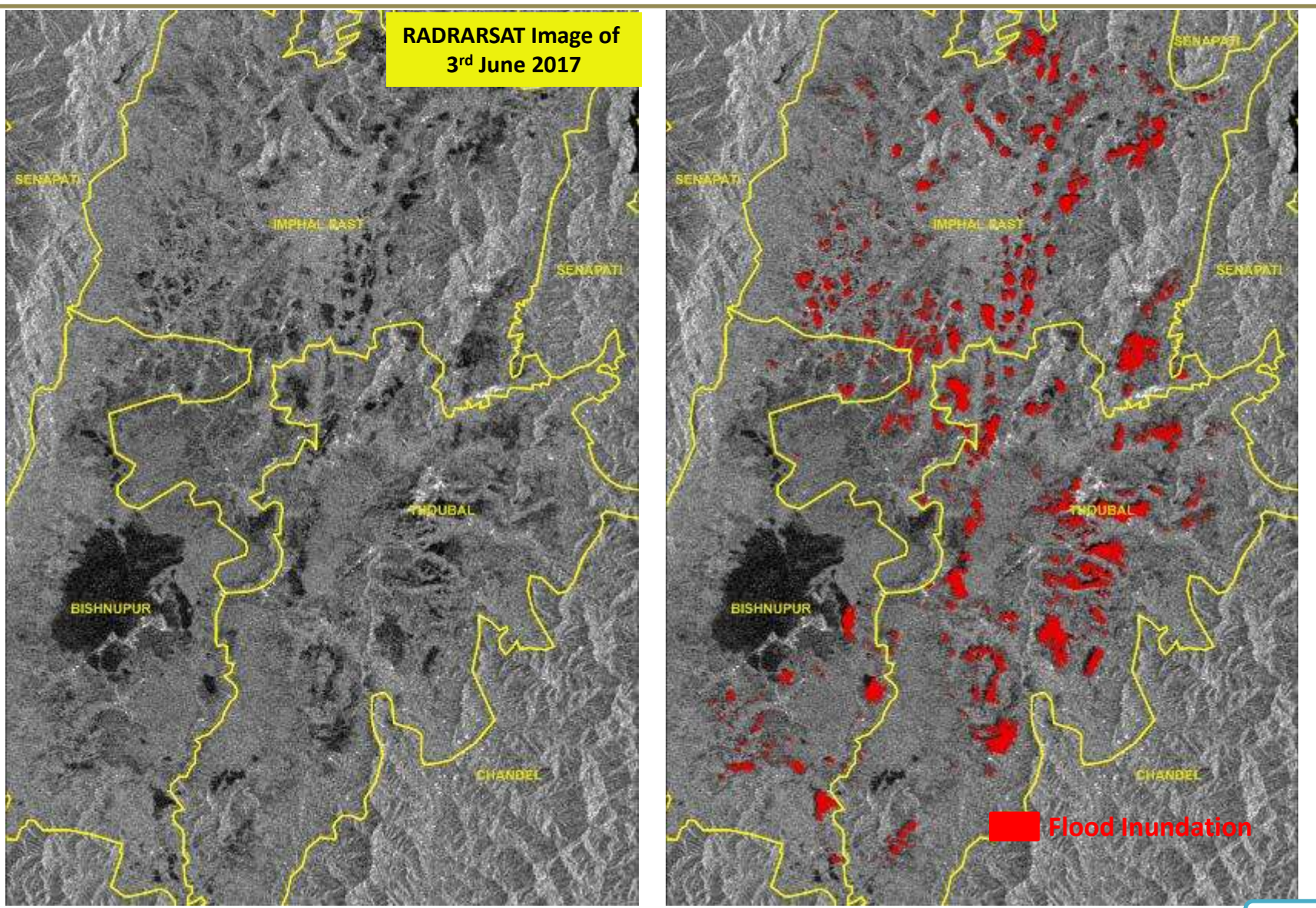


Fig.21.1. Flood affected area in Manipur State


RISAT 1 Image of
2nd August 2015
SENAPATI
SENAPATI
BISHNUPUR
THOUBAL
CHANDEL
SENAPATI
SENAPATI
BISHNUPUR
THOUBAL
CHANDEL
Flood Inundation


RADRARSAT Image of
3rd June 2017
SENAPATI
IMPHAL EAST
SENAPATI
THOUBAL
BISHNUPUR
CHANDEL
SENAPATI
IMPHAL EAST
SENAPATI
THOUBAL
BISHNUPUR
CHANDEL
Flood Inundation

Meghalaya

22. Meghalaya

The state of Meghalaya is mountainous, with stretches of valley and highland plateaus, and it is geologically rich. It mainly consists of Archean rock formations. The elevation of the plateau ranges between 150 m to 1,961 m . The central part of the plateau comprising the Khasi Hills has the highest elevations, followed by the eastern section comprising the Jaintia Hills region. With the average annual rainfall as high as 12,000 mm in some areas, Meghalaya is the wettest place on Earth. The western part of the plateau, comprising the Garo Hills region with lower elevations, experiences high temperatures for most of the year. Meghalaya has many rivers. Most of these are rainfed and seasonal. The important rivers in the Garo Hills region are Ganol, Daring, Sanda, Bandra, Bugai, Dareng, Simsang, Nitai and the Bhupai. In the central and eastern sections of the plateau, the important rivers are Khri, Umtrew, Digaru, Umiam or Barapani, Kynshi (Jadukata), Umngi, Mawpa, UmiamKhwan, Umngot, Umkhen, Myntdu and Myntang. In the southern Khasi Hills region, these rivers have created deep gorges and several waterfalls.

22.1 Flood Problem in Meghalaya

The state of Meghalaya is bordered on the northwest by mighty Brahmaputra river. Heavy led incessant rainfall followed by frequent overspill of water from Brahmaputra river on the northwest side of the state has lead to floods in the West Garo Hills and South west garo hills. Although the state has many rivers, the main cause of floods is mostly riverine pertaining to spill over from Brahmaputra. Floods were witnessed during the years of 2014, 2019, 2022 . Heavy torrential rains have lashed the Garo Hills region due to heavy rains in Upper catchment areas of Brahmaputra river followed by rise in water levels during fourth week of September 2014. NRSC/ISRO has acquired Resourcesat-2 AWiFS image of 30-Sep-2014. Major flood events in Meghalaya is listed in Table 22.1 for which satellite derived spatial flood inundation maps were generated and disseminated to state / central government disaster support management organizations .

Table.22.1 . Major flood events in Meghalaya state

	Year	Description of the flood event	Districts affected
1	2004	Floods hit Meghalaya due to incessant rains in the North-Eastern India during the second week of July	2
2	2014	Floods were reported during 4th week of Sep 2014 due to heavy rains	1
3	2020	Floods occurred in various parts of Meghalaya state in the third week of July 2020 due to heavy rains	
4	2022	Floods were reported during the second week of June, 2022 under the influence of heavy incessant rains	2

22.2 Flood Affected Area in Meghalaya

Cumulative flood inundation maps were utilised for generation of total flood affected area map in Meghalaya and is estimated as 8,787 ha. Flood Affected Area Map is shown in Figure.22.1. and district wise flood affected area statistics are shown in Table. 22.2. Two districts in Meghalaya have flood affected area <10000 ha. About 6000 ha is observed to be inundated in West Garo Hills district.

Table.22.2 District wise statistics of Flood affected area in Meghalaya

S. No.	District	Flood Affected Area (ha)
1	West Garo Hills	7513
2	South West Garo Hills	1275
	TOTAL	**8787**

Glimpses of satellite images / flood inundation over the time period are depicted in this section.

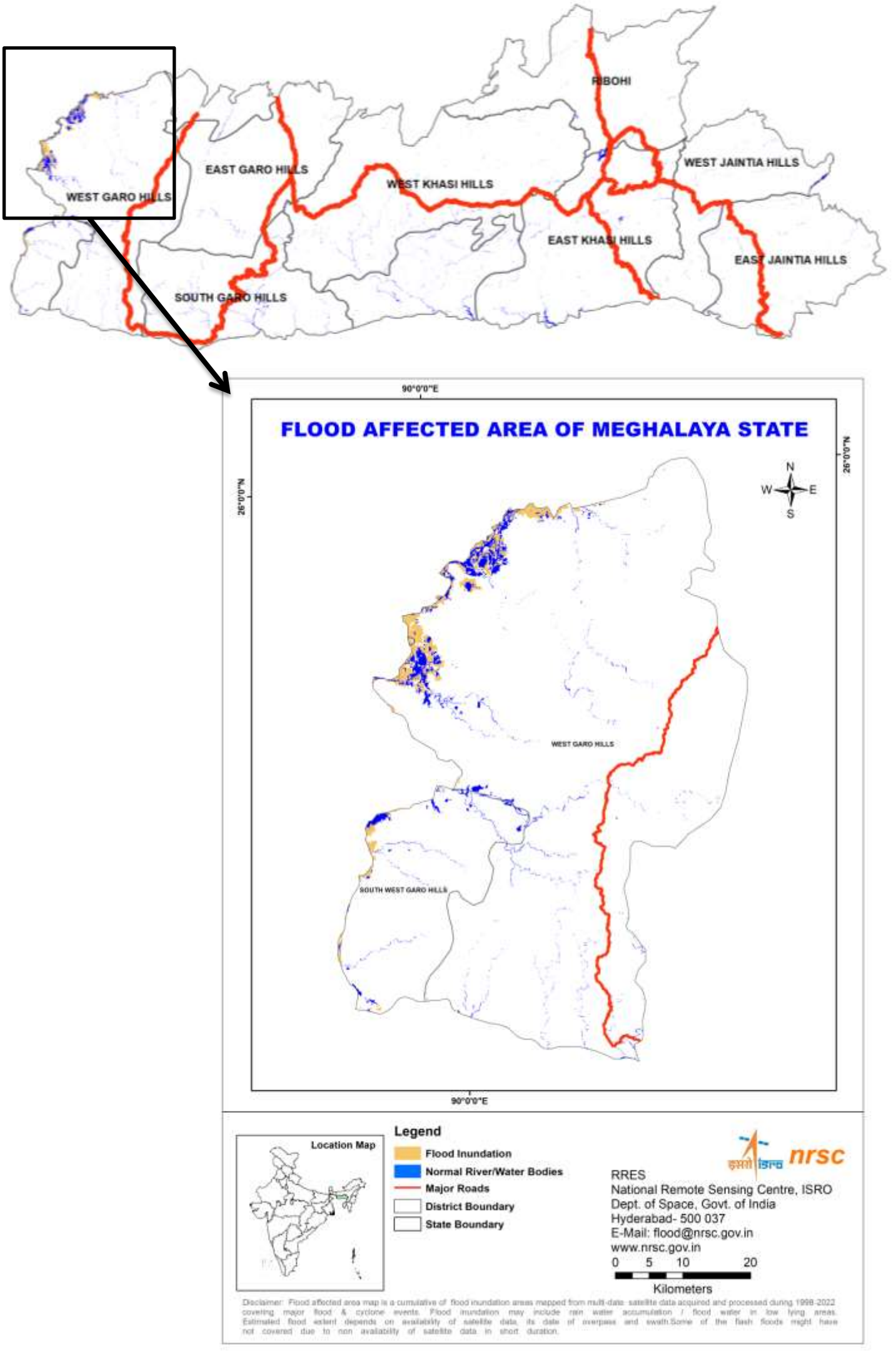
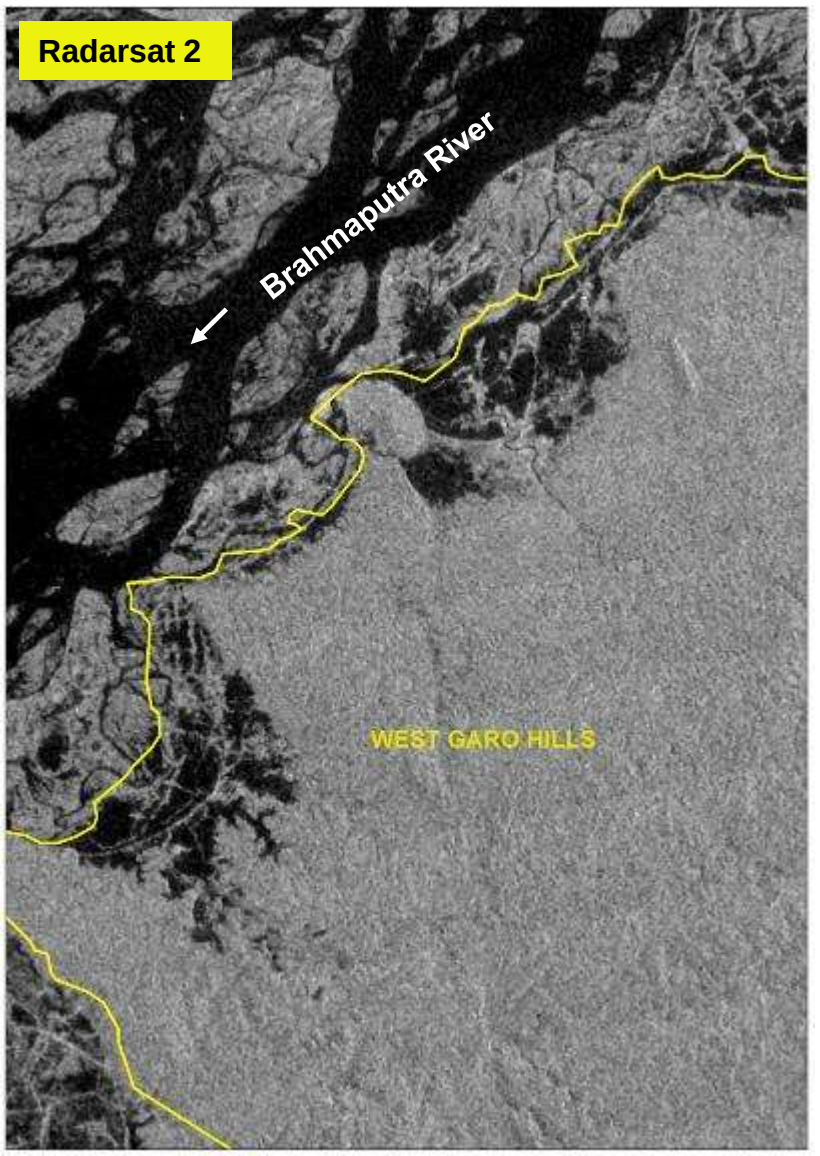
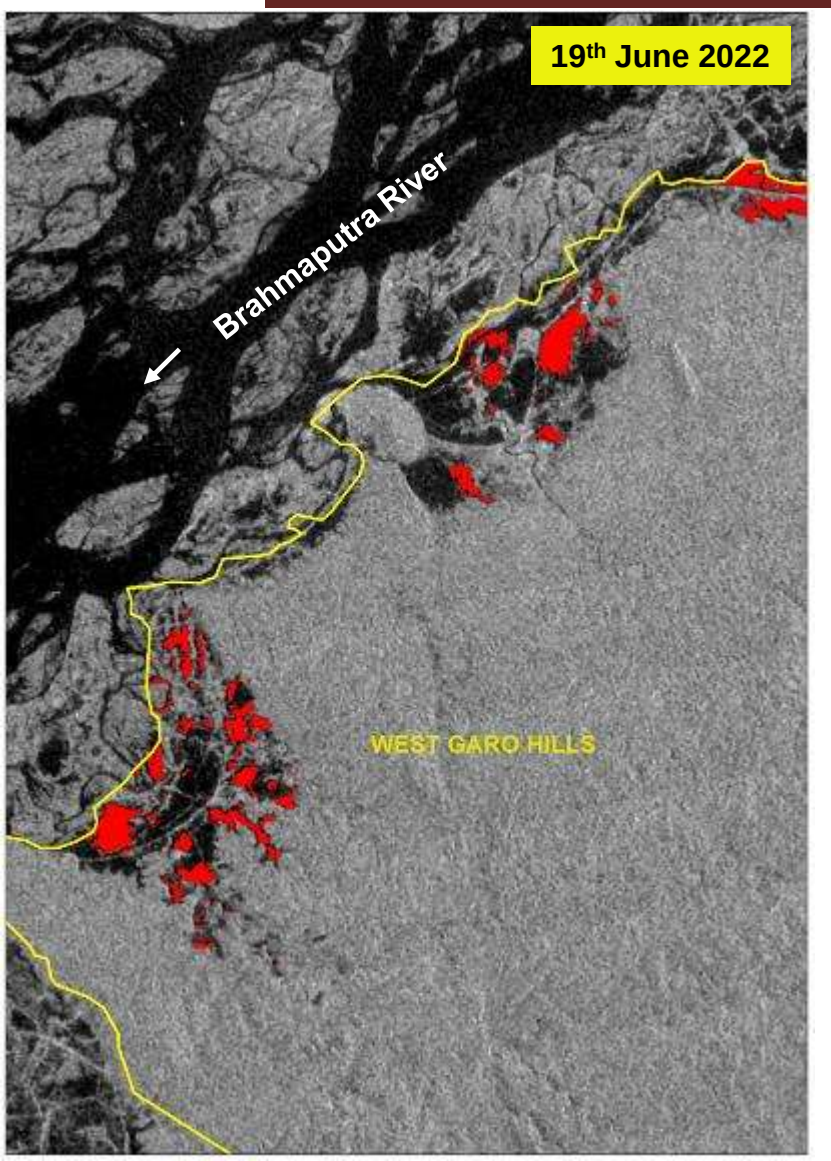
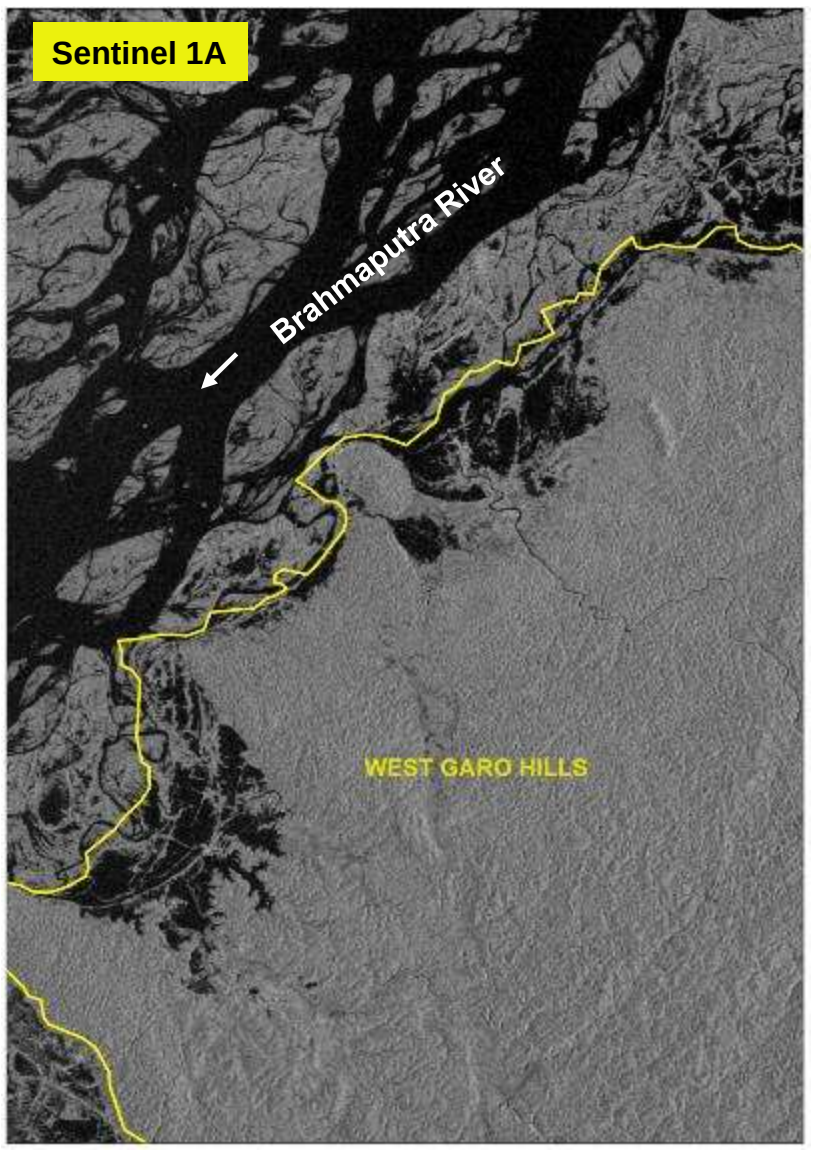
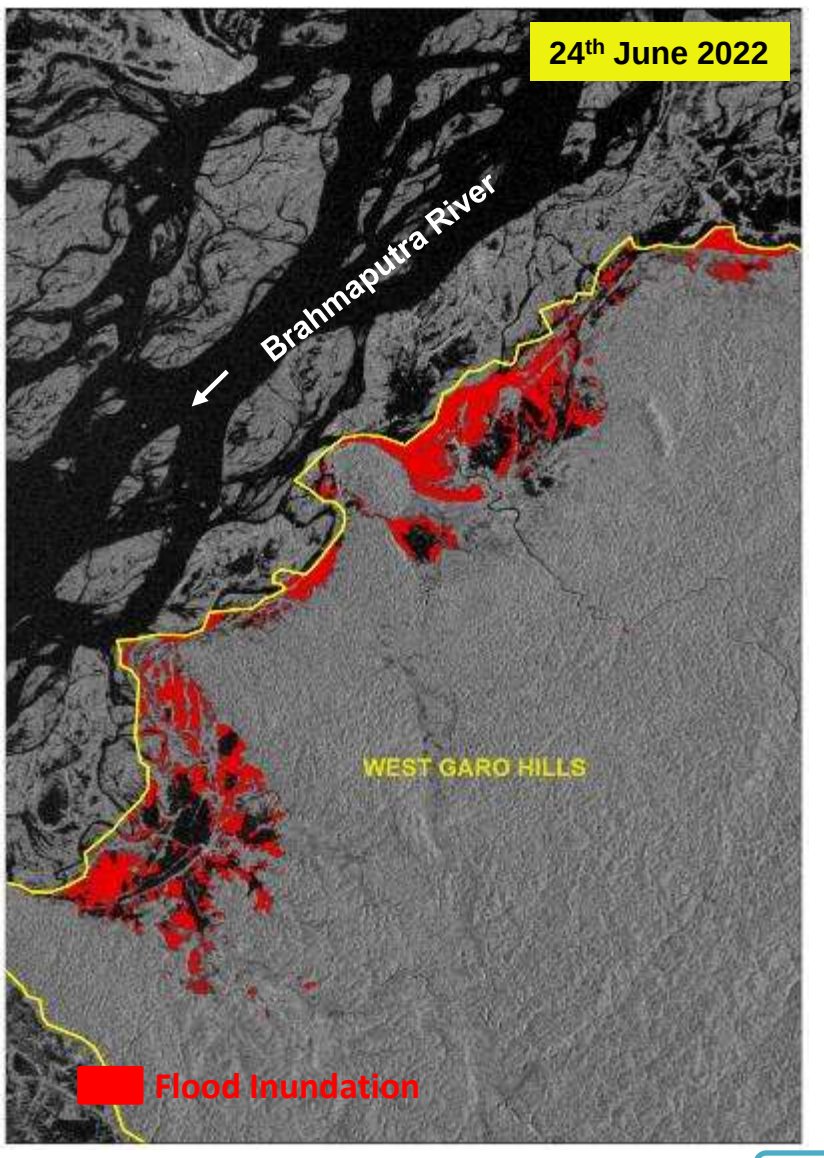


Fig.22.1 Flood affected area in Meghalaya State


Radarsat 2
Brahmaputra River
WEST GARO HILLS


19th June 2022
Brahmaputra River
WEST GARO HILLS
Flood Inundation


Sentinel 1A
Brahmaputra River
WEST GARO HILLS


24th June 2022
Brahmaputra River
WEST GARO HILLS
Flood Inundation

23. Odisha

Odisha is bounded by the Bay of Bengal on the east; Chhattisgarh on the west, Jharkhand and West Bengal on the north and Andhra Pradesh on the south. It has a coast line of about 480 km. It extends over an area of 1,55,707 km^2 covering about 4.87% of the total area of India. The State is broadly divided into four geographical regions viz. the northern plateau, central river basins, eastern hills and coastal plains. The northern plateau region comprises mainly Mayurbhanj, Keonjhar and Sundargarh districts. The central river basins lie between the northern plateau and eastern hills and include Bolangir, Sonepur,Sambalpur, Deogarh, Baragarh, Jharsuguda, Dhenkanal & Angul districts and a part of Cuttack district. The eastern hills which constitute the last portion of the Eastern Ghats, lie to the south and southwest of central river basins stretching for about 250 km in northeast – southwest direction through the districts of Koraput, Rayagada, Nabarangpur,Malkangiri, Kalahandi, Nuapada, Gajapati and a part of Ganjam district. The eastern hills are elevated and are generally 900 m above sea level. The coastal plains comprise mostly of Balasore, Bhadrak, Kendrapada, Jagatsinghpur, Jajpur, Puri, Khordha, Nayagarh districts and a portion of Ganjam and Cuttack districts. The areas of the state north of latitude 20°N have elevation up to 500m above sea level, in general and in the south western districts, they rise to 1500-1600m above sea level.

There are four groups of rivers which flow through Odisha into the Bay of Bengal viz. (i) Rivers that have a source outside the State (the Subarnarekha, the Brahmani and the Mahanadi), (ii) Rivers having a source inside the State (the Budhabalanga, the Baitarini, the Salandi, and the Rushikulya), (iii) Rivers having a source inside the Odisha, but flow through other states (the Bahudu, the Vansadhara, and the Nagavali), (iv) Rivers having a source inside Odisha, but tributary to rivers which flow through other states (the Machkund, the Sileru, the Kolab, and the Indravati). All the rivers of Odisha are primarily peninsular rivers and have originated from (a) the Chhota Nagpur plateau in Jharkhand, (b) the Amarkantak plateau in Chhattisgarh, or (c) the Eastern Ghats within Odisha. All these rivers are non-perennial in character.

3.1 Floods & Cyclones - Odisha State

Amongst all the natural disasters afflicting the State, floods are the most frequent and devastating. Almost 80% of the annual rainfall is concentrated over a short monsoon period of 3 months. While the coastal plains are very flat, the slopes in the inlands are precipitous. This leads to heavy siltation, flash floods and poor discharge of flood waters into the sea and thus the embankments are breached with alarming frequency.

In Odisha, damages due to floods are caused mainly by the Mahanadi, the Brahmani and the Baitarani, which have a common delta where floodwaters intermingle, and, when in spate simultaneously, wreak considerable havoc. The problem is further accentuated when flood synchronises with high tide. The silt deposited constantly by these rivers in the delta area raises the bed levels and the rivers often overflow their banks or break through new channels causing heavy damages. Floods and drainage congestion also affect the lower reaches along the Subarnarekha River. Rivers Rushikulya, Vansadhara and Budhabalanga also cause occasional floods. The entire coastal belt is prone to storm surges, which is usually accompanied by heavy rainfall thus making the estuary region vulnerable to both storm surges and river flooding.

Odisha has witnessed two devastating cyclones during 2013 cyclone “PHAILIN" and Cyclone "TITLI" during 2018. Cyclone Phailin has caused extensive damage to crops and infrastructure and was categorised as Very Severe Tropical Cyclone by India Meteorological Department, Government of India. Odisha witnessed severe floods and cyclones on the last two decades. The years 2006, 2007, 2008, 2009, 2011, 2013, 2018, 2019 witnessed severe damages brought in due to the floods and cyclones. Major flood events in Odisha is listed in Table 23.1 for which satellite derived spatial flood inundation maps were generated and disseminated to state / central government disaster support management organizations by NRSC, ISRO.

Table.23.1 Major flood events in Odisha state

S.No	Year	Description of the flood event	Districts affected
1	1998	Super cyclone	10
2	2003	Floods occurred during 31st Aug – 20th Sep 2005. Water levels in Mahanadi, Kathajodi rivers and their tributaries Devi, Kandala and Biluakhaicrossed danger level at several locations. Incessant rains coupled with excess water releases from Hirakud reservoir on Mahanadi river and Rengali reservoir on Brahmanri river resulted in severe floods in coastal districts of Orissa.	12
3	2004	Floods occurred during 26th-30th August 2004 due to heavy rainfall in the catchment of Baitarani, Subarnarekha and Budhabalanga rivers and rise in water levels.	4
4	2005	Floods occurred in 3 spells during 06th Jul, 07th August, 17-24th Sep 2005 due to Heavy rains in the catchment areas of Baitarani, Kharasrota and Brahmani rivers have triggered floods.	3
5	2006	Floods occurred during 1st week of Sep 2006 due to heavy rains caused by a depression over northwest Bay of Bengal triggering floods due to rise in levels in Baitarani, Brahmani.	14
6	2007	Floods occurred during 4-13th , 21-23rd Aug, 23-24th Sep 2007 due to y rains triggered floods in Subarnarekha, Baitarini, Vamsadhara, Nagavalli and Hati rivers.	12

S.No	Year	Description of the flood event	Districts affected
7	2008	Floods occurred due to extreme rainfall and rise in water levels of Baitarani and Brahmani rivers during 19th -30th Jun, 7th -24th Jul, 18-30th Sep 2008.	14
8	2009	Due to the depression in the Bay of Bengal floods have occurred during 14th -29th Jul , 8th -12th Sep 2009.	14
9	2011	Floods were reported in Northern parts of Orissa due to depression in Bay of Bengal during 18-22nd Jun 2011 ; During 5th Sep – 1st Sep 2011 the first week of September, heavy downpour in the catchment areas and release of water from Hirakud dam worsened the flood situation.	10
10	2013	Floods occurred due to rains, and rise in water level in Brahmani, Subarnarekha, Budhabalanga, and Jalaka rivers during 2nd week of August , 25-29th Oct 2013	12
11	2014	Floods occurred due to rains, and rise in water level in Mahanadi, Baitarni, Subarnarekha & Budhabalanga.	11
12	2016	Flood occurred on 09-09-2016	1
13	2017	Floods occurred due to rains, and rise in water level in Baitarani, Burhabalang, Subarnrekha.	5
14	2018	Rise in water level in river Baitarani due to flood occurrence during 23rd Jul – 25th August, 20th Aug -25th Sep, 12th -16th Oct 2018.	13
15	2019	Cyclone Fani was the strongest tropical to strike Odisha since Phailin in 2013. Fani made landfall near Puri in Odisha at 8am (IST) on the 3rd of May, 2019.	11
16	2020	Heavy rains were reported in Mahanadi, Brahmani, Baitarani & Subarnarekha catchment regions during the fourth week of August, 2020. As a result Mahanadi, Brahmani, Baitarani & Subarnarekha rivers were flowing in extreme flood situation.	16
17	2022	Heavy rainfall and runoff during August 2022 in the Mahanadi river basin has hit the coastal region of Odisha, inundating many villages spread in 13 different districts. Districts that have come under flood impact include Cuttack, Khordha, Puri, Kendrapara, Jagatsinghpur, Boudh, Sambalpur, and Angul.	13

23.2 Flood Affected Area in Odisha

Cumulative flood inundation maps were utilised for generation of map of total flood affected area in Odisha and is estimated as 14,24,313ha. Flood affected area map is shown in Figure.23.1 and district wise flood affected area statistics are shown in Table. 23.2. Seven districts in Odisha has flood affected area> 1,00,000 ha, 2 districts between 50,000-1,00,000 ha, 2 districts between25,000-50,000 ha, 2districts between 10,000-25,000 ha and 10 districts<10000 ha.

Table.23.2 District wise statistics of Flood affected area in Odisha

S. No.	District	Flood Affected Area (Ha)
1	Baleshwar	229691
2	Bhadrak	203525
3	Kendraparha	189195
4	Puri	168662
5	Jajapur	143973
6	Cuttack	120270
7	Jagatsinghapur	118994
8	Khordha	73503
9	Ganjam	56136
10	Mayurbhanj	30976
11	Kendujhar	29508
12	Dhenkanal	24483
13	Nayagarh	20766
14	Anugul	6587
15	Bauda	4171
16	Koraput	1901
17	Sundargarh	453
18	Jharsuguda	448
19	Deogarh	354
20	Sonapur	294
21	Baragarh	152
22	Sambalpur	138
23	Nabarangapur	133
TOTAL		**1424313**

Glimpses of satellite images / flood inundation over the time period are depicted in this section.

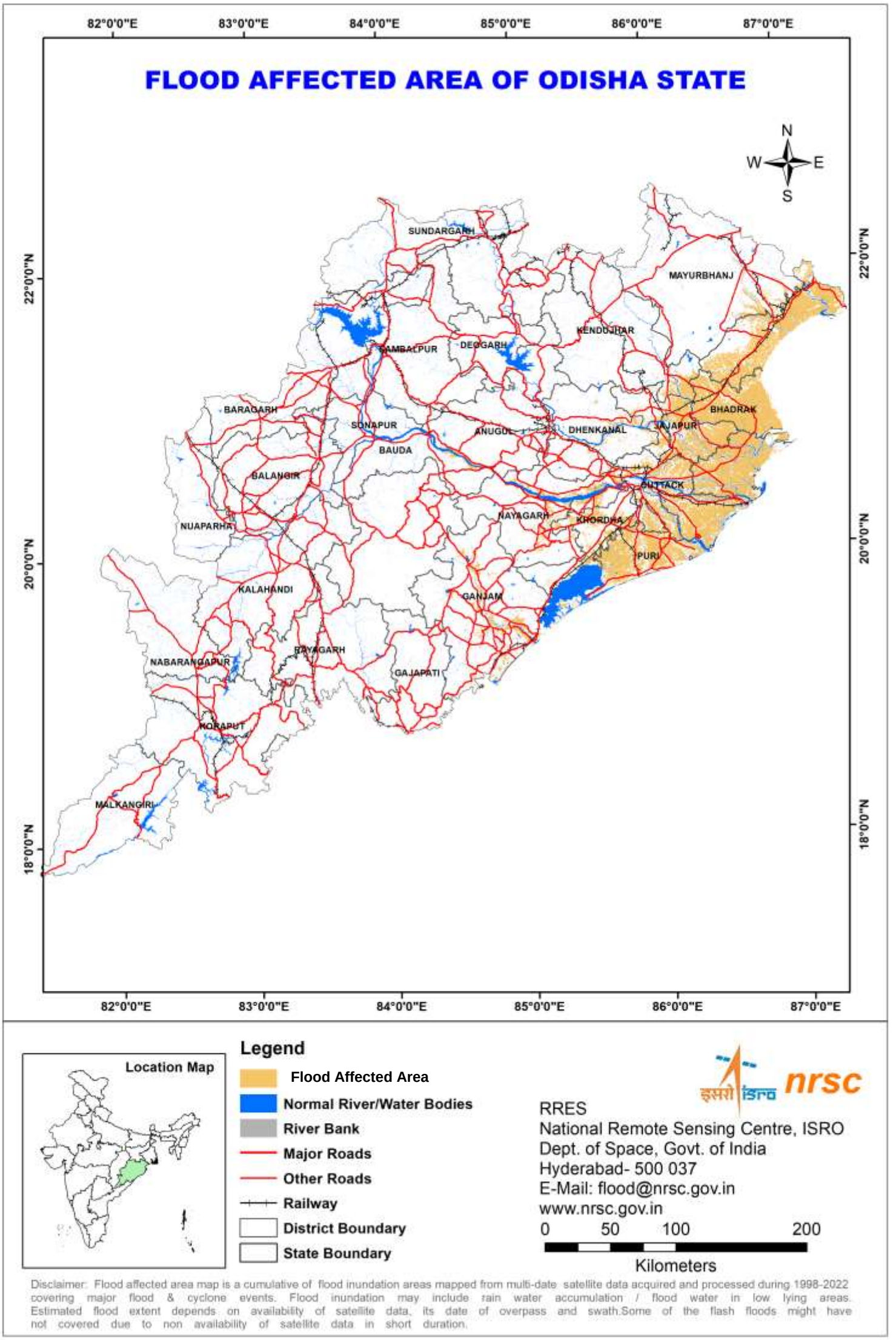
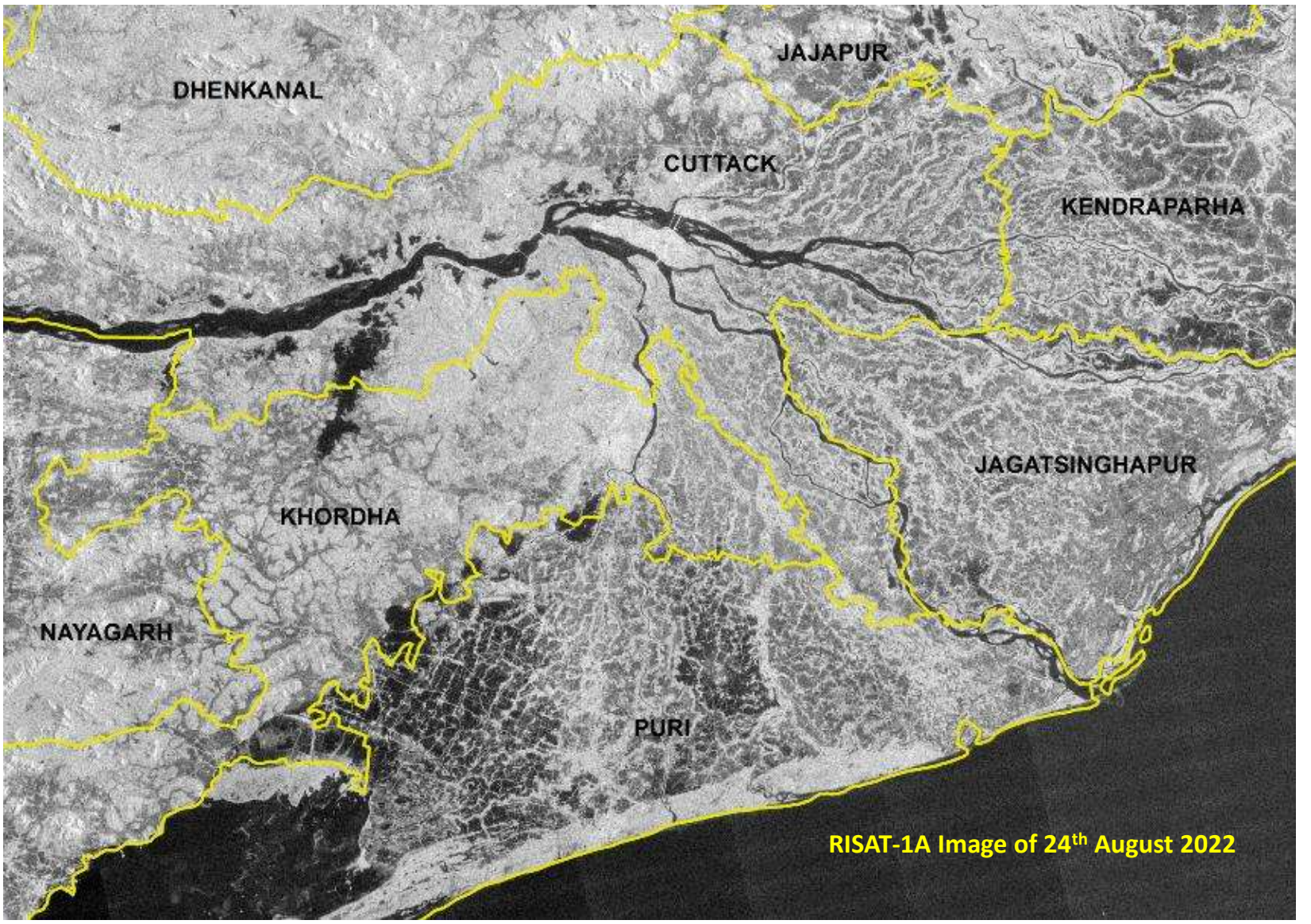
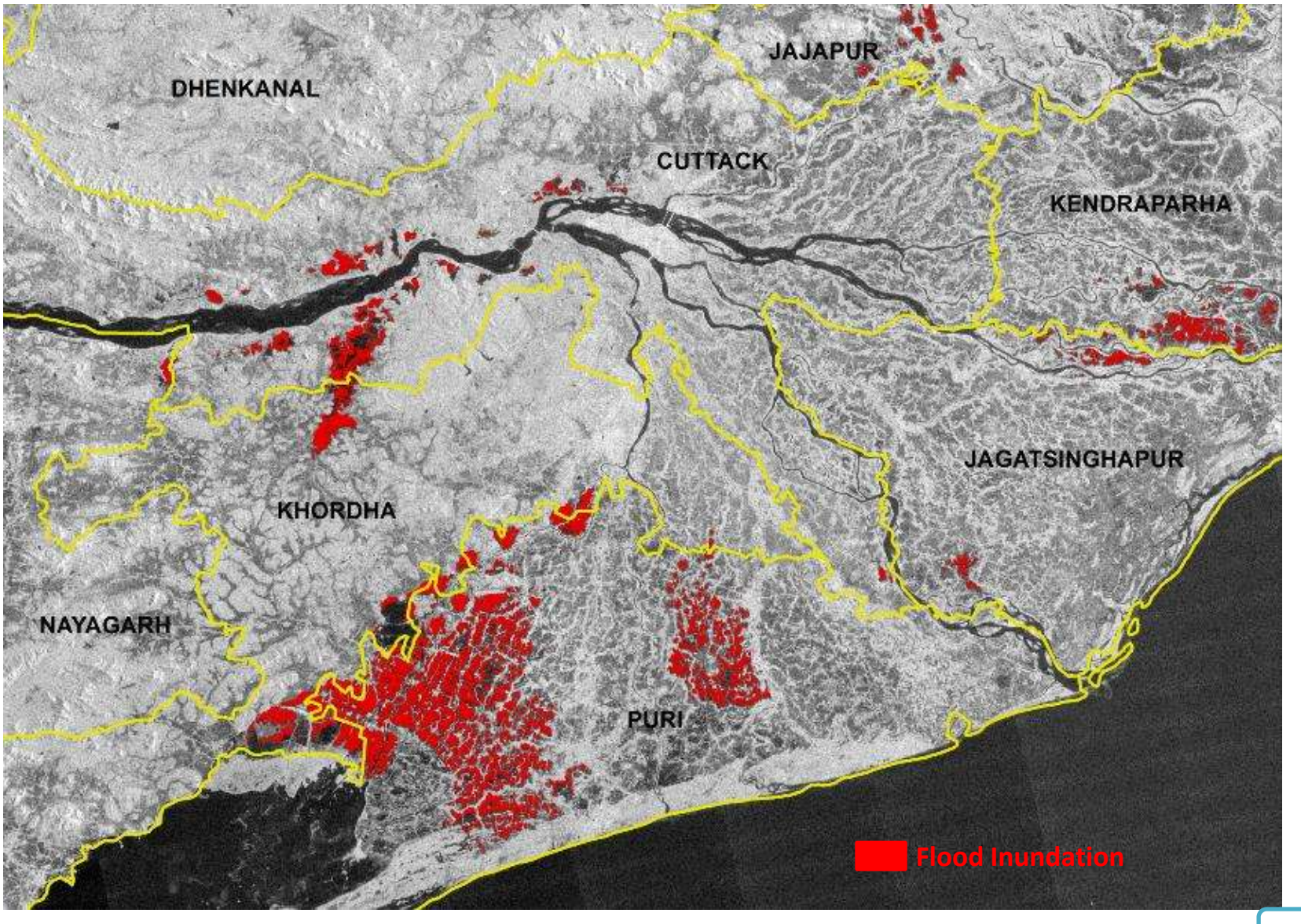
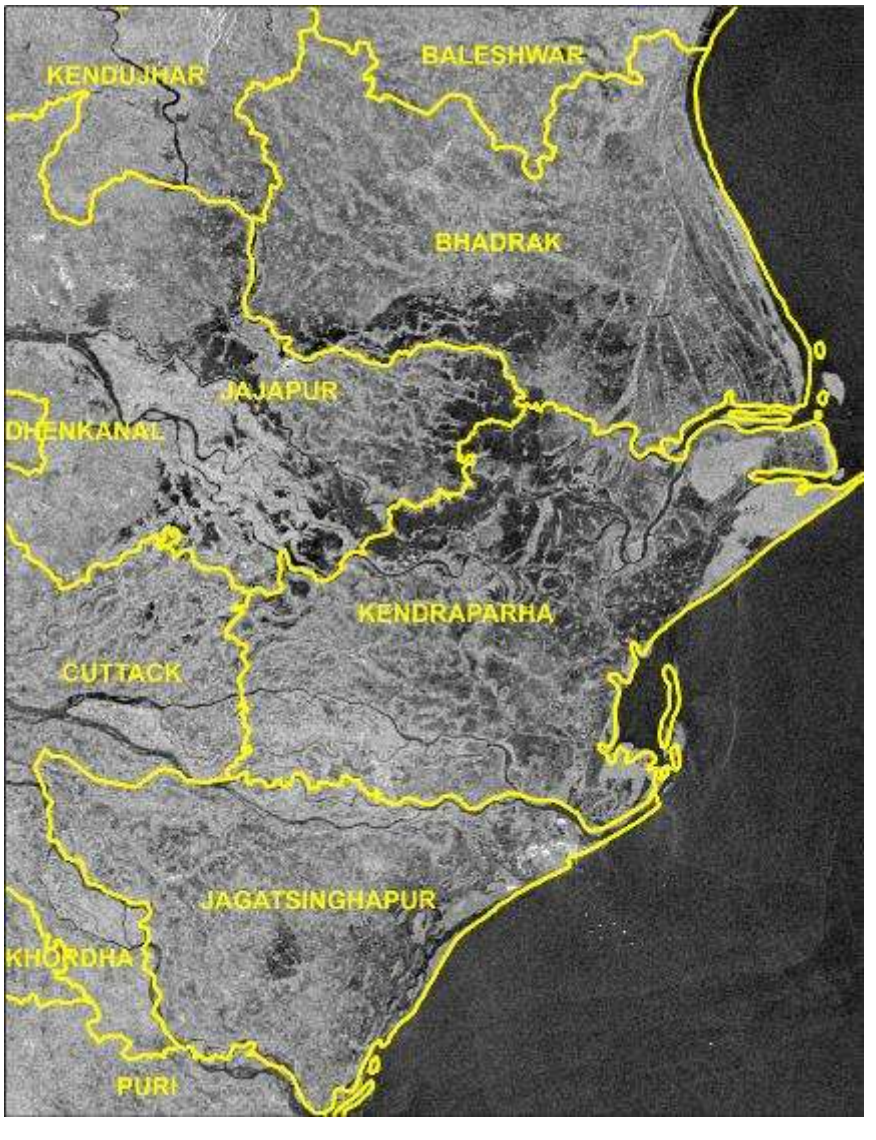
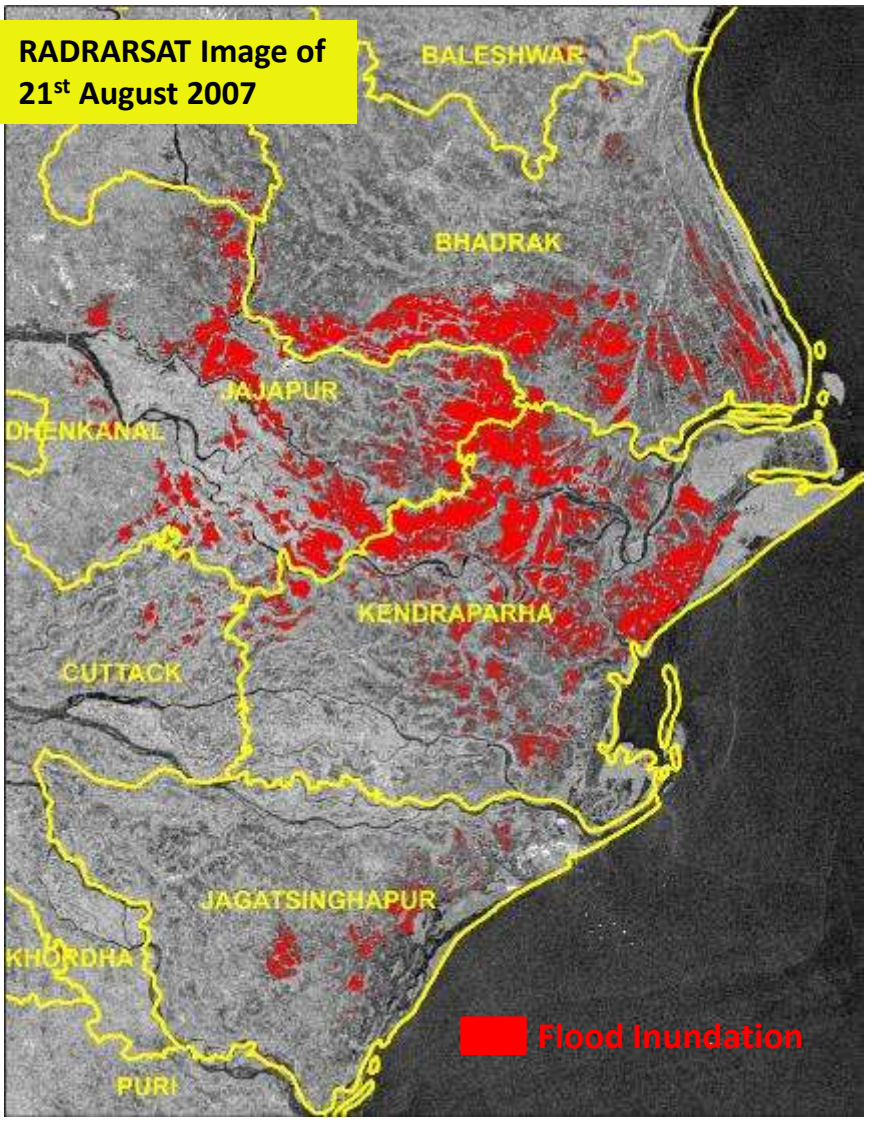


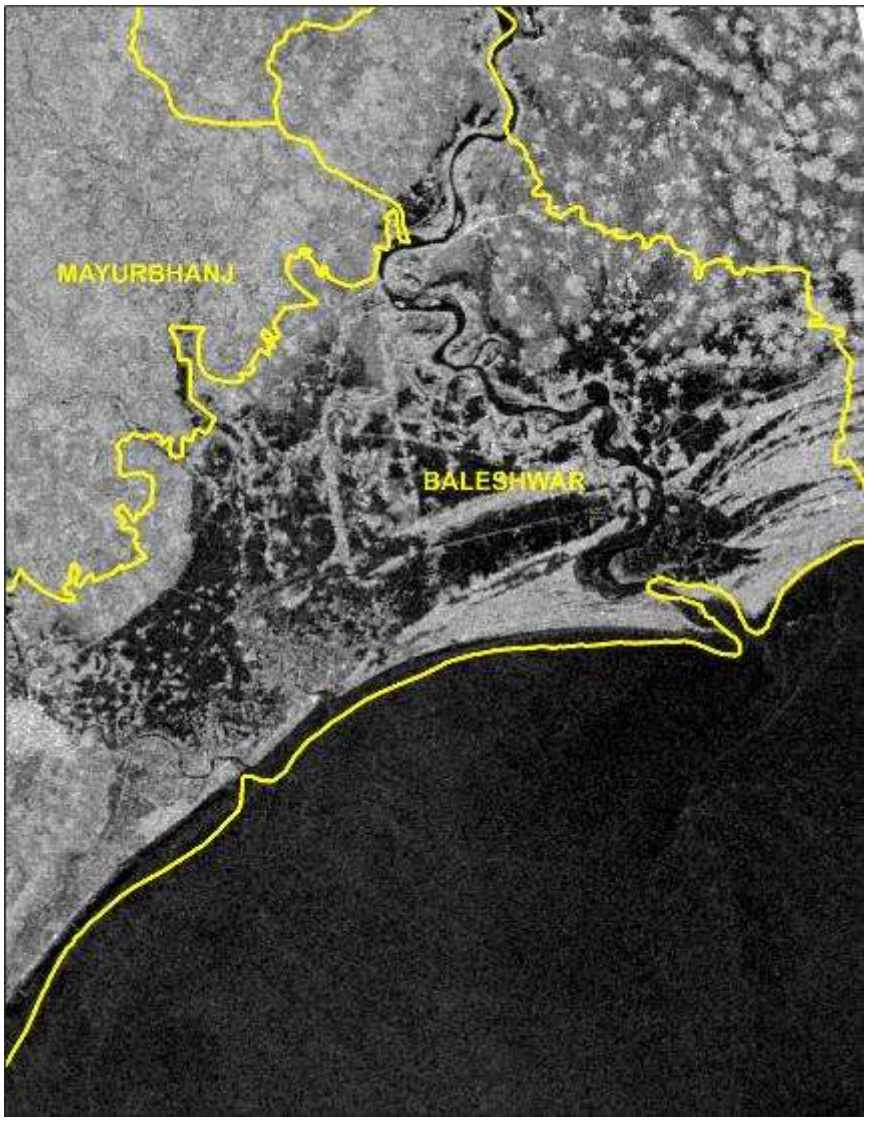
Fig.23.1 Flood affected area in Odisha State

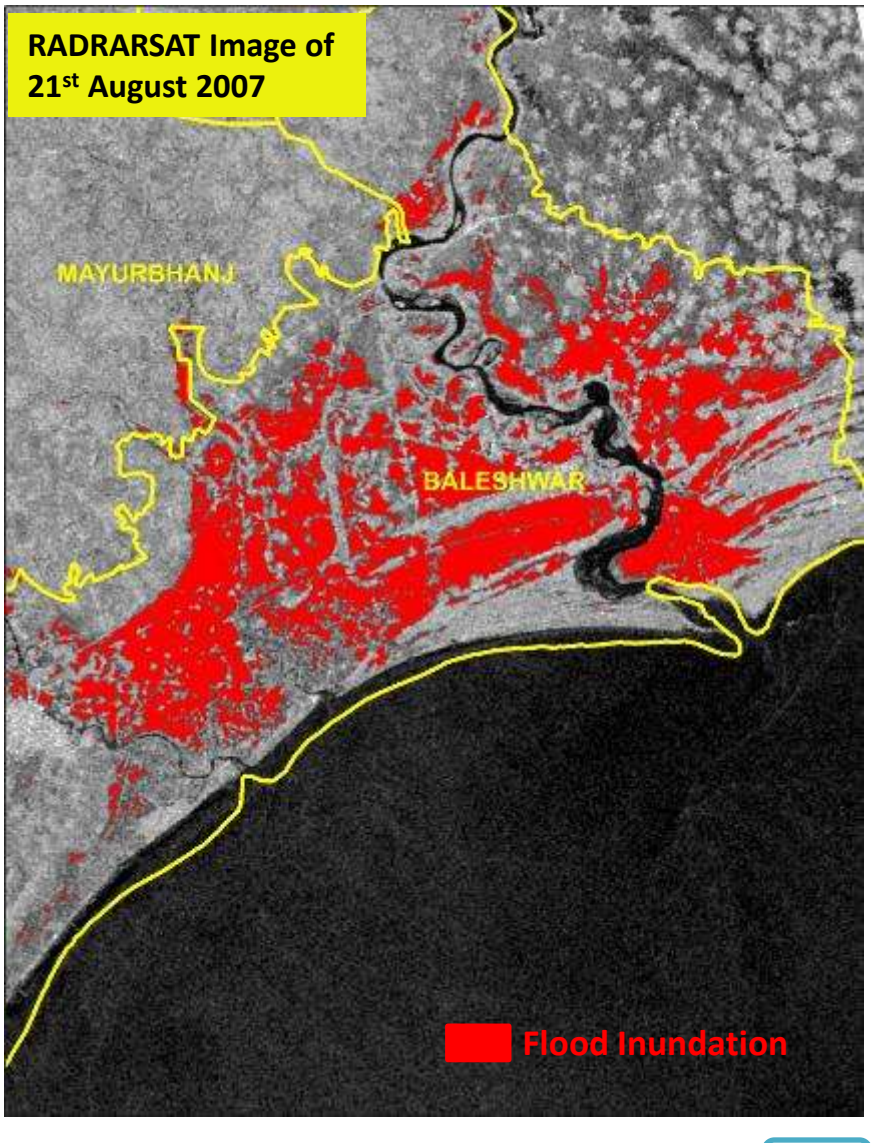

DHENKANAL
JAJAPUR
CUTTACK
KENDRAPARHA
JAGATSINGHAPUR
KHORDHA
NAYAGARH
PURI
RISAT-1A Image of 24th August 2022

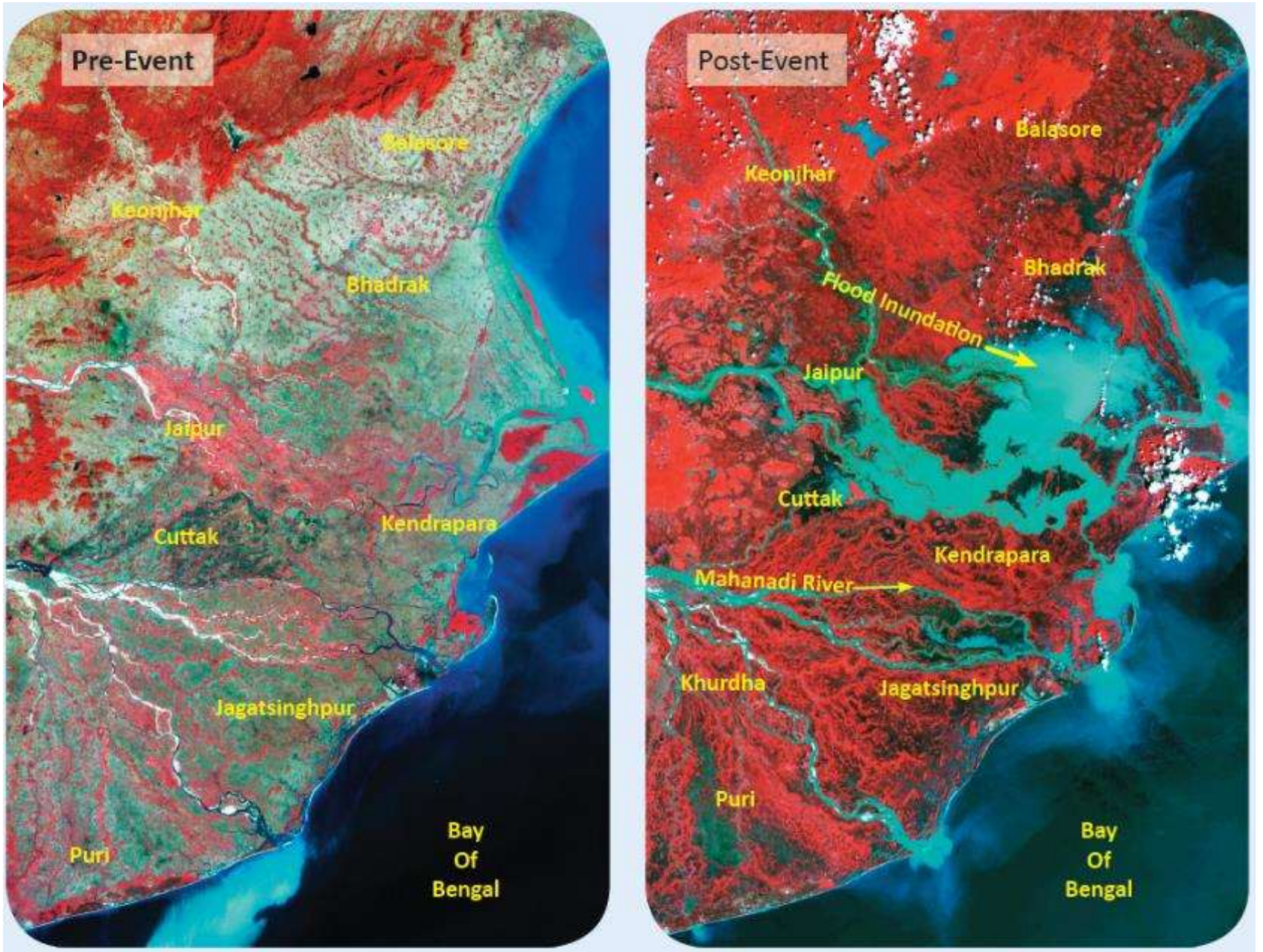

DHENKANAL
JAJAPUR
CUTTACK
KENDRAPARHA
JAGATSINGHAPUR
KHORDHA
NAYAGARH
PURI
Flood Inundation


KENDUJHAR
BALESHWAR
BHADRAK
JAJAPUR
DHENKANAL
KENDRAPARHA
CUTTACK
JAGATSINGHAPUR
KHORDHA
PURI


RADRARSAT Image of
21st August 2007
BALESHWAR
BHADRAK
JAJAPUR
DHENKANAL
KENDRAPARHA
CUTTACK
JAGATSINGHAPUR
KHORDHA
PURI
Flood Inundation

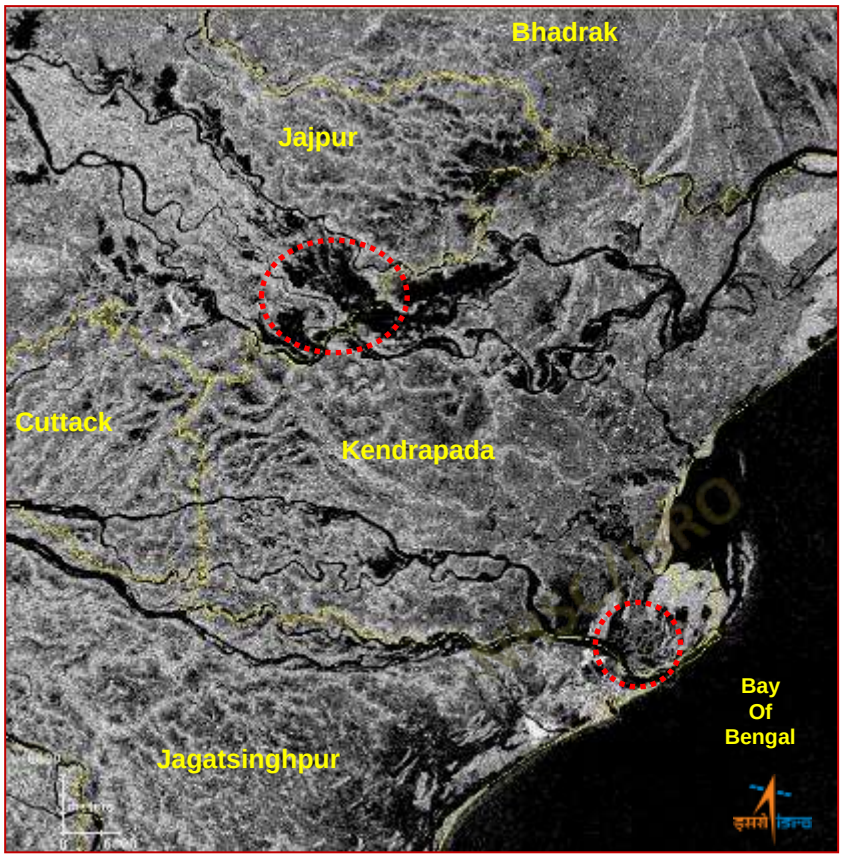

MAYURBHANJ
BALESHWAR


RADRARSAT Image of
21st August 2007
MAYURBHANJ
BALESHWAR
Flood Inundation

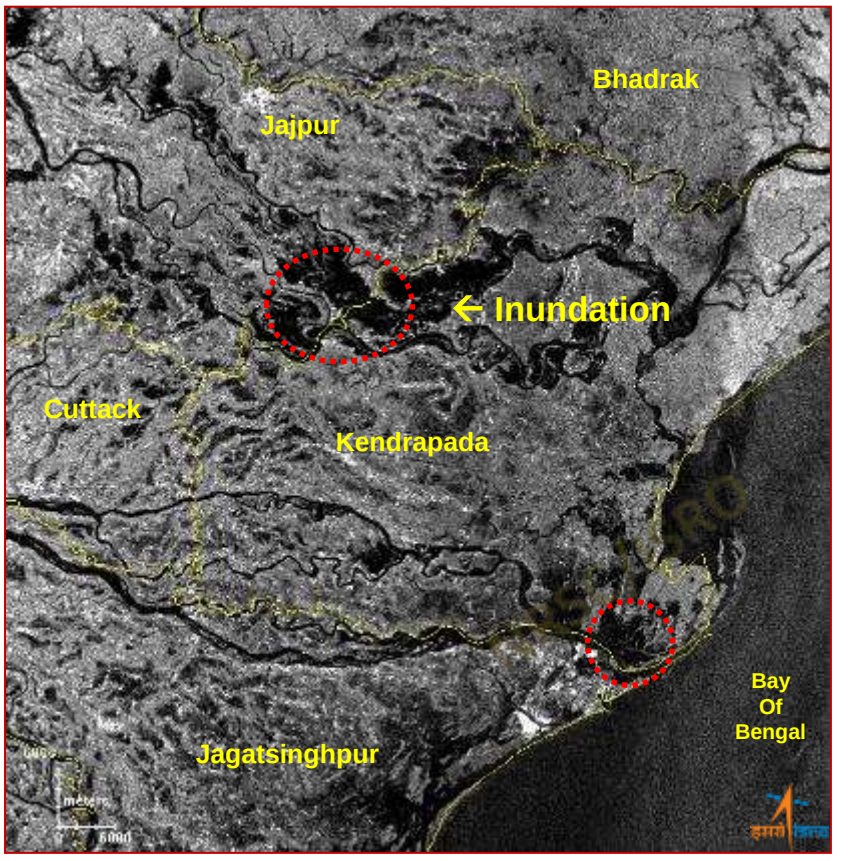


IRS-P6 AWiFS | IRS-P6 AWiFS 28 -Sep- 2011

RADARSAT image of 12-Oct-2013 (17:48 hours IST)



RISAT-image of 13-Oct-2013 (06:00 hours IST)

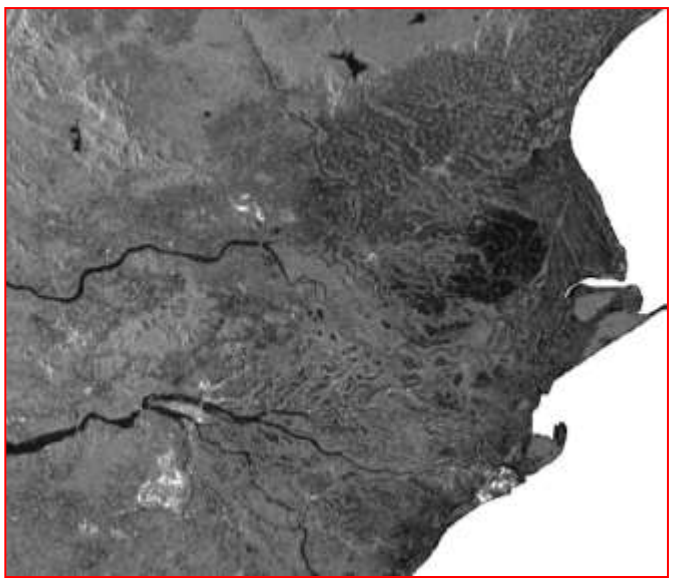


Increase in the inundation within 12 hours

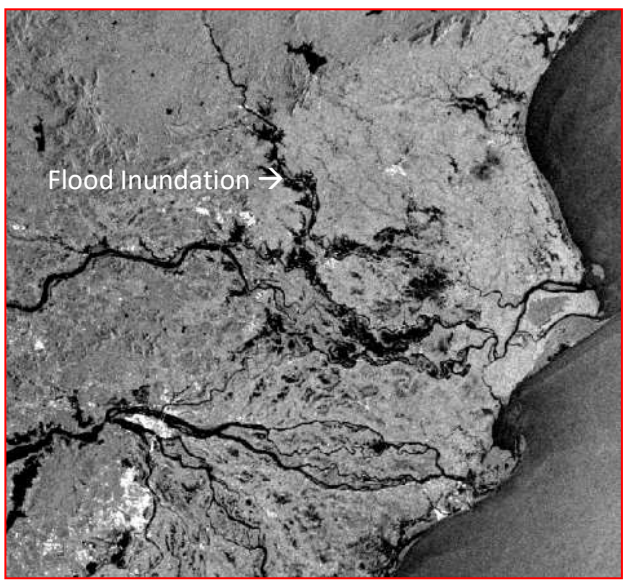
Multi mission satellite images showing flood inundation in coastal Odisha throughout the years

2017

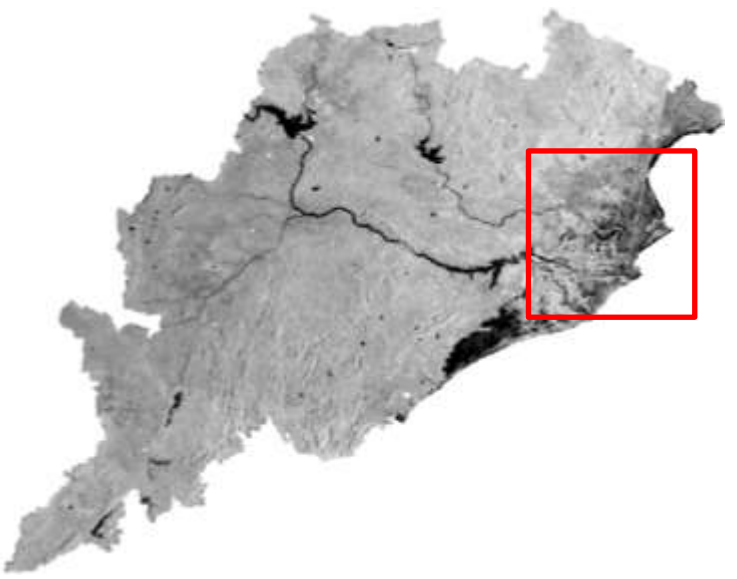
2015



2013

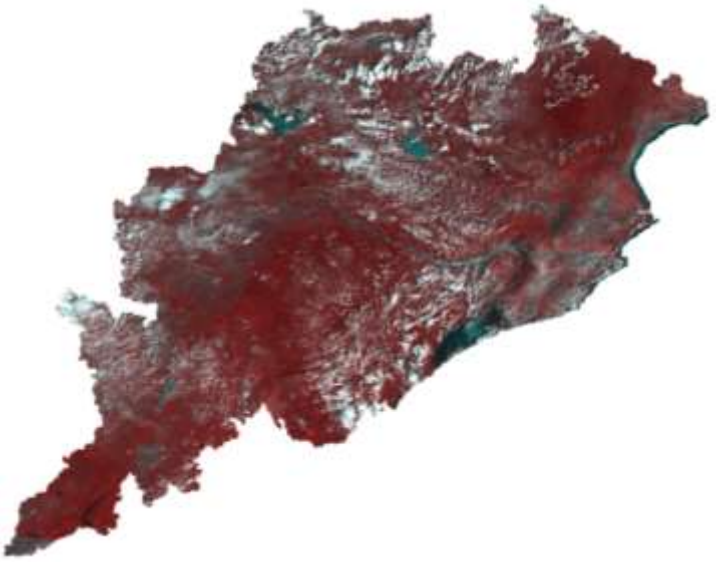


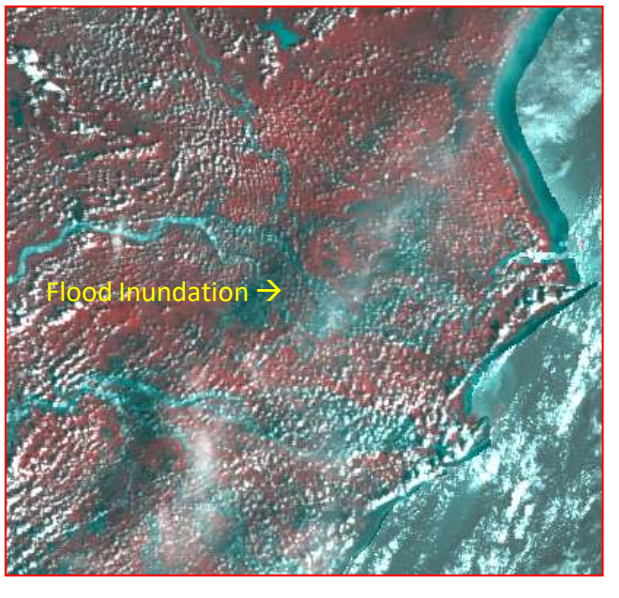
2009



2008

2003





24. Punjab

Punjab

A major part of geographical area of the state is prone to floods although substantial part has been protected through flood control measures. Nevertheless, the protected area also faces risk, although in reduced magnitude, because of possibility of flood in case of failure of protection works. Punjab is a state in northwestern India that is prone to flooding during the monsoon season. The state is crisscrossed by several major rivers, including the Sutlej, Beas, and Ravi rivers, and their tributaries. These rivers can overflow their banks during heavy rainfall, causing flooding in the low-lying areas along their banks.

Punjab has also witnessed severe floods 2010 which have caused extensive damage to crops, houses, and infrastructure. The floods in Punjab are mainly caused by heavy rainfall and the overflowing of the rivers and their tributaries.
The major rivers that flow through Punjab are the Sutlej, Beas, and Ravi rivers. These rivers originate in the Himalayas and flow through the state before entering Pakistan. When these rivers receive heavy rainfall, they can cause flooding in the low-lying areas along their banks.

In 2019, Punjab witnessed one of the worst floods in recent years, which affected several districts in the state. The floods were caused by heavy rainfall and the overflowing of the Sutlej River and its tributaries.

The flood risk in Punjab is also heightened by factors such as deforestation, soil erosion, and the rapid urbanization of flood-prone areas. Deforestation can cause soil erosion, leading to the sedimentation of rivers and the reduction of their carrying capacity. Urbanization can also increase the risk of flooding by altering the natural drainage systems and by constructing buildings and infrastructure in flood-prone areas.

Punjab is a state in northwestern India that is crisscrossed by several major rivers, including:

Sutlej River: The Sutlej River is the longest of the five rivers that flow through the historic region of Punjab. The river originates in the Himalayas and flows through the states of Himachal Pradesh, Punjab, and Haryana before entering Pakistan. The Sutlej River is an important source of water for irrigation in Punjab and plays a crucial role in the state's economy.
Beas River: The Beas River is a major tributary of the Sutlej River and originates in the Himalayas. The river flows through the states of Himachal Pradesh and Punjab before entering Pakistan. The Beas River is an important source of water for irrigation in Punjab and is also used for hydroelectric power generation.
Ravi River: The Ravi River is another major tributary of the Sutlej River and originates in the Himalayas. The river flows through the states of Himachal Pradesh and Punjab before entering Pakistan. The Ravi River is an important source of water for irrigation in Punjab and is also used for hydroelectric power generation.
Ghaggar River: The Ghaggar River, also known as the Hakra River, is a seasonal river that originates in the Shivalik Hills of Himachal Pradesh. The river flows through the states of Punjab, Haryana, and Rajasthan before entering Pakistan. The Ghaggar River is an important source of water for irrigation in Punjab.

These rivers and their tributaries are a vital source of water for agriculture and other economic activities in Punjab. However, during the monsoon season, these rivers can overflow their banks and cause severe flooding in the low-lying areas along their banks.

Major flood events in Punjab is listed in Table 24.1 for which satellite derived spatial flood inundation maps were generated and disseminated to state / central government disaster support management organizations by NRSC, ISRO.

24.1 Flood Problem in Punjab

Table.24.1 . Major flood events in Punjab state

S.No	Year	Description of the flood event	Districts affected
1	2004	Floods hit Punjab due to continuous rains during the 6th-09th August, 2004	4
2	2008	Floods occurred in Punjab due to heavy rains during the third week of August. Breach in the embankment of Sutlej River at different places caused inundation	4
3	2010	Floods occurred due to heavy rains in 1st week of Jul 2010	4
4	2013	Incessant rains and overflowing waters of River Sutlej has inundated several villages inundating many low lying areas along its	5
5	2019	Incessant rains in the third week of July caused a 50ft breach in the River Ghaggar in Sangrur district 9-15th Aug 2019	9

24.2 Flood Affected Area in Punjab

Cumulative flood inundation maps were utilised for generation of map of total flood affected area in Punjab and is estimated as 1,42,692ha. Flood affected area map is shown in Figure.24.1 and district wise flood affected area statistics are shown in Table. 24.2. One district in Punjab has flood affected area 50,000-1,00,000 ha, 1district between 10,000-25,000 ha and 13 districts<10000 ha.

Table.24.2 District wise statistics of Flood affected area in Punjab

S. No.	District	Flood Affected Area (ha)
1	Patiala	77358
2	Sangrur	14651
3	Fatehgarh Sahib	9995
4	Jalandhar	8314
5	Ludhiana	6654
6	Kapurthala	5095
7	Firozpur	3996
8	Tam Taran	3762
9	Rupnagar	3292
10	Nawan Shahr	2803
11	Sas Nagar	2074
12	Moga	2045
13	Amritsar	1362
14	Mansa	754
15	Fazilka	536
TOTAL		**142692**

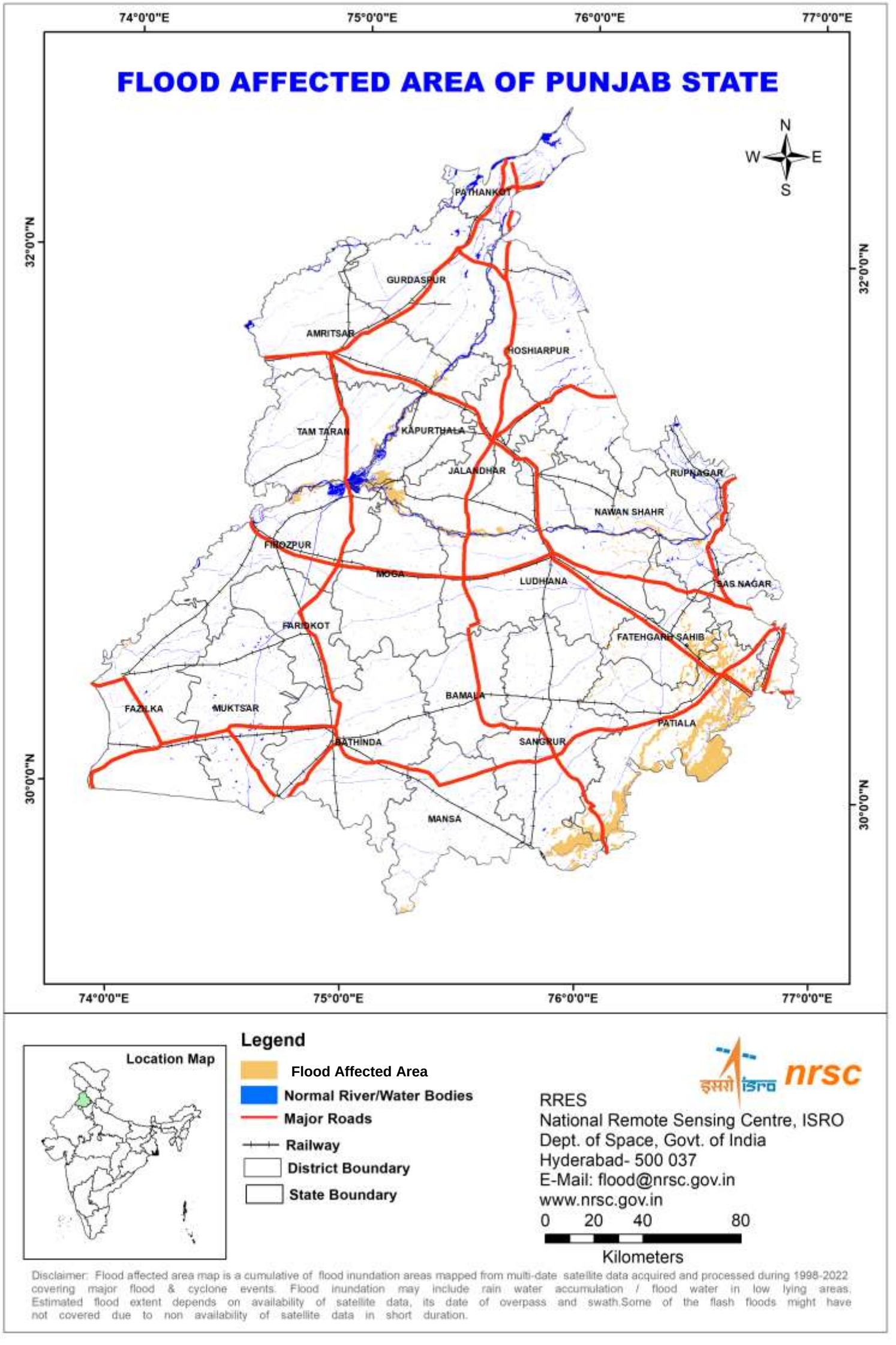


Fig.24.1 Flood affected area in Punjab State

25. Rajasthan

Rajasthan is a state in northern India. It covers 342,239 square kilometres or 10.4% of India's total geographical area. It is the largest Indian state by area and the seventh largest by population. It is on India's northwestern side, where it comprises most of the wide and inhospitable Thar Desert (also known as the Great Indian Desert) and shares a border with the Pakistani provinces of Punjab to the northwest and Sindh to the west, along the Sutlej-Indus River valley. It is bordered by five other Indian states: Punjab to the north; Haryana and Uttar Pradesh to the northeast; Madhya Pradesh to the southeast; and Gujarat to the southwest. Its geographical location is 23.3 to 30.12 North latitude and 69.30 to 78.17 East longitude, with the Tropic of Cancer passing through its southernmost tip. MajorRivers are mentioned here

Chambal River : Chambal is a significant river in central India and a significant tributary of the Yamuna. Its origins are in the Vindhya mountain range in West Central India, near Janapav(Madhya Pradesh). The Chambal River travels northeast through Madhya Pradesh before entering Rajasthan and forming a boundary between the two states. It then continues southeast toward Uttar Pradesh, where it joins the Yamuna. During its 900-kilometre journey, the river passes through several physical features and terrains before joining the Yamuna at Pachnada near Bhareh in Uttar Pradesh.

Banas River :The Banas River originates in Rajasthan and flows into the Chambal River. The Khamnor hills in the Aravalli mountain range (approximately 5 kilometres from Kumbhalgarh in Rajasthan's Rajsamand district) are the source of this river. The river travels through the Mewar area before entering Chambal near the Rameshwar hamlet in the SawaiMadhopur district. During its 512-kilometer trip, rivers such as Berach, Menali, Kothari, Khari, Dai, Dheel, Sohadara, Morel, and Kalisil join it.

Ghaggar-Hakra River :The Ghaggar-Hakra River is a significant waterway that flows across the plains of northern India in a western direction. The Ghaggar-Hakra rises in Himachal Pradesh's Shivalik hills and runs south through the states of Haryana and Rajasthan before entering Pakistan and drying out before reaching the Arabian Sea. The current length of the waterway is around 320 kilometres.

Luni River :The Luni River flows through Rajasthan's western region and originates in the Aravalli Ranges in Naga hills near Pushkar. The river begins its journey in the Ajmer region and flows through the peaty plains of Gujarat's Rann of Kutch. The river runs about 530 kilometres from Rajasthan to Gujarat. This river is known by several names depending on where it alters its path. The Luni River Basin covers 37,363 km2 and includes numerous areas of the Ajmer area from Barmer to Jalor before proceeding on through Jodhpur, Nagaur, and Pali before entering the Sirohi district.

Mahi River : The Mahi River flows from Minda Village in the Dhar Madhya Pradesh District to the Gulf of Khambat. It begins in Madhya Pradesh and runs through the Vagad district of Rajasthan before entering Gujarat and spilling into the Arabian Sea.

In addition to these, rivers like Arvari, Bandi, Berach, Jawai and Kali Sindh also flow through Rajasthan.

25.1 Flood Problem in Rajasthan

Even though Rajasthan is largely water deficit, there are incidents of flood. The flood prone areas in Rajasthan include Ajmer, Barmer, Jodhpur, Pali, Jalore, Kota, Jaipur etc. These regions are spread across the basins and sub-basins of rivers like Chambal, Banas, Banganga, Ghaggar and Luni. The floods in rivers mostly occur either due to heavy rainfall or obstructions that restrict the flow of rivers. In urban areas, floods usually occur because of lack of proper planning and choking of drainage systems. 2022, 2021 and 2016 are the recent years during which NRSC has mapped floods in Rajasthan. Major flood events in Rajasthan is listed in Table 25.1 for which satellite derived spatial flood inundation maps were generated and disseminated to state / central government disaster support management organizations by NRSC, ISRO.

Table.25.1 . Major flood events in Rajasthan state

S.No	Year	Description of the flood event	Districts affected
1	2006	Floods were reported in the state due to heavy rains during 21st Aug – 1st Sep 2006	2
2	2016	Floods were reported in 2nd week of August 2016	1
3	2022	Heavy incessant rains were reported in parts of Rajasthan during the first week of August, 2022. Many low lying areas along the Chambal river were inundated	5

25.2 Flood Affected Area in Rajasthan

Cumulative flood inundation maps were utilised for generation of map of total flood affected area in Rajasthan and is estimated as 1,55,144 ha. Flood affected area map is shown in Figure.25.1 and district wise flood affected area statistics are shown in Table. 25.2. One district in Rajasthan has flood affected area >1,00,000 ha and 9 districts<10000 ha.

Table.25.2 District wise statistics of Flood affected area in Rajasthan

S.No	District	Flood Affected Area (ha)
1	Barmer	129206
2	Dhaulpur	8935
3	Kota	6602
4	Jalor	2723
5	Karauli	1577
6	Baran	1510
7	Jodhpur	1316
8	Jaisalmer	1188
9	Sawai Madhopur	1132
10	Pali	955
TOTAL		**155144**

Glimpses of satellite images / flood inundation over the time period are depicted in this section.

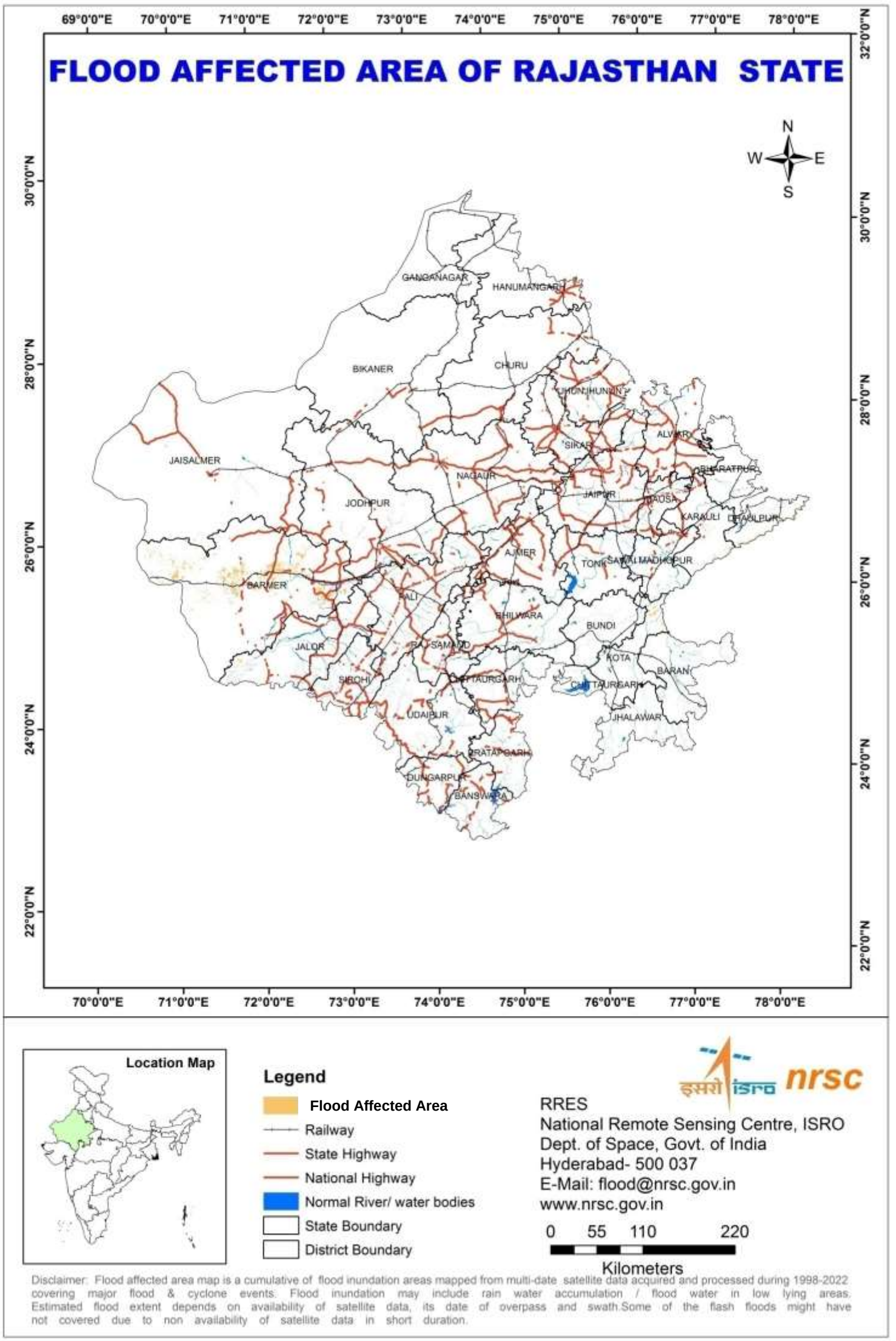
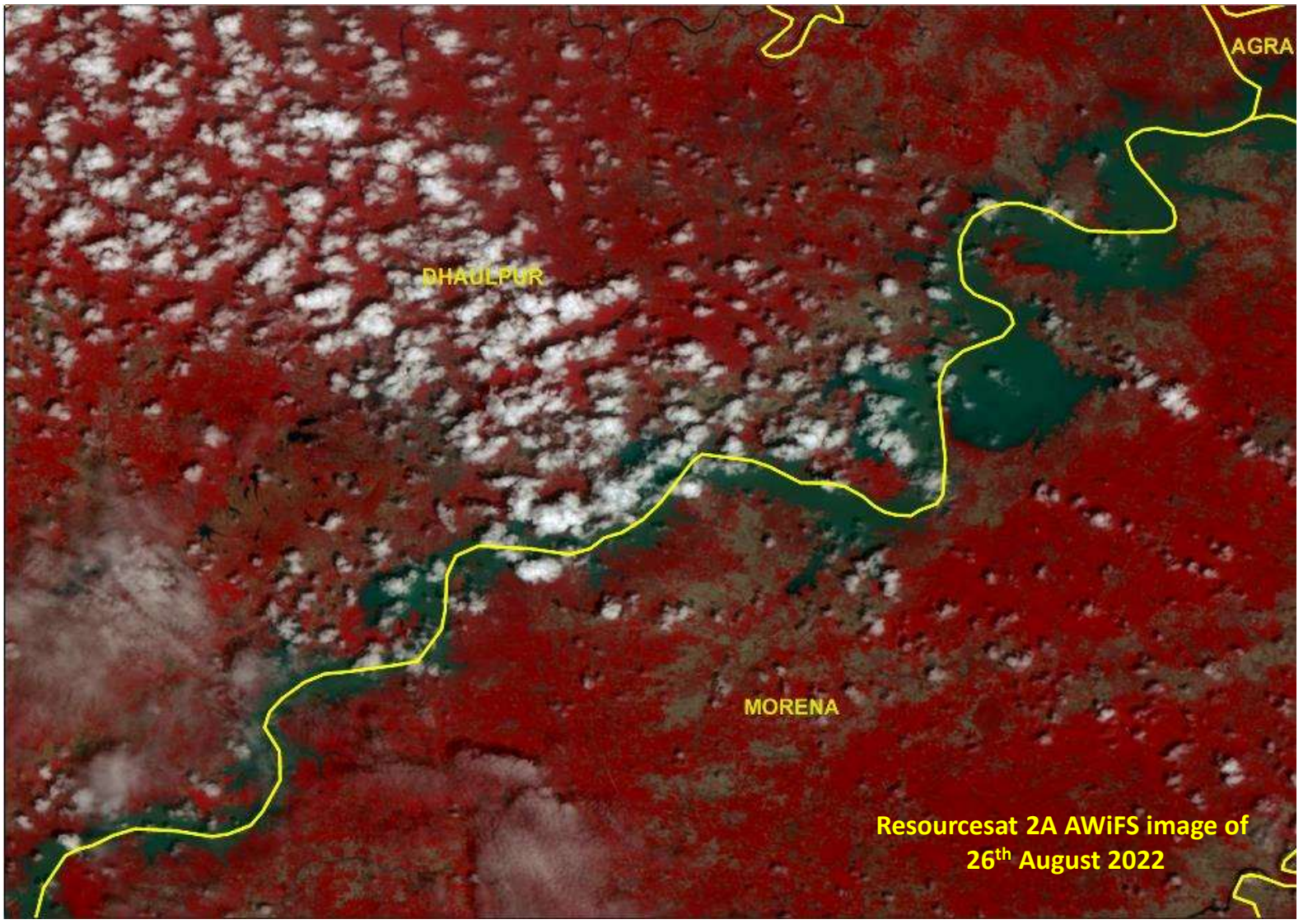
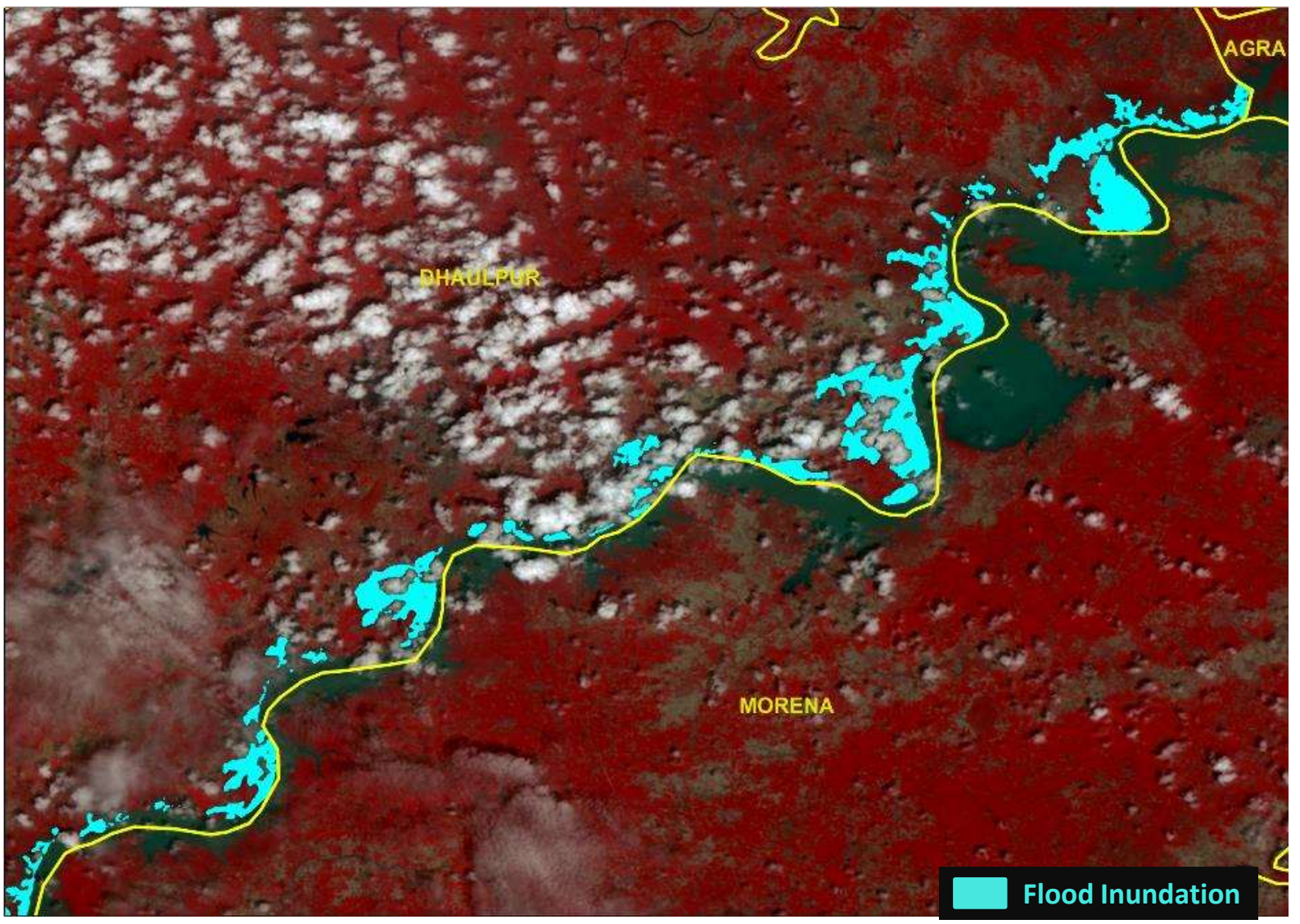
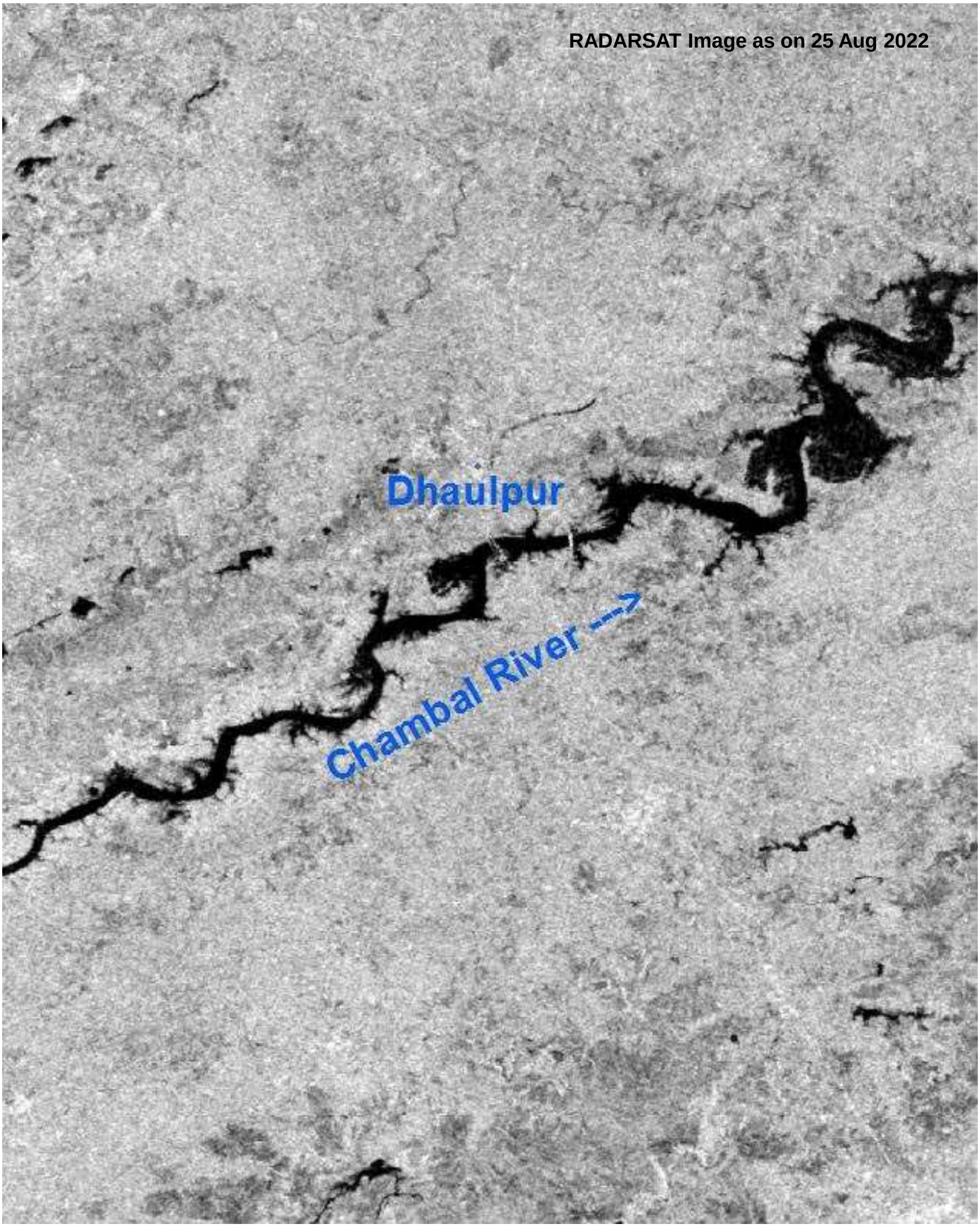


Fig.25.1 Flood affected area in Rajasthan State


AGRA
DHAULPUR
MORENA
Resourcesat 2A AWiFS image of
26th August 2022

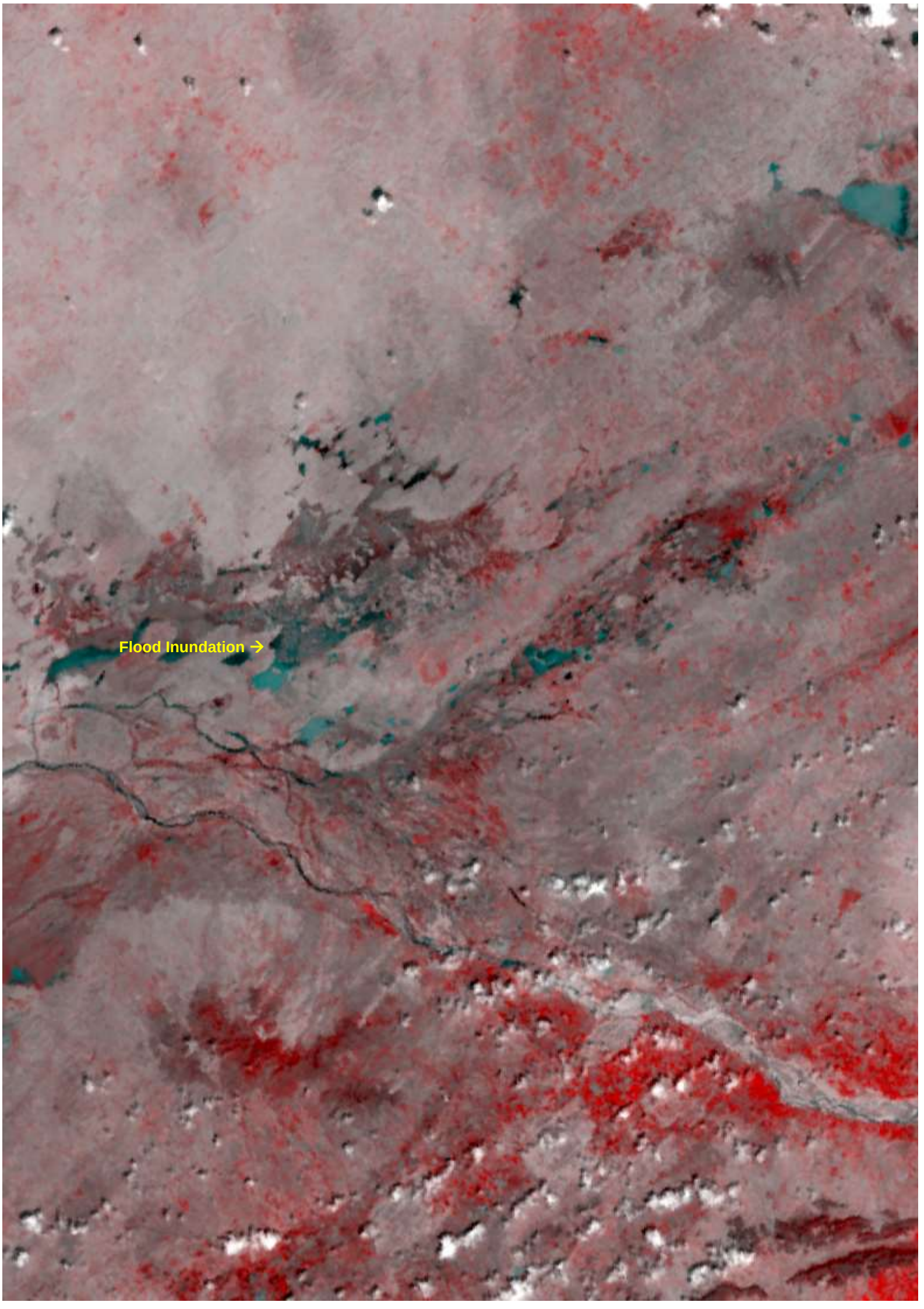

AGRA
DHAULPUR
MORENA
Flood Inundation

RADARSAT Image as on 25 Aug 2022



Part of Barmar District, Rajasthan

IRS P6 AWiFS image as on 1 Sep 2006



26. Tamil Nadu

Tamil Nadu is a state in southern India. It is the tenth largest Indian state by area and the sixth largest by population. Located in the southernmost part of the Indian peninsula, Tamil Nadu is bordered by the Indian union territory of Puducherry and states of Kerala, Karnataka, and Andhra Pradesh, as well as an international maritime border with Sri Lanka. Naturally, it is bound by the Western Ghats in the west, the Eastern Ghats in the north, the Bay of Bengal in the east, the Gulf of Mannar and the Palk Strait to the south-east, and the Indian Ocean in the south. Major Rivers: Kaveri River: Among the several rivers flowing through the state, Kaveri River, with 760 km of length, is the longest among all the Tamil Nadu rivers. Since, it is among the sacred rivers of the country, this river is popularly called the "Ganga of the South" or the "Dakshina Ganga". This rivers flow eastward in this state. From the Hogenakkel Waterfalls, the river flows towards south direction though Perennial Rivers in Tamil Nadu .

Following are the perennial rivers, which flow through this southernmost region of the Indian peninsula: Bhavani River: Rain-fed, mostly, by the south western monsoon, this is one of the main tributaries of the river Kaveri. Cheyyar River: This tributary of River Palar is a major seasonal river that flows through the district of Tiruvannamalai. Chittar River: The main river originates from the Courtallam Hills of the Shencottah taluk and Tenkasi taluk in the district of Tirunelveli. It flows through the state along with its 5 tributaries, 3 distributaries and many small streams. Ponniyar River: Flowing across the borders in between the taluks of Villupuram and Cuddalore, it finally drains into the Bay of Bengal. Thamirabarani River: This river originates from the peaks named Agathimalai, AduppukkalMottai and CherumunjiMottai in the Tirunelveli district. Vaigai River: While flowing towards the Palk Strait, it changes its course towards south east near Sholavandan and passes through the town of Madurai. In addition non-perennial rivers like Gundar, Noyil, Suruli and Vaipar also flow through Tamil Nadu.

26.1 Flood and Cyclone Problem in Tamil Nadu

Tamil Nadu Floods 2015 : It resulted from heavy rainfall generated by the annual northeast monsoon in November–December 2015. They affected the Coromandel Coast region of the South Indian states of Tamil Nadu and Andhra Pradesh. Between 9 and 10 November 2015, Neyveli received 483 mm of rainfall; rains continued to lash Cuddalore, Chidambaram, Tiruvallur, Kanchipuram and Chennai. Several low-lying areas in Kanchipuram, including major thoroughfare Gandhi Road, were inundated as the city and its neighbourhood received a heavy precipitation of 340mm during the 24-hours that ended with 8.30 a.m. on 13 November 2015. Rainfall over Tamil Nadu existed until next week

Cyclone Nivar 2020 : Very Severe Cyclonic Storm Nivar was a tropical cyclone which brought severe impacts to portions of Tamil Nadu and Andhra Pradesh in late November 2020. In the early hours of November 24, it intensified into a cyclonic storm and it was named Nivar. On 25th, the cyclone reached its peak intensity of 120 kmph which makes it as a Very Severe Cyclonic Storm. The JTWC designated it as a category 1 tropical cyclone of 130 kmph. It made a landfall in Marakkanam close to Pondicherry on the midnight of November 25. Then it gradually weakened into a Deep Depression on early hours of 26th November.

26.2 Flood Affected Area in Tamil Nadu

Cumulative flood inundation maps were utilised for generation of map of total flood affected area in Tamil Nadu and is estimated as 5,52,010 ha. Major flood events in Tamil Nadu is listed in Table 26.1 for which satellite derived spatial flood inundation maps were generated and disseminated to state / central government disaster support management organizations by NRSC, ISRO. Flood affected area map is shown in Figure.26.1 and district wise flood affected area statistics are shown in Table. 26.2. Two districts in Tamil Nadu have flood affected area between 50,000-1,00,000 ha, 7 districts between 25,000-50,000 ha, 4 districts between 10,000-25,000 ha and 11 districts <10,000 ha.

Table.26.1 . Major flood events in Tamil Nadu state

S.No	Year	Description of the flood event	Districts affected
1	2007	Floods were reported in Tamilnadu due to heavy rains, resulted from a low pressure in Bay of Bengal in the third week of December, 2007.	4
2	2008	Heavy rains lashed different parts of Tamilnadu due to the influence of a depression in Bay of Bengal and the cyclonic storm.	1
3	2009	Heavy monsoon rains lashed Tamilnadu during 2nd Week of November 2009.	1
4	2010	Floods occurred due to heavy rains	10
5	2012	Flood-like situation prevailed in majority of the coastal districts in Tamilnadu by first week of November 2012.	3
6	2020	Tamilnadu Floods& Cyclones (Cyclone NIVAR and BUREVI)	11

Table.26.2 District wise statistics of Flood affected area in Tamil Nadu

S. No.	District	Flood Affected Area (ha)
1	Kanchipuram	89794
2	Tiruvarur	81215
3	Cuddalore	47191
4	Thanjavur	44251
5	Nagappattinam	41708
6	Tirunelveli	36894
7	Tiruvallur	36537
8	Ramanathapuram	35732
9	Tuticorin (Tuttukudi)	27640
10	Sivaganga	23307
11	Tiruchchirappalli	17449
12	Villupuram	15656
13	Madurai	12388
14	Pudukkottai	9884
15	Ariyalur	9647
16	Virudunagar	9526
17	Tiruvannamalai	5010
18	Chennai	4892
19	Tiruppur	1079
20	Perambalur	763
21	Krishnagiri	603
22	Karur	521
23	Kanniyakumari	215
24	Dharmapuri	111
TOTAL		**552010**

Glimpses of satellite images / flood inundation over the time period are depicted in this section.

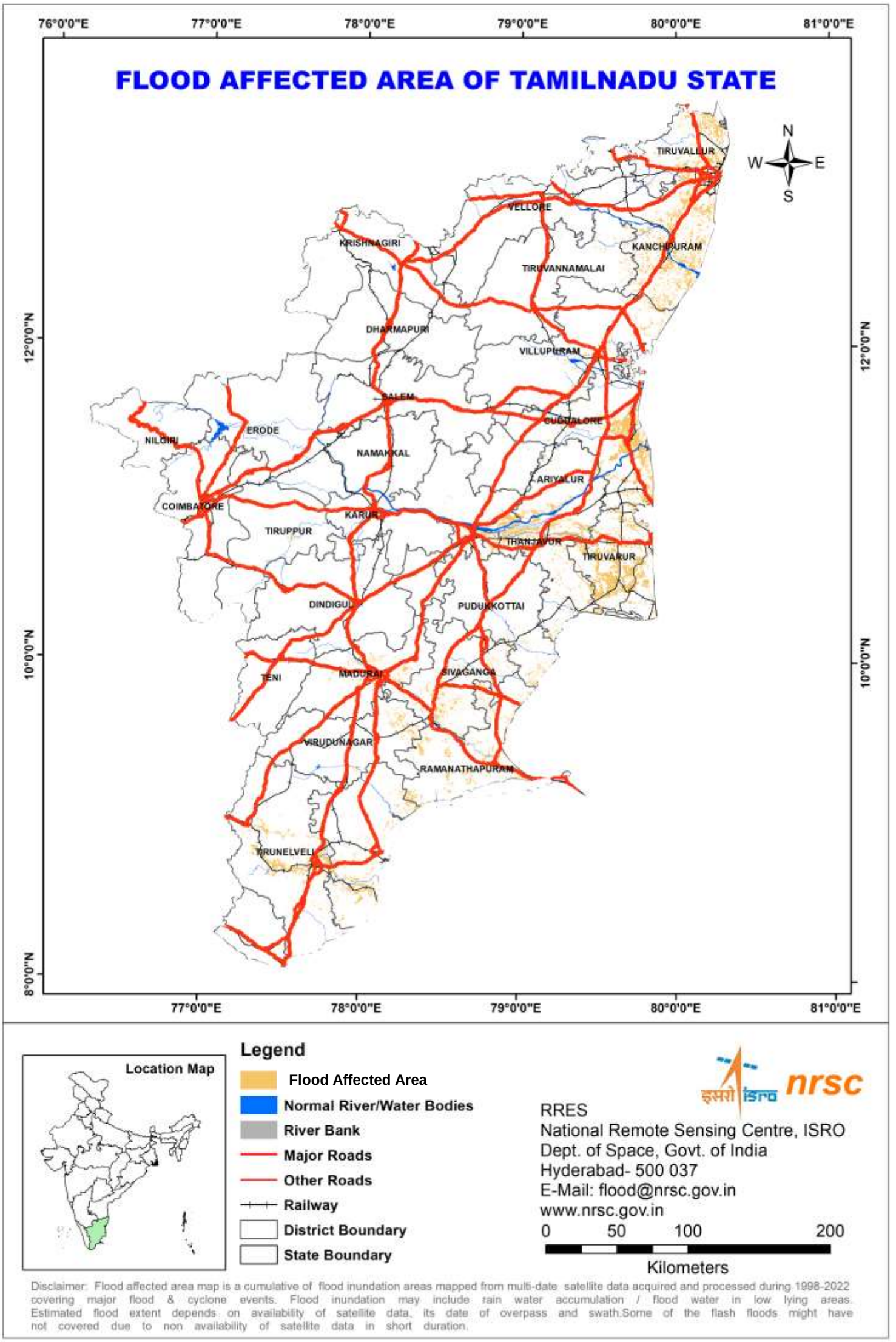


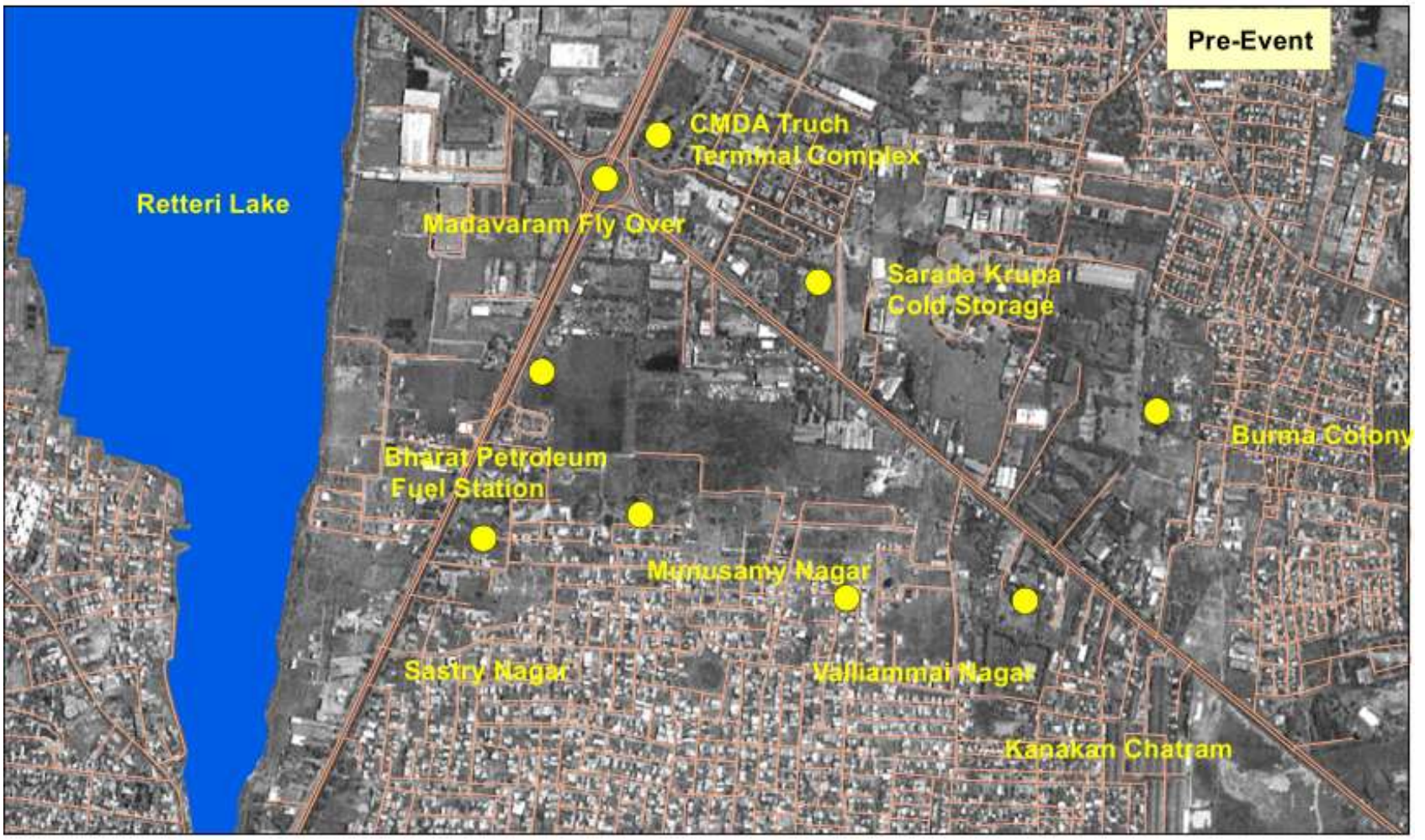
Fig.26.1 Flood affected area in Tamil Nadu State

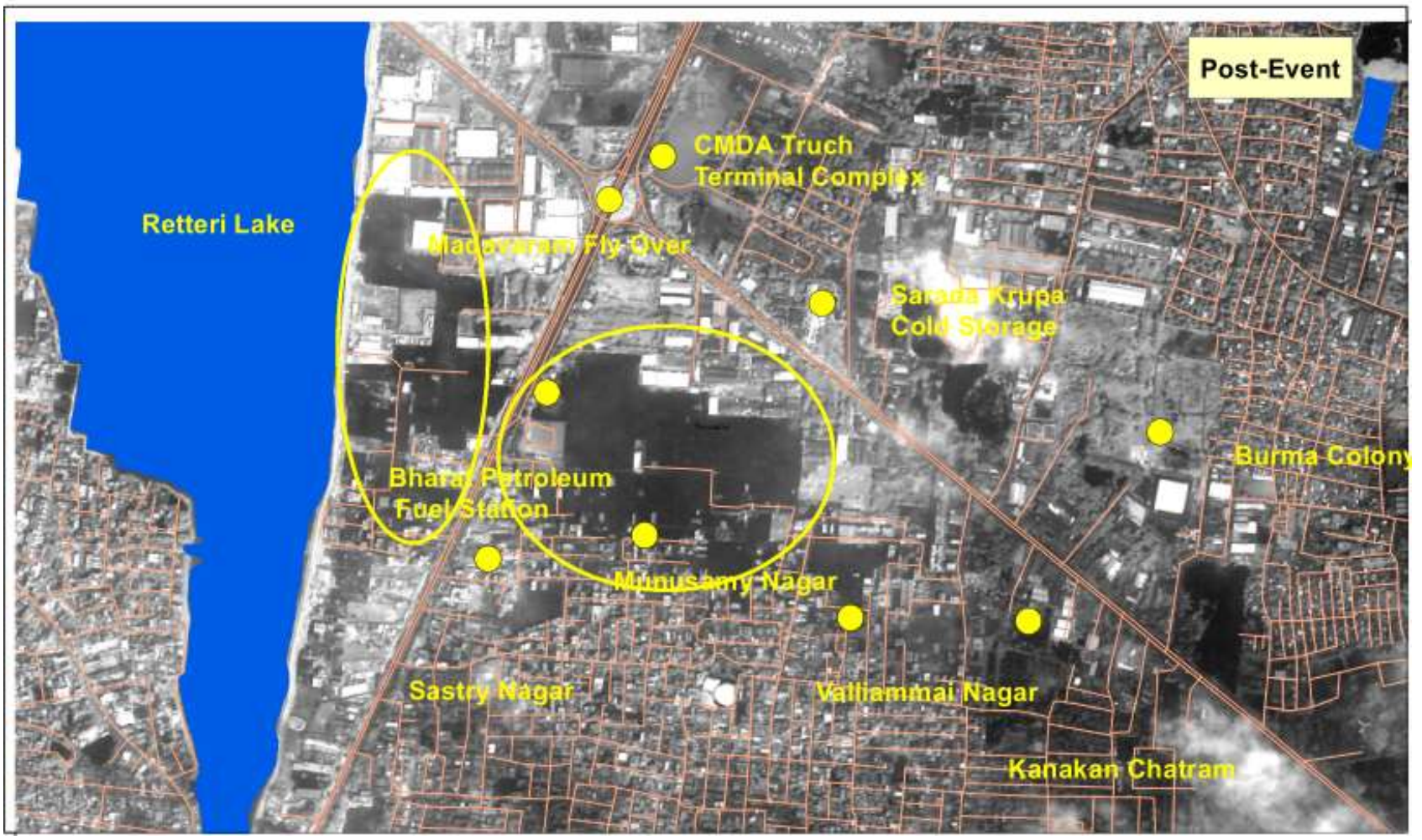
Heavy Rains in the part of Tamil Nadu State

Inundated Areas in part of Thiruvallur District

(Surroundings of Munuswamy Nagar)

Based on the analysis of cartosat-2 satellite data of 21st November ,2015





27. Telangana

Telangana is a state in India situated on the south-central stretch of the Indian peninsula on the high Deccan Plateau. It is the eleventh-largest state and the twelfth-most populated state in India with a geographical area of 112,077 km^2 and 35,193,978 residents as per 2011 census. On 2 June 2014, the area was separated from the northwestern part of Andhra Pradesh as the newly formed state of Telangana, with Hyderabad as its capital. Its other major cities include Warangal, Nizamabad, Khammam, Karimnagar and Ramagundam. Telangana is bordered by the states of Maharashtra to the north, Chhattisgarh to the northeast, Karnataka to the west, and Andhra Pradesh to the east and south. The terrain of Telangana consists mostly of the Deccan Plateau with dense forests covering an area of 27,292 km2. As of 2019, the state of Telangana is divided into 33 districts.

Major Rivers

Situated at a high altitude, Telangana has prominent perennial rivers such as Godavari in the north and the Krishna in the south. Other rivers such as Bhima, Manair, Penganga, Akeru, Dindi, Manjeera, Paleru, and PeddaVagu also irrigate the state.

Krishna River:Telangana is separated from Andhra Pradesh by the Krishna River, which acts as a geographical divider between the two. The Krishna River is the third-longest river of the country, originating in the Satara District of Maharashtra in the Western Ghats. These rivers flow across the state of Karnataka before reaching Telangana and Andhra Pradesh. Bhima is one of the prominent tributaries of Krishna River in Telangana.

Godavari River: It is the second-longest river of the country. This river originates in the Nashik district of Maharashtra and runs across the Deccan Plateau, before crossing Telangana and entering the Bay of Bengal. The river Manjeera is one of its major tributaries.

27.1 Flood Problem in Telangana

Hyderabad Floods 2020

The 2020 Hyderabad floods were a series of floods associated with Deep Depression BOB 02 that caused extensive damage and loss of life as a result of flash flooding in Hyderabad, India in October 2020. Among the most affected areas were Balapur, L. B. Nagar,parts of Old City such as Hafiz Baba Nagar, Al Jubail Colony, Omer colony, Osman Nagar, Nabeel Colony, Falaknuma, Chaderghat etc. The fourth tropical cyclone and third deep depression of the 2020 North Indian Ocean cyclone season, BOB 02 formed on 11 October over the west-central Bay of Bengal and slowly drifted towards the east coast of India over the following three days.

Godavari Floods 2022

Heavy rains were reported in Telangana during 2nd week of week of July 2022.Godavari River passes through Telangana State and the villages adjacent to it are prone to flood inundation during heavy rainfall and runoff into river.Heavy to extremely heavy Rainfall intensities in Godavari River basin led to heavy inflows in Godavari River which caused inundation in parts of KomaramBheemAsifabad, JayasankarBhoopalpally, Peddapalli, Manchiryal, Mulugu, BhadradriKothagudem districts and also resulted in water stagnation in other districts of Telangana State.

27.2 Flood Affected Area in Telangana

Cumulative flood inundation maps were utilised for generation of map of total flood affected area in Telangana and is estimated as 1,02,318 ha. Major flood events in Telangana is listed in Table 27.1 for which satellite derived spatial flood inundation maps were generated and disseminated to state / central government disaster support management organizations by NRSC, ISRO. Flood affected area map is shown in Figure.27.1. and district wise flood affected area statistics are shown in Table. 27.2. Five districts in Telangana have flood affected area between 10,000-25,000 ha and 9 districts<10000 ha.

Table.27.1 . Major flood events in Telangana state

	Year	Description of the flood event	Districts affected
1	2006	Floods occurred during 5th -8th July, 5th – 18th Aug 2006 due to rise in water in Godavari River.	1
2	2010	Floods were reported due to heavy rains during 7-10th July 2010	3
3	2012	During fourth week of August 2012, heavy rains lashed Telangana. Flood alerts were issued for Godavari and Sabari rivers.	1
4	2013	Floods occurred due to rise in water level in Godavari during 20-26th Jul, 2-6th, oct 2013	2
5	2020	Floods were reported in Parts of Telangana state during the third week of August, 2020 under the influence of heavy incessant rains. River Godavari and its tributaries were reported to be flowing in severe flood situation	7
6	2022	Heavy rains were reported in Telangana during 2nd week of July 2022. Godavari river and its tributaries were flowing above the danger level at many places in Telangana State, and the villages adjacent to the Godavari river were inundated by floods. Satellite data was analyzed from 14 – 27th July 2022	6

Table.27.2 District wise statistics of Flood affected area in Telangana

S. No.	District	Flood Affected Area (ha)
1	Bhadradri Kothagudem	20100
2	Mulugu	14806
3	Macherial	13469
4	Jayashankar	13084
5	Jogulamba Gadwal	12920
6	Komaram Bheem	9456
7	Wanaparthy	6929
8	Peddapalle	6430
9	Nalgonda	1317
10	Suryapet	1220
11	Nagarkurnool	969
12	Khammam	863
13	Adilabad	589
14	Mahabubabad	163
TOTAL		**102318**

Glimpses of satellite images / flood inundation over the time period are depicted in this section.

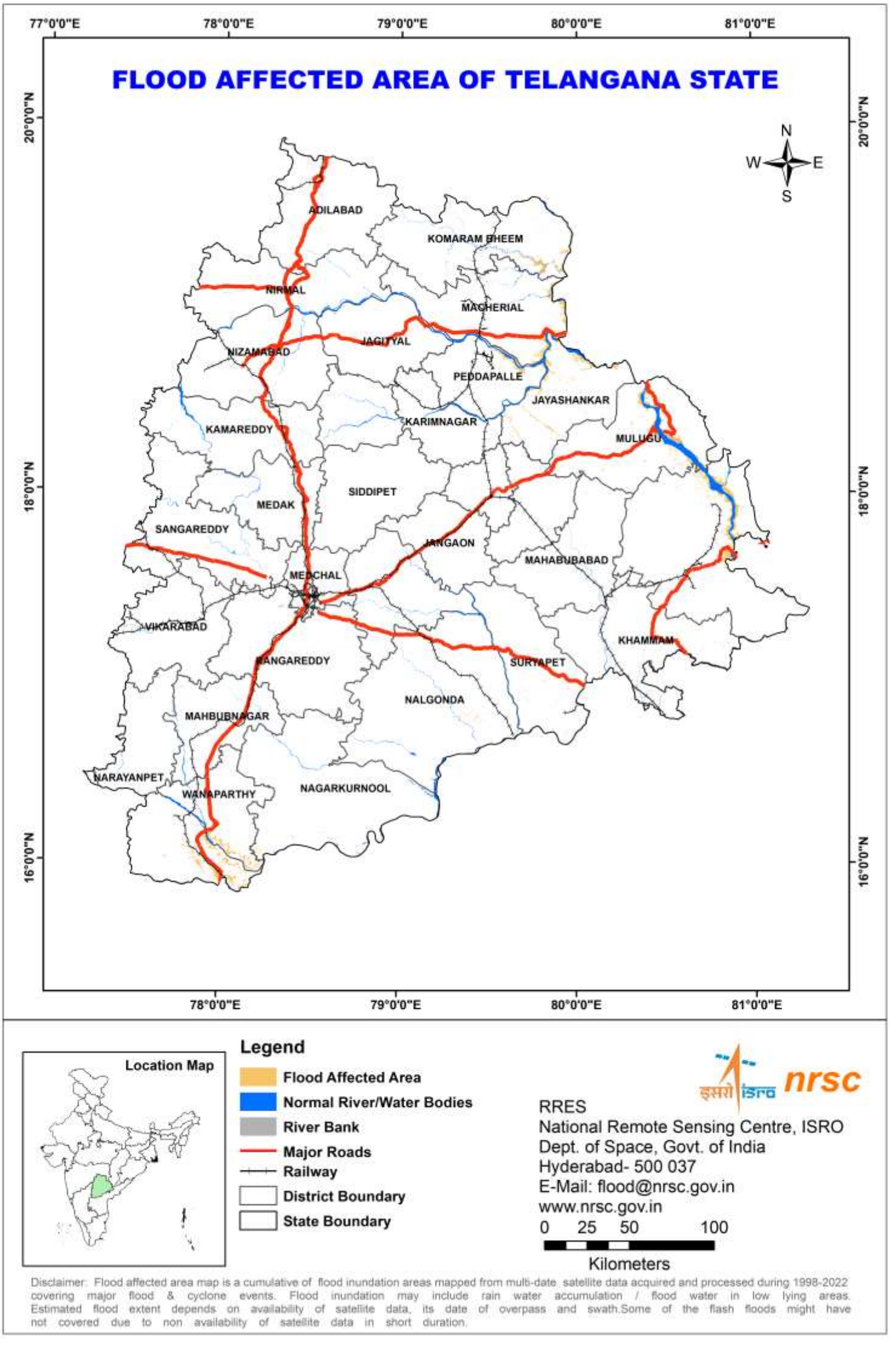
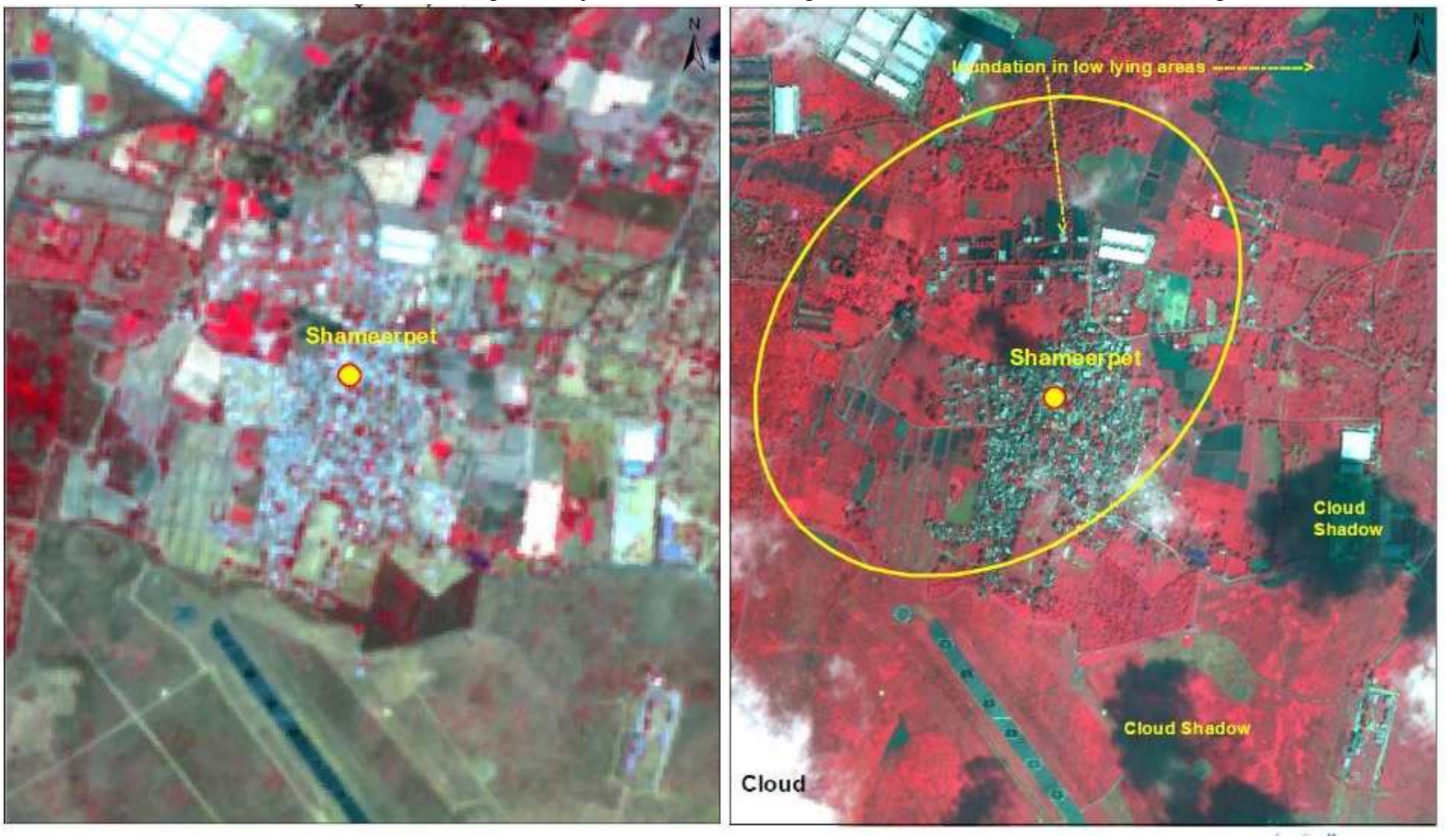


Fig.27.1 Flood affected area in Telangana State

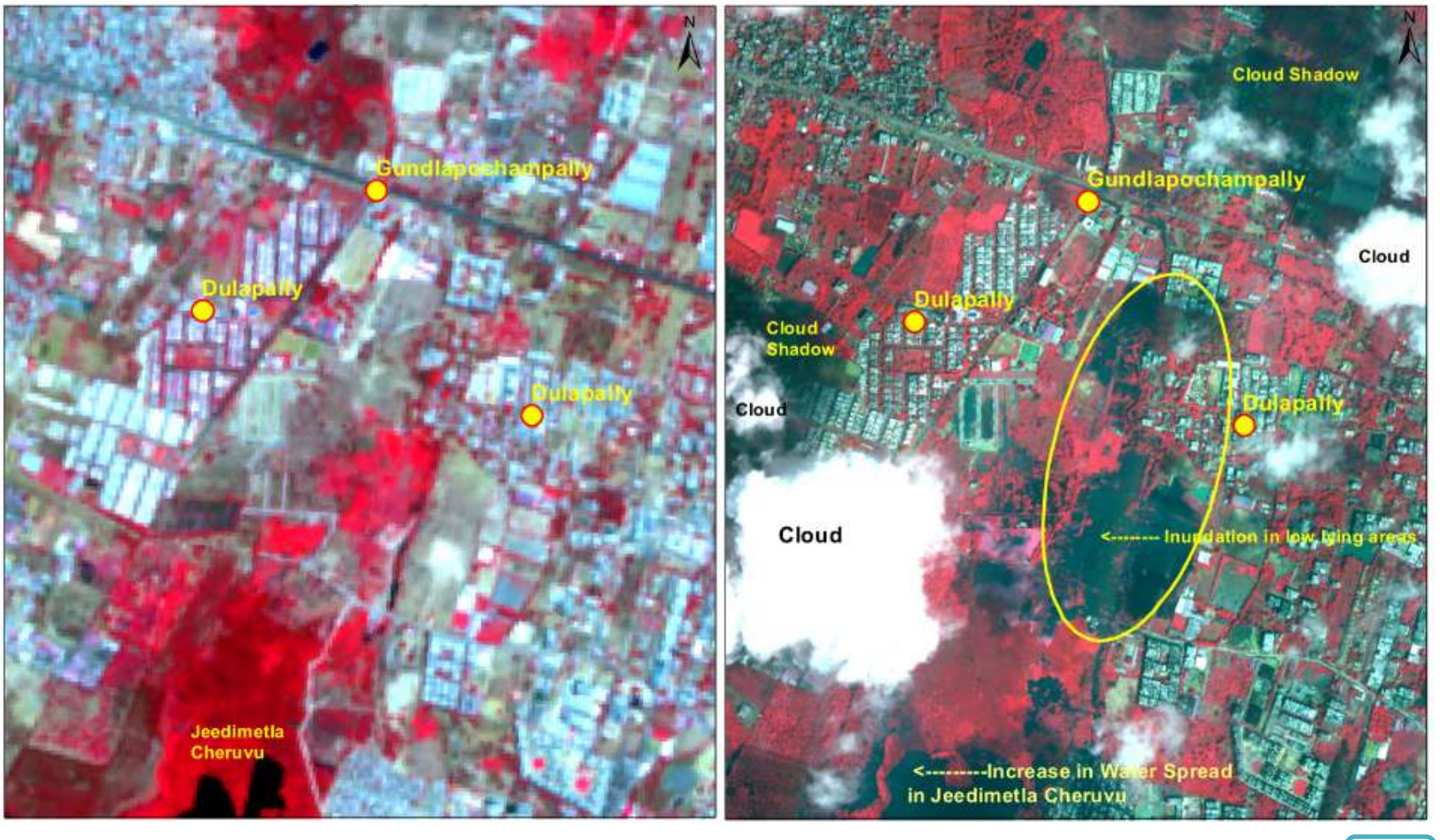
Water accumulation in low lying areas of Shameerpet, Hyderabad

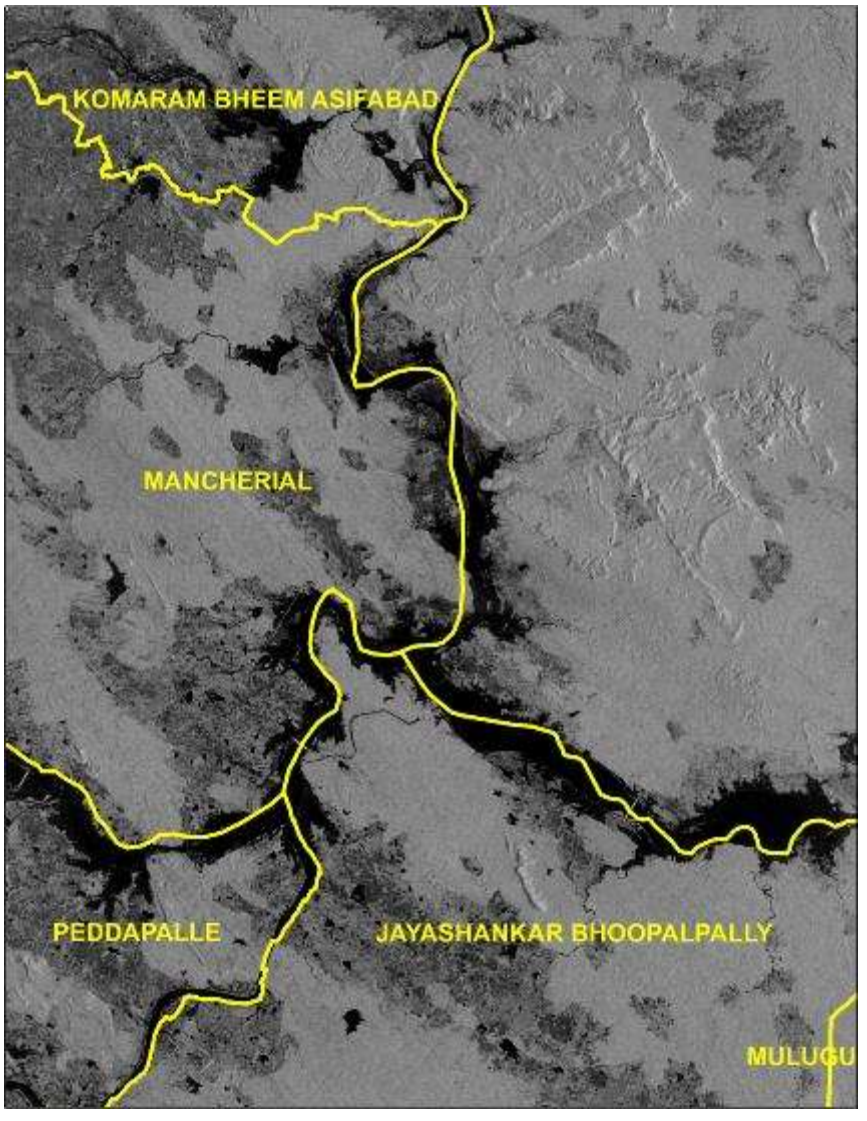
Pre-Flood — Sentinel-2A image of May 28, 2020 — During-Flood — Cartosat image of Oct 18, 2020

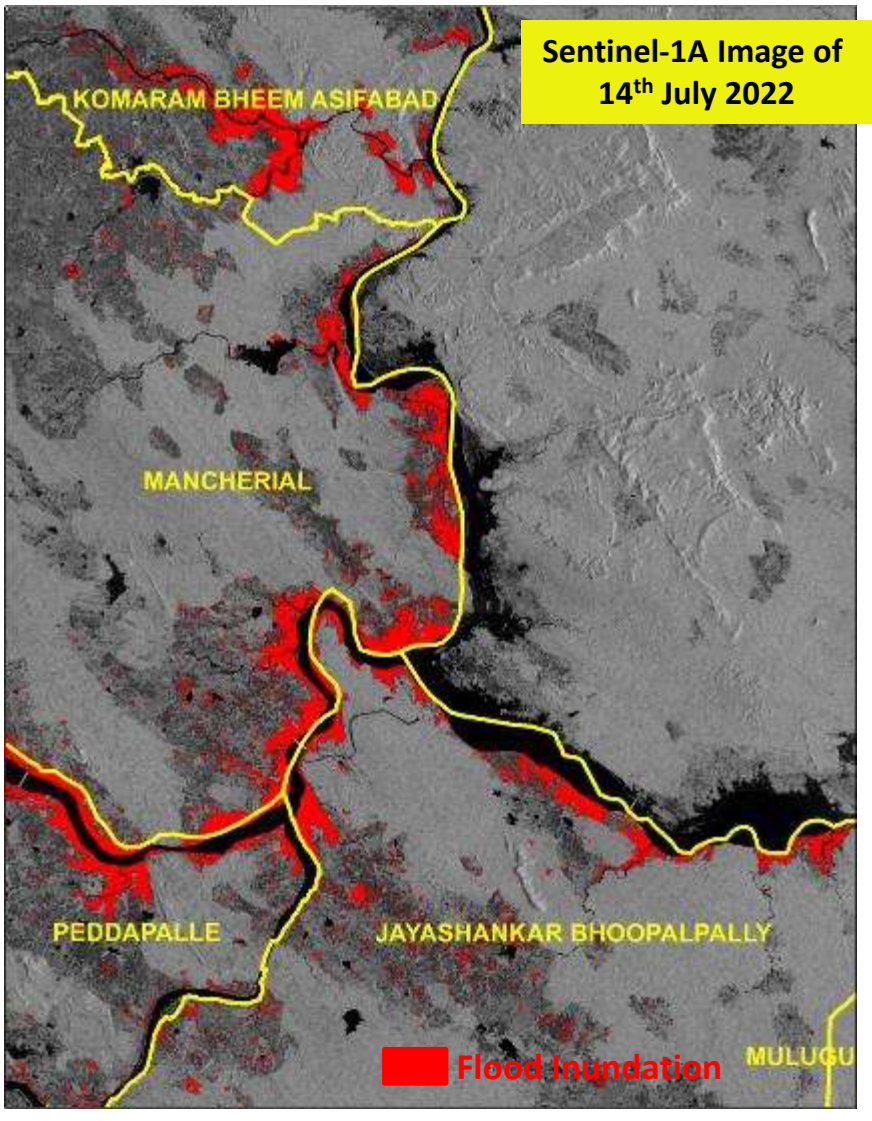


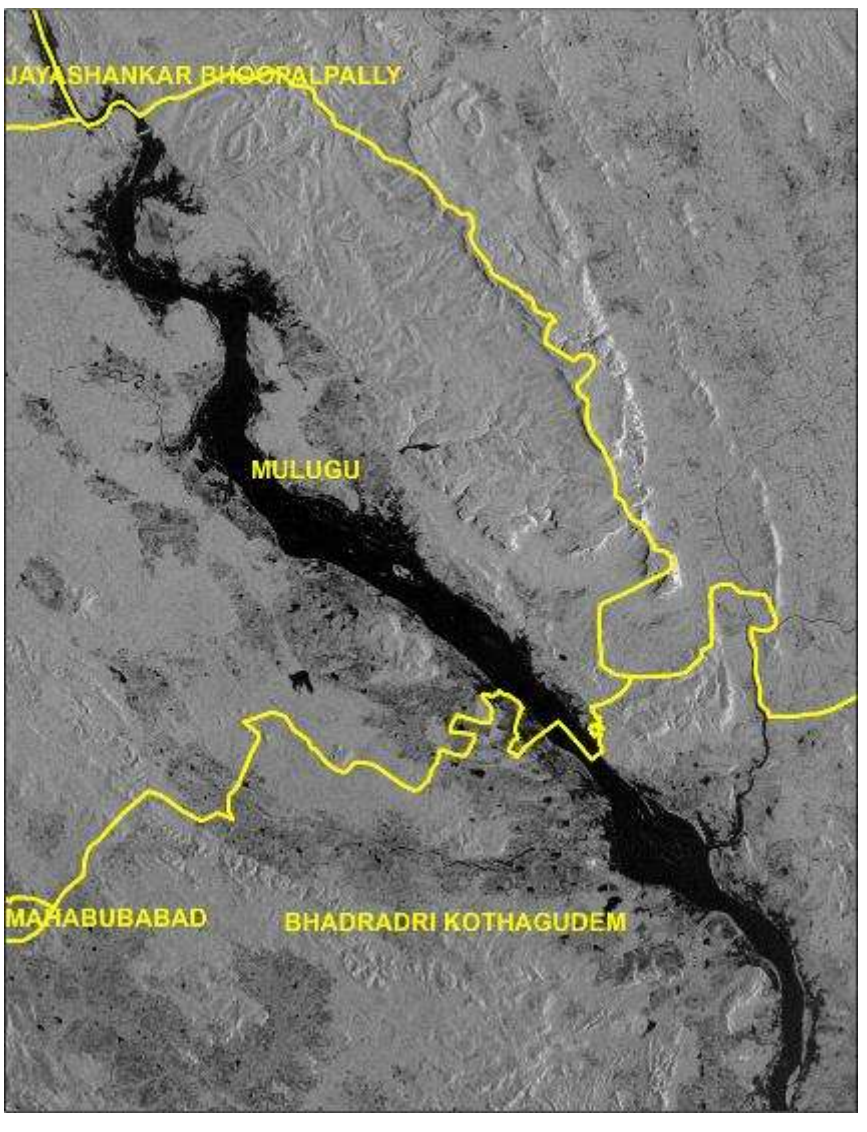
Water accumulation/ Increase in lake water spread of Jeedimetla Cheruvu, Kompally, Hyderabad

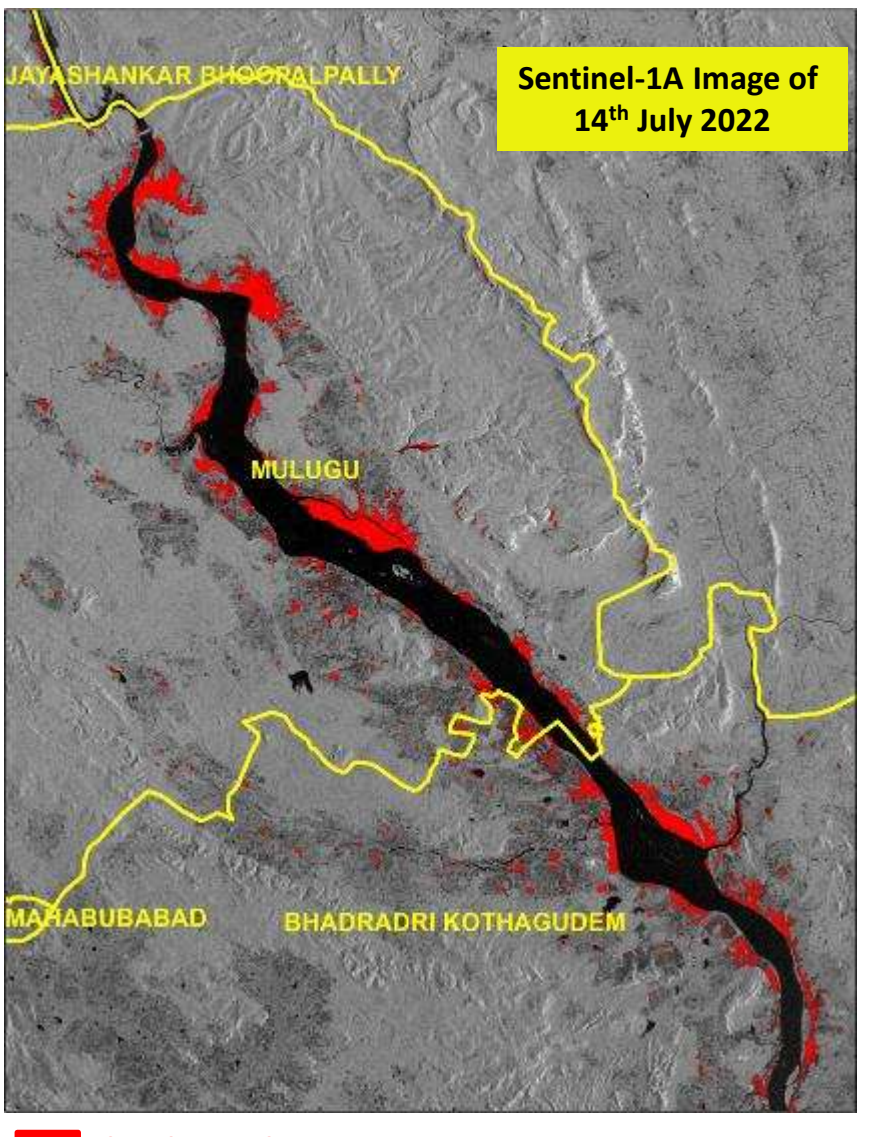
Pre-Flood — Sentinel-2A image of May 28, 2020 — During-Flood — Cartosat image of Oct 18, 2020







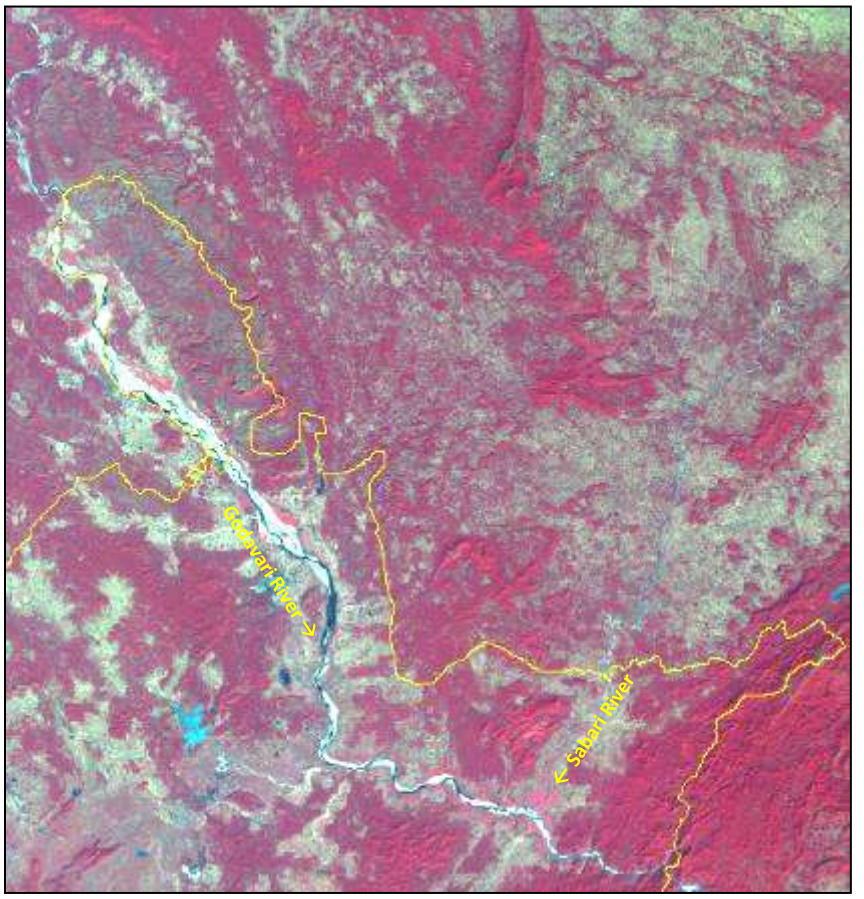




Flood Inundation

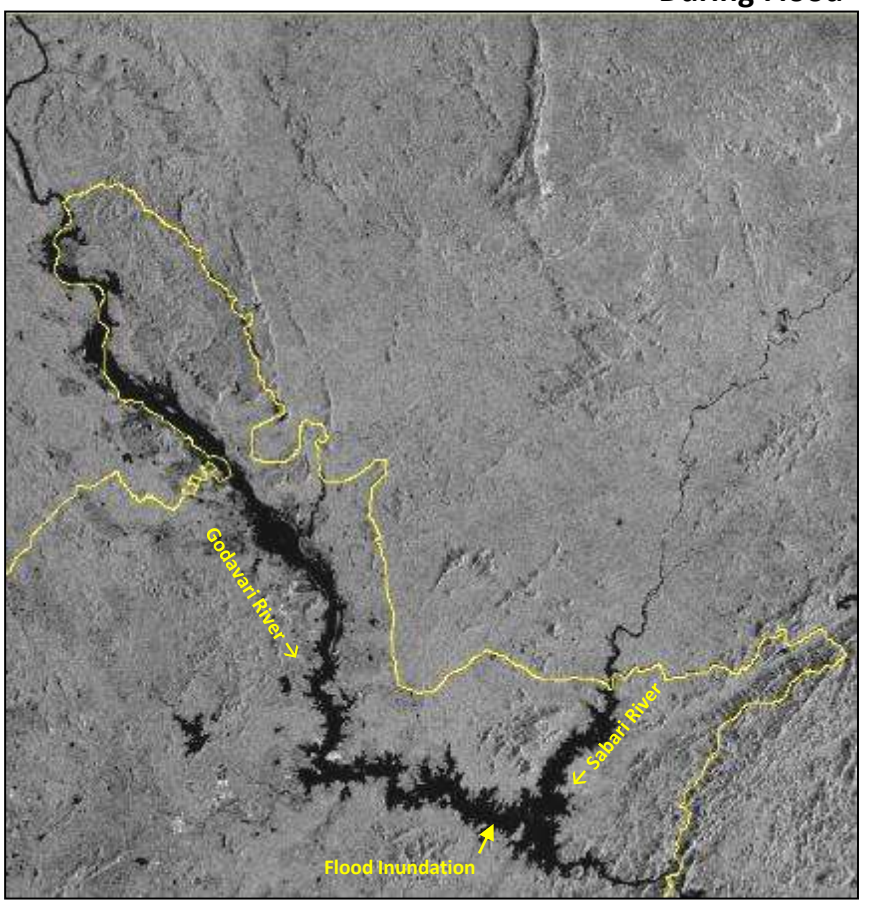
Flood situation in part of Khammam district, Telangana as on 07-Aug-2006

Pre-Flood



IRS-P6 AWiFS image of 20-Jan-2006

During Flood



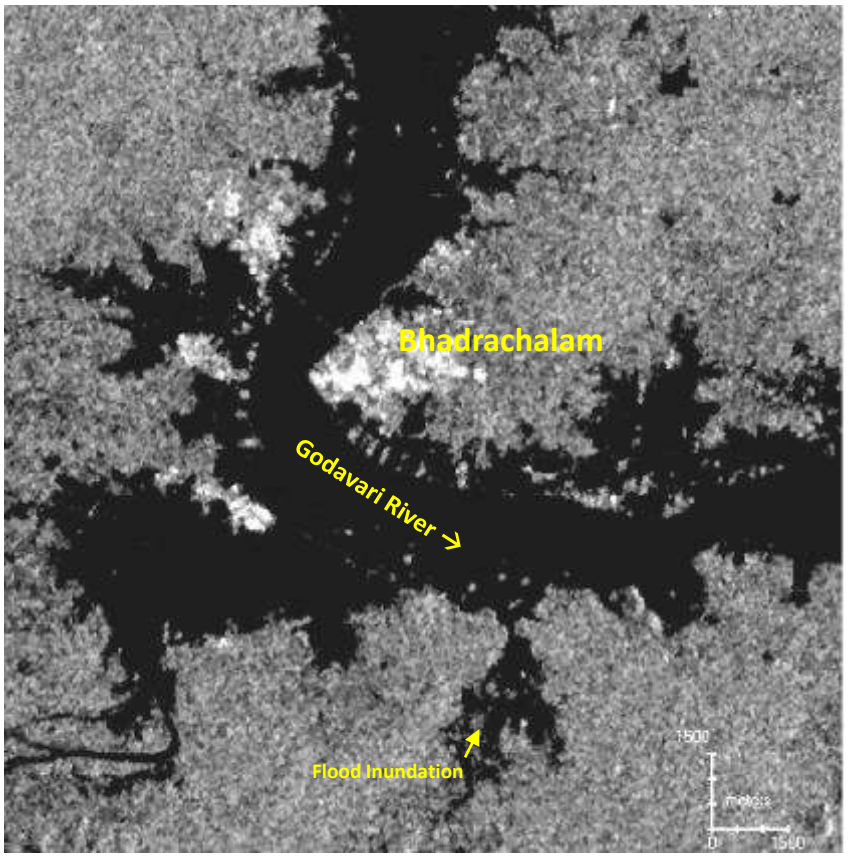
Radarsat image of 07-Aug-2006

Surroundings of Bhadrachalam town, Khammam District

Pre-Flood

IRS-P6 AWiFS image of 20-Jan-2006

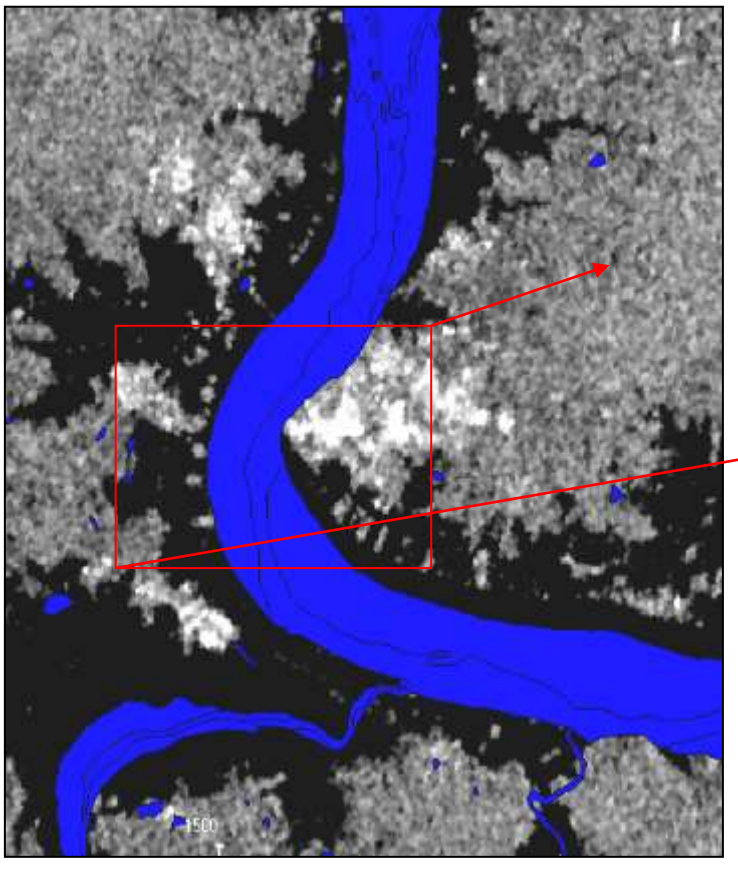
During Flood



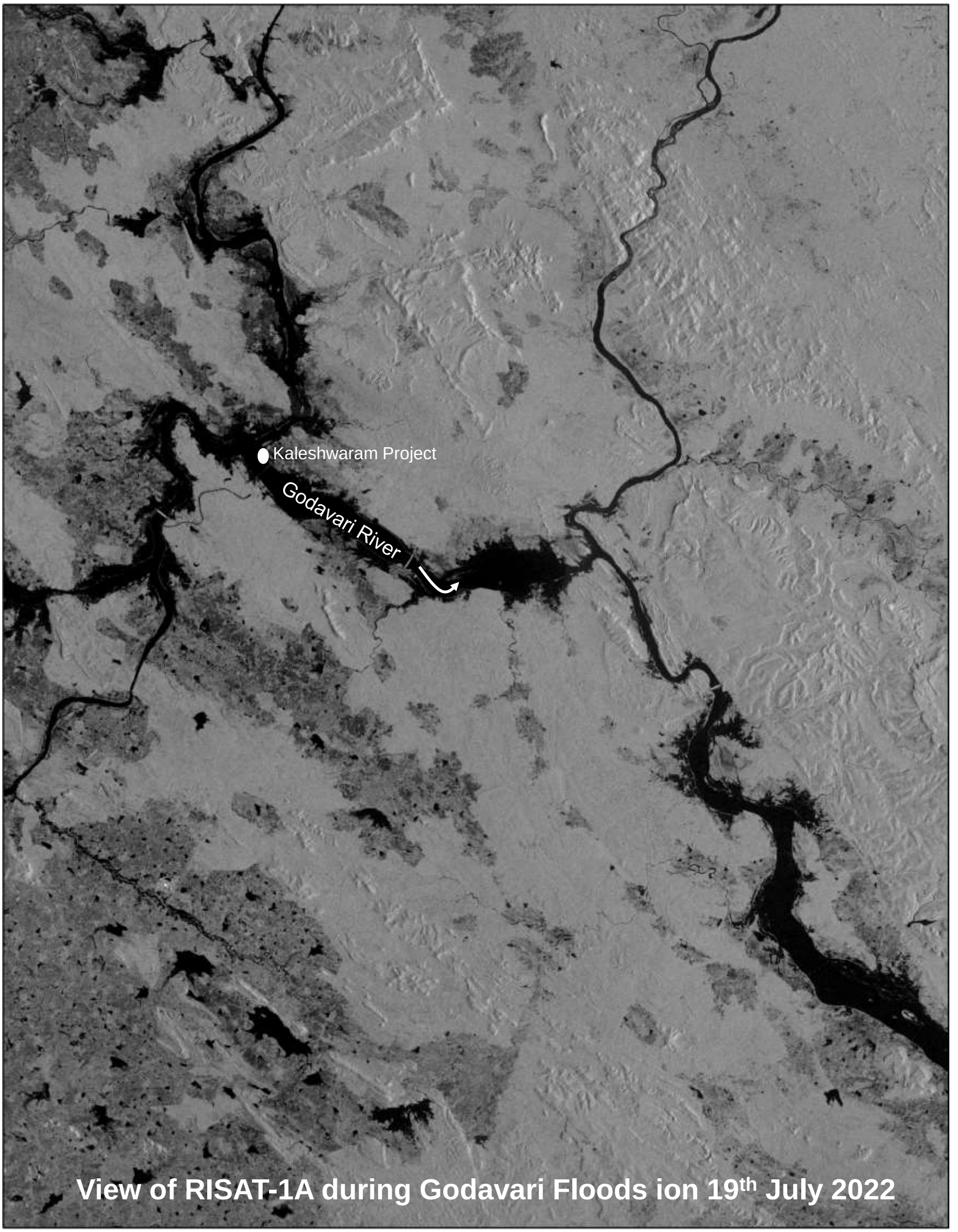
Radarsat image of 07-Aug-2006

Normal river course

IRS-P6 L4 MX image of 29-Mar-2006



Radarsat image of 07-Aug-2006



View of RISAT-1A during Godavari Floods ion 19th July 2022

Tripura

28. Tripura

Tripura is a landlocked state in North East India, where the seven contiguous states – Arunachal Pradesh, Assam, Manipur, Meghalaya, Mizoram, Nagaland and Tripura – are collectively known as the Seven Sister States. Spread over 10,491.69 km2 (4,050.86 sq mi), Tripura is the third-smallest among the 29 states in the country, behind Goa and Sikkim. It extends from 22°56'N to 24°32'N, and 91°09'E to 92°20'E.[27]:3 Its maximum extent measures about 178 km (111 mi) from north to south, and 131 km (81 mi) east to west. Tripura is bordered by the country of Bangladesh to the west, north and south; and the Indian states of Assam to the north east; and Mizoram to the east. It is accessible by national highways passing through the Karimganj district of Assam and Mamit district of Mizoram.

Major rivers

There are 10 (ten) major rivers in the state. They are generally ephemeral in nature and their flow is directly related to the rainfall, being in spate in rainy season and running almost dry during summer months. The Burima, Gomati, Khowai, Howrah, Longai, Dhalai, Muhuri, Feni, Juri, Manu are the major rivers. Besides, there are many small lakes and ponds in the state. There are as many as 13 lakes inside Trishna wildlife sanctuary, and 2 inside Sepahijala wildlife sanctuary.

Floods in Tripura

The state of Tripura conventionally has 10 rivers which are active during monsoon and as a result their flow is directly related to rainfall intensity and duration. Floods were reported on two occasions due to intense rainfall and over spilling of Gomti river and inundating low lying areas along its banks during 2018 & 2022.

28.1 Flood Problem in Tripura

The state of Tripura conventionally has 10 rivers which are active during monsoon and as a result their flow is directly related to rainfall intensity and duration. Floods were reported on two occasions due to intense rainfall and over spilling of Gomti river and inundating low lying areas along its banks during 2018 & 2022.

Major flood events in Tripura is listed in Table 28.1 for which satellite derived spatial flood inundation maps were generated and disseminated to state / central government disaster support management organizations by NRSC, ISRO.

Table.28.1 . Major flood events in Tripura state

	Year	Description of the flood event	Districts affected
1	2004	The water levels of Gomti, Dhalai rivers in Tripura have crossed the danger levels and floods occurred during 28th-30th June 2004	3
2	2010	Floods occurred due to heavy rains and rise in water levels in Gumati and Manu rivers during 2nd week of Oct 2010	2
3	2018	Heavy incessant rains were reported in Tripura state during the second week of June 2018 inundating many low lying areas. South Tripura and West Tripura districts were reported to be affected	2
4	2022	Heavy incessant rains during the third week of June, 2022 has led floods in the state of Tripura inundating many low lying areas of West and South Tripura regions of stat 19-21 Jun 2022	2

28.2 Flood Affected Area in Tripura

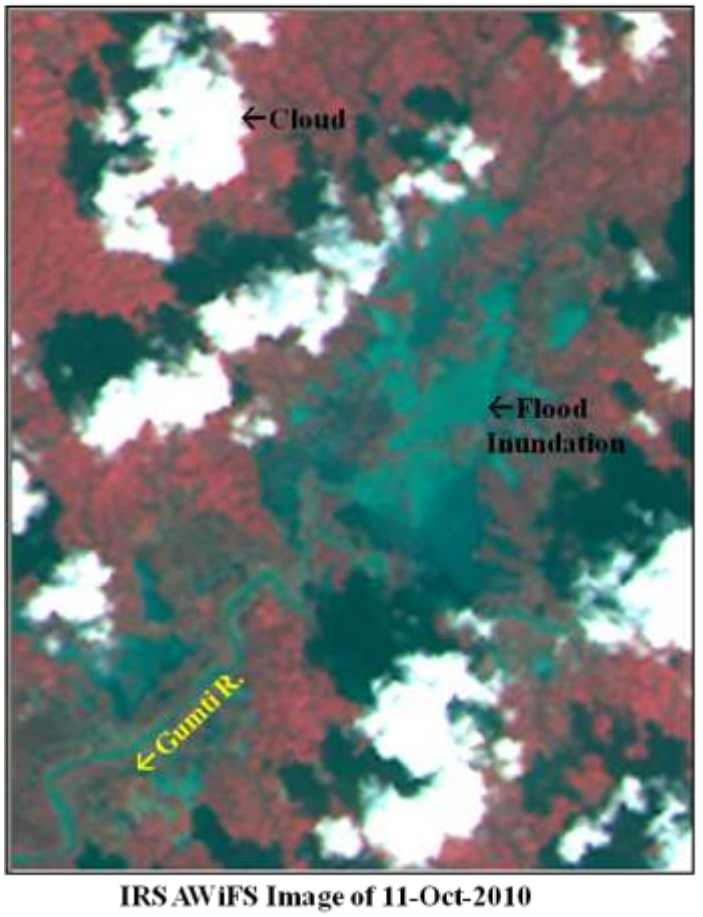
Cumulative flood inundation maps were utilised for generation of map of total flood affected area in Tripura and is estimated as 3,928 ha. Flood affected area map is shown in Figure.28.1 and district wise flood affected area statistics are shown in Table. 28.2. Four districts in Tripura have flood affected area <10,000 ha.

Table.28.2 District wise statistics of Flood affected area in Tripura

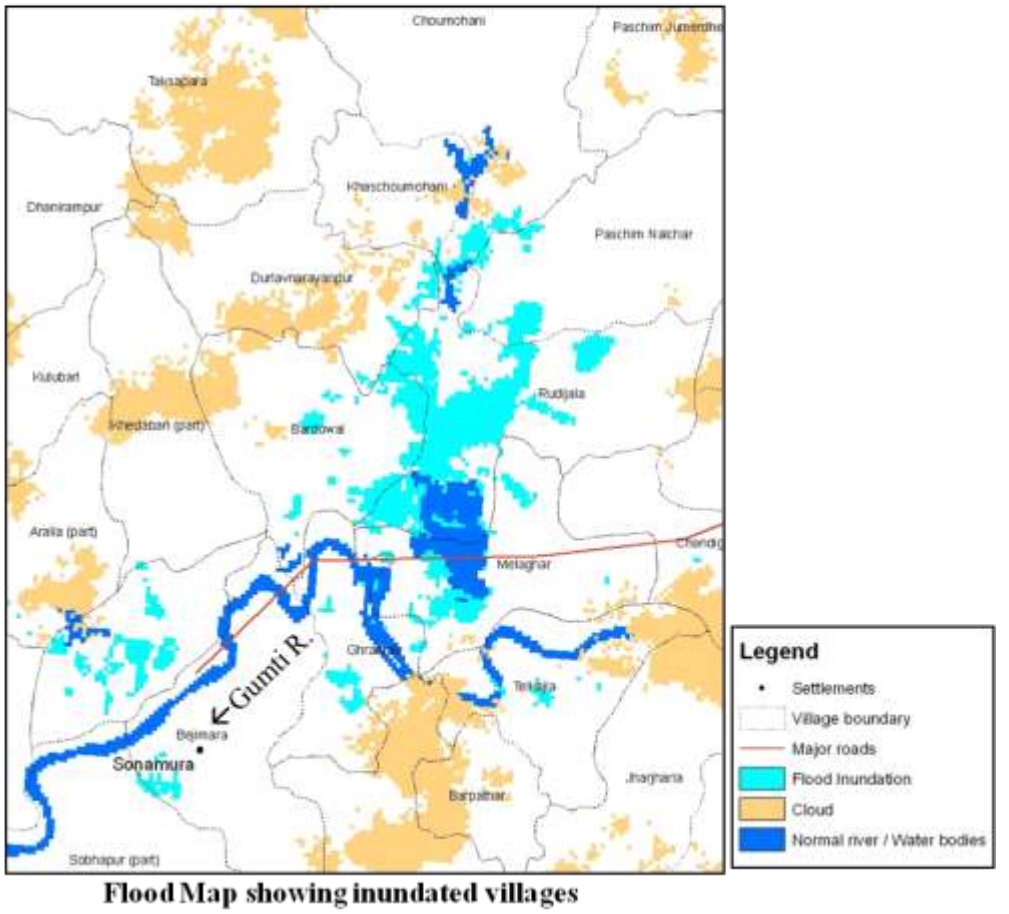
Sl. No.	District	Flood Affected Area (ha)
1	Gomati	2097
2	Sipahijala	1238
3	West Tripura	461
4	North Tripura	132
TOTAL		**3928**

Floods In Tripura - 2010

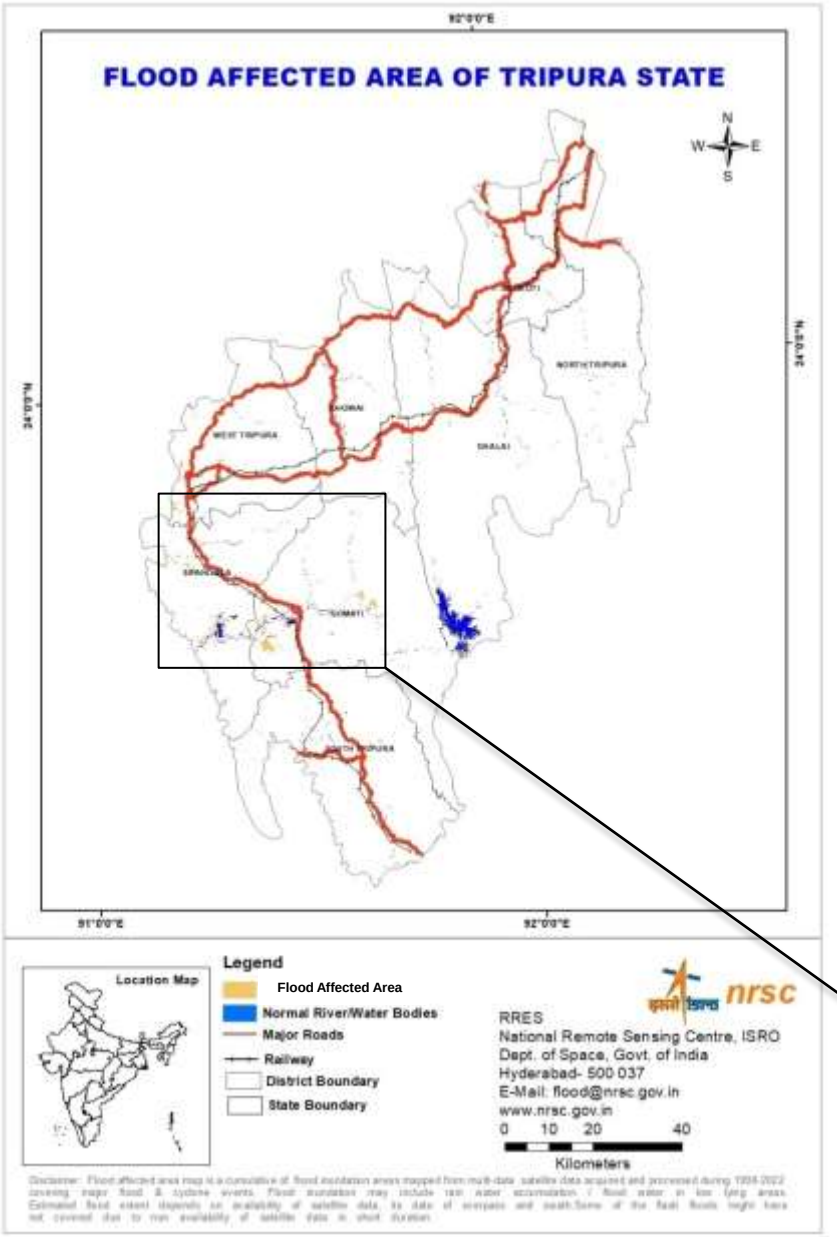
Floods were reported in Tripura during October, 2010 due to heavy rainfall. From the satellite data analysis of IRS AWiFS image of 11-Oct-2010 flood inundation was observed in Kakraban, Silghati, Garjanmura,Rajdamagar, Sonamura, Rani, Harijala, Bardowal, Melaghar, Hurijala & Khilpara villages of West & South Tripura districts.



IRS AWiFS Image of 11-Oct-2010



Flood Map showing inundated villages



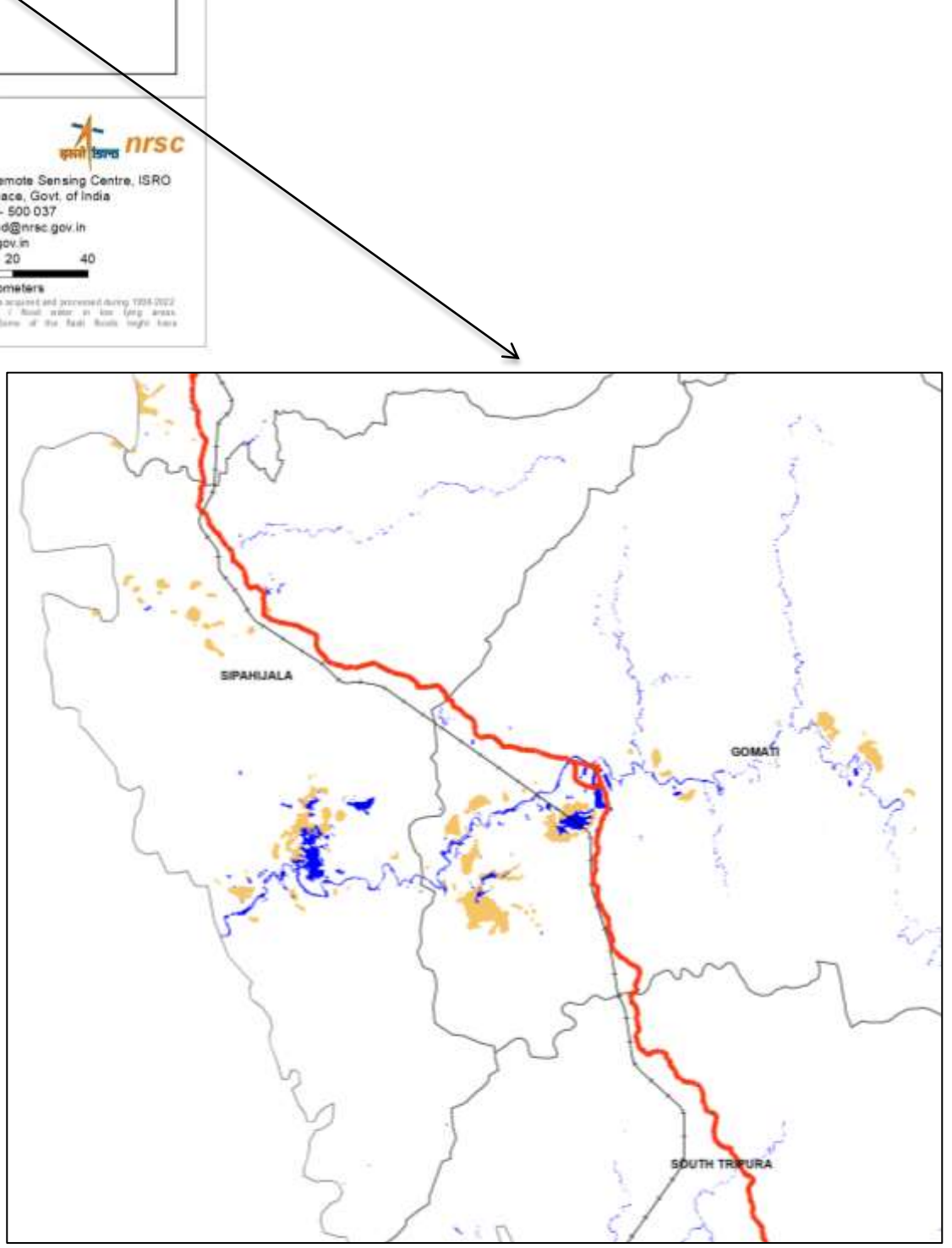


Fig.28.1 Flood affected area in Tripura State

29. Uttar Pradesh

Uttar Pradesh is located between the parallels of 23°52'N and 31°28'N latitudes and meridians of 77°3′E and 84°39'E longitudes. It is bordered by Rajasthan to the West, Haryana, Himachal Pradesh and Delhi to the Northwest, Uttarakhand and an international border with Nepal to the North, Bihar to the East, Madhya Pradesh to the South, and touches the states of Jharkhand and Chhattisgarh to the Southeast. It covers 240,928 km^2 (93,023 sq mi), equal to 7.34% of the total area of India.

The state can be divided into two physiographic regions: the central plains of the Ganges (Ganga) River and its tributaries (part of the Indo-Gangetic Plain) and the Southern Uplands. The vast majority of Uttar Pradesh lies within the Gangetic Plain, which is composed of alluvial deposits brought down from the Himalayas to the North by the vast Ganges network. Most of that area is a featureless, though fertile, plains varying in elevation from about 300m in the Northwest to about 60m in the extreme East. The Southern Uplands form part of the highly dissected and rugged Vindhya Range, which rises generally toward the Southeast. The elevation of that region rarely exceeds 300m.
The climate of Uttar Pradesh is of tropical monsoon type, with year-round warm weather. Average high temperatures in Lucknow range from about low 20 °C in January to over 38 °C in May and June. High temperatures of about 50 °C have been recorded at Gonda, northwest of Ayodhya.

Annual rainfall in the state ranges from 1,000–2,000 mm in the east to 600–1,000 mm in the west. According to IMD, UP, about 90 percent of the rainfall occurs during the southwest monsoon, lasting from about June to September. With most of the rainfall concentrated during that four-month period, floods are a recurring problem and can cause fatalities and heavy damage to crops and property, particularly in the eastern part of the state. Periodic failure of monsoons results in drought conditions. Figure 5 shows the location and physical features of Uttar Pradesh State.

Major Rivers

The State of Uttar Pradesh is enriched with water resources, both the ground water resources and the surface water resources. The major river basins in the State are Ganges, Yamuna, Ghaghra, Gomti, Ramganga,Rapti, Gandak, Son and Sarda river basins which criss-cross the State. The following section briefly describes the various river basins of Uttar Pradesh. Fig 8 shows the major river basins of UP and details are given below.

Ganga

Ganga is formed by 6 headstreams and 5 of their confluences. Bhagirathi is considered as source of River Ganga which rises at the foot of Gangotri glacier at Gaumukh at an elevation of 3892 mts, though there are many small streams that feed Bhagirathi. The six headstreams are the Alaknanda, Dhauliganga, Nandakini, Pindar, Mandakini, and Bhagirathi rivers. The five confluences, known as the PanchPrayag, are all along the Alaknanda. They are, in downstream order, Vishnuprayag, where the Dhauliganga joins the Alaknanda, Nandprayag, where the Nandakini joins Karnaprayag, where the Pindar joins, Rudraprayag, where the Mandakini joins; and finally, Devprayag, where the Bhagirathi joins the Alaknanda to form the Ganges River proper. It is the longest river of India and also the largest and most fertile basin the country.

Bhagirathi

It is considered as the source of river Ganga, rising at the foot of Gangotri glacier. The upper catchment of the river is glaciated and thus continuously feeds the river throughout the year. The river cuts spectacular gorges as it cuts through the granites and crystalline rocks of the middle Himalayas. Its main tributary is Bhilganga which joins it at Tehri, where the Tehri dam has been constructed.

Gomti

The Gomti river originates from Gomat Taal which is formally known as Fulhaarjheel, near Madho Tanda, Pilibhit, India. It extends 900 km (560 mi) through Uttar Pradesh and meets the Ganges River near Saidpur, Kaithi in Ghazipur. Another major tributary is the Sai River, which joins near Jaunpur. It meets Ganges near Ghazipur.

Ghaghra

It is a perennial river originating near Mansarovar lake, joins sharda river near Brahmaghat in Uttar Pradesh.Ghaghra river joins Ganges at Dariganjbhiar.It is the largest tributary of Ganges in terms of volume. The river flows through Katarniaghat wildlife sanctuary, part of Dudhwa National Park. The upper course of river is famous for gangetic dolphins.

Yamuna

Yamuna river originates from Yamunotri glacier in the lower Himalayas, Uttarkashi distict of Uttarakhand. Flows for 1370 kms before it meets Ganges at Allahabad. The river is fed by Tons (in Uttarakhand) and Giri (Himachal P) it forms boundary of Haryana,passes through Delhi along the border of Uttar Pradesh passing through the major cities like Baghpat, Noida, Mathura, Agra, Firozabad, Etawah& Hamirpur. The industrial development all along the course of river is now the major cause of Yamuna being polluted so much.

Chambal

The river rises in the Malwa on the northern slopes of Vindhyan near Mhow. The river is part of the confluence of 5 rivers near Etawah district called “Pachnada”(in hindi). The river is famous for the ravines that have been created due to flooding and break of channel by the Chambal River. Most rice and oil seeds are grown along the banks. Chambal is liable to heavy floods due to steep gradient of its bed before it debouches on the alluvial plains. The volume discharge is greater than Yamuna. Clear waters and alligators are common in the river. Hydropower and irrigation projects Gandhi Sagar (MP) and Ranapratap Sagar (Rajasthan) and Kota barrage are built on Chambal River.

Betwa

The Betwa rises in the Vindhya Range just North of Hoshangabad in Madhya Pradesh and flows North-East through Madhya Pradesh and flow through Orchha to Uttar Pradesh. Matatila Dam, an undertaking between the states of Madhya Pradesh and Uttar Pradesh, Paricha Dam, Rajghat Dam situated on Betwa river.

Tons River / Tamsa

The Tamsa River (also known as the Tons River) is a tributary of the Ganges flowing through the Indian states of Madhya Pradesh and Uttar Pradesh. The Tamsa rises in a tank at Tamakund in the Kaimur Range at an elevation of 610 meters. It flows through the fertile districts of Satna and Rewa. The river receives the Belan in UP and joins the Ganges at Sirsa, 300 km from Sangam. The Tamsa River while descending through the Rewa Plateau and draining northwards makes a vertical falls of 70m known as Purwa Falls, Chachai Falls (127m) on the Bihad River, a tributary of the Tamsa, the Keoti Falls (98m) on the Mahana River, a tributary of the Tamsa, and Odda Falls (145m) on the Odda River, a tributary of the Belah River, which is itself a tributary of the Tamsa.

Son River

The Son originates near Amarkantak in Madhya Pradesh,just East of the headwaters of the Narmada River. The Son parallels the Kaimur hills, flowing East-Northeast through Uttar Pradesh, Jharkhand and Bihar states to join the Ganges just above Patna. Its chief tributaries are the Rihand and the North Koel. The Bansagar Dam in Madhya Pradesh is made on this river.

29.1 Major Floods in Uttar Pradesh

The State of Uttar Pradesh accounts for approximately 24 percent of the total flooded area and 23 percent of the total damages in the country during the period 1971-1978, The eastern half of the State is more vulnerable wherein some area gets affected by floods almost every year. Eastern districts of Uttar Pradesh are worst affected by the floods. The rivers which cause damage in this area are the Ghaghara, the Sarda, Gandak, and Rapti, The Ghaghara submerges an area of 7769.97 Sq, Km, and the Rapti about 3107.988 Sq. Km near the confluence of the Ganga and Ram Ganga, The problem of drainage congestion is also found in the Western and North-western districts of Uttar Pradesh.

Records from Central Water Commission say that Ghaghara and Rapti river basin has experienced major floods during 1965, 1969, 1973 & 1998. Flood has occurred 2 times in the Balrampur district. 9 times in Basti district and 21 times in Birdghat (Gorakhpur) between 1987 to 1996. (Nandargi& Dhar D.N., 1998). The severe flood of the year 1998 and losses thereof have necessitated to study the area in detail and develop the methodology for flood risk mapping, silt load assessment and creation of data base for flood management information system for long term flood prone area planning (RSAC, 1998 & 2008). Major flood events in Uttar Pradesh is listed in Table 29.1 for which satellite derived spatial flood inundation maps were generated and disseminated to state / central government disaster support management organizations by NRSC, ISRO.

Table.29.1 . Major flood events in Uttar Pradesh state

S.No	Year	Description of the flood event	Districts affected
1	2003	Floods occurred during 20-21st Sep 2003 due to rise of water level of Ganga and Ghaghara rivers and their tributaries	7
2	2005	Floods occurred during 12th July 31st Aug 2005 due to rise in water levels in the upper hilly regions affecting the rise in Ganga, Yamuna, Ghagra, Boodhi, Rapti and Sharda rivers	4
3	2007	Floods occurred during 31st Jul – 2nd Sep 2007 due to rise in water levels in the upper hilly regions affecting the rise in water levels in Gaghra and Gomti rivers	20
4	2008	Floods occurred during 7-28th Jul, 1-30th Aug, 8-26th Sep 2008 due to the continuous rise in the water level of Ghaghra, Saryu, Sharda, Rapti and Yamuna rivers	33
5	2009	Floods occurred during 3rd -27th, Jul, 9th oct-14th Oct 2009 due to rise in water levels Sharda, Ghaghra, Saryu and Rapti rivers	31
6	2010	Floods occurred during 22-23rd Jul, due to rise in water levels Sharda, Ghaghra, Saryu and Rapti rivers	44

S.No	Year	Description of the flood event	Districts affected
7	2011	Heavy rains were reported during fourth week of July, 2011; and rise in water levels of Ken river. Breach in the Elgin-Charsadi embankment of Ghagra river on August 01, 2011 ; Rise in levels during Aug 2011 in River Ghaghara , River Ganga	20
8	2012	Floods occurred during 22-23rd Jul, due to rise in water levels Burhi Rapti, Ghaghra river and its tributaries during 26-28th August, 3rd week of Sep 2012	10
9	2013	Floods occurred during 18-19th Jun, 4th Jul-4th Oct 2013 due to rise in water levels in Burhi Rapti, Ghaghra and Sharda rivers	35
10	2014	Floods due to rise in water levels in Ghgra and Rapti rivers	19
11	2016	Floods occurred during 20th – Jul 30th Aug 2016 due to rise in water levels in Ghgra and Rapti rivers	30
12	2017	Floods occurred during 6th Aug – 2nd Sep due to rise in water levels in Ghgra and Rapti rivers	19
13	2018	Floods occurred during 4th Aug -12th Sep due to rise in water levels in Ghgra and Rapti rivers	31
14	2019	Floods occurred during 7th Jul -29th Sep due to rise in water levels in River Ganga at Ballia, Gazipur and Kachhlabridge. River Yamuna at Mavi was reported to be flowing in sever flood situation. River Rapti at Balrampur and River Ghaghra at Ayodhya in Faizabad	24
15	2020	Floods occurred during 13th Jul – 29th Sep due to rise in water levels of River Gandak, Rapti and Ganga	30
16	2022	Floods occurred during August – October 2022 due to unprecedented and intense rains. Major floods have occurred in Ganga River Basin along the Rapti & Ghagra river reaches due to heavy rainfall and runoff. The floods have occurred four times (1) 9-15th Aug 2022, (2) 15-23rd Sep 2022, (3) 27- 20th Sep 2022, and (4) 5-15th October 2022.	54

28.2 Flood Affected Area in Uttar Pradesh

Cumulative flood inundation maps were utilised for generation of map of total flood affected area in Uttar Pradesh and is estimated as 26,62,942 ha. Flood Affected Area Map is shown in Figure.29.1 and district wise flood affected area statistics are shown in Table. 29.2. Six districts in Uttar Pradesh have flood affected area > 1,00,000 ha, 15 districts between 50,000-1,00,000 ha, 12 districts between 25,000-50,000 ha, 19 districts between 10,000-25,000 ha and 20 districts <10,000 ha.

Table.29.2 District wise statistics of Flood affected area in Uttar Pradesh

Sl. No.	District	Flood Affected Area (ha)
1	Siddharth Nagar	180929
2	Gorakhpur	158713
3	Maharajganj	127378
4	Azamgarh	121019
5	Ghazipur	112660
6	Ballia	111199
7	Bahraich	94900
8	Balrampur	89762
9	Hardoi	81419
10	Badaun	79188
11	Kheri	75768
12	Deoria	73652
13	Unnao	73342
14	Shahjahanpur	71177
15	Farrukhabad	70712
16	Sant Kabir Nagar	64406
17	Jalaun	63190
18	Banda	58830
19	Basti	58566
20	Allahabad	52678
21	Sitapur	50393
22	Shrawasti	47771
23	Bareilly	44203
24	Mau	43507
25	Etawah	38821
26	Bara Banki	36042
27	Gonda	34914
28	Mirzapur	33609
29	Mainpuri	32503
30	Chandauli	32162
31	Kansiramnagar	28213
32	Ambedkarnagar	27040
33	Kushinagar	26976
34	Auraiya	24827
35	Rampur	24548
36	Jaunpur	18796
37	Fatehpur	17443
38	Bhimnagar	16805
39	Hamirpur	16404
40	Agra	14570
41	Kanpur Dehat	14192
42	Rae Bareli	14114
43	Pilibhit	13785
44	Meerut	12861
45	Kannauj	12703
46	Aligarh	12541
47	Mathura	12415
48	Kaushambi	12354
49	Moradabad	12234
50	Sultanpur	11898
51	Faizabad	11676
52	Muzaffarnagar	10197
53	Chitrakoot	9270
54	Firozabad	9141
55	Bijnor	9037
56	Kanpur Nagar	8241
57	Jyotiba Phule Nagar	8181
58	Varanasi	8160
59	Etah	6208
60	Hathras	5462
61	Bulandshahr	4131
62	Lucknow	3783
63	Pratapgarh	2501
64	Jhansi	2159
65	Gautambudh Nagar	1621
66	Sant Ravi Das Nagar(bhadohi)	1551
67	Saharanpur	1420
68	Prabudhnagar	765
69	Baghpat	580
70	Amethi	303
71	Panchshil Nagar	233
72	Ghaziabad	191
	TOTAL	**2662942**

Glimpses of satellite images / flood inundation over the time period are depicted in this section.

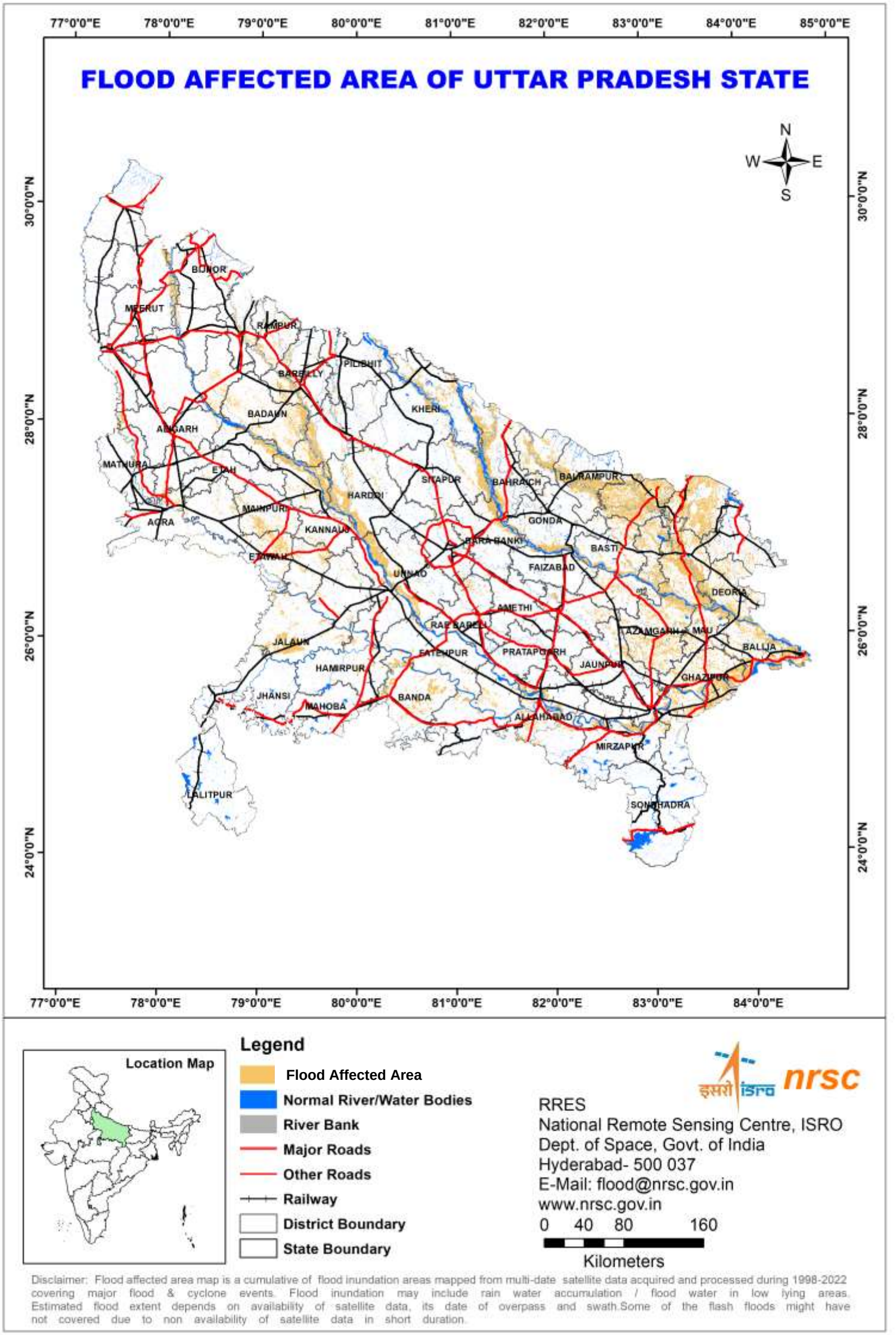
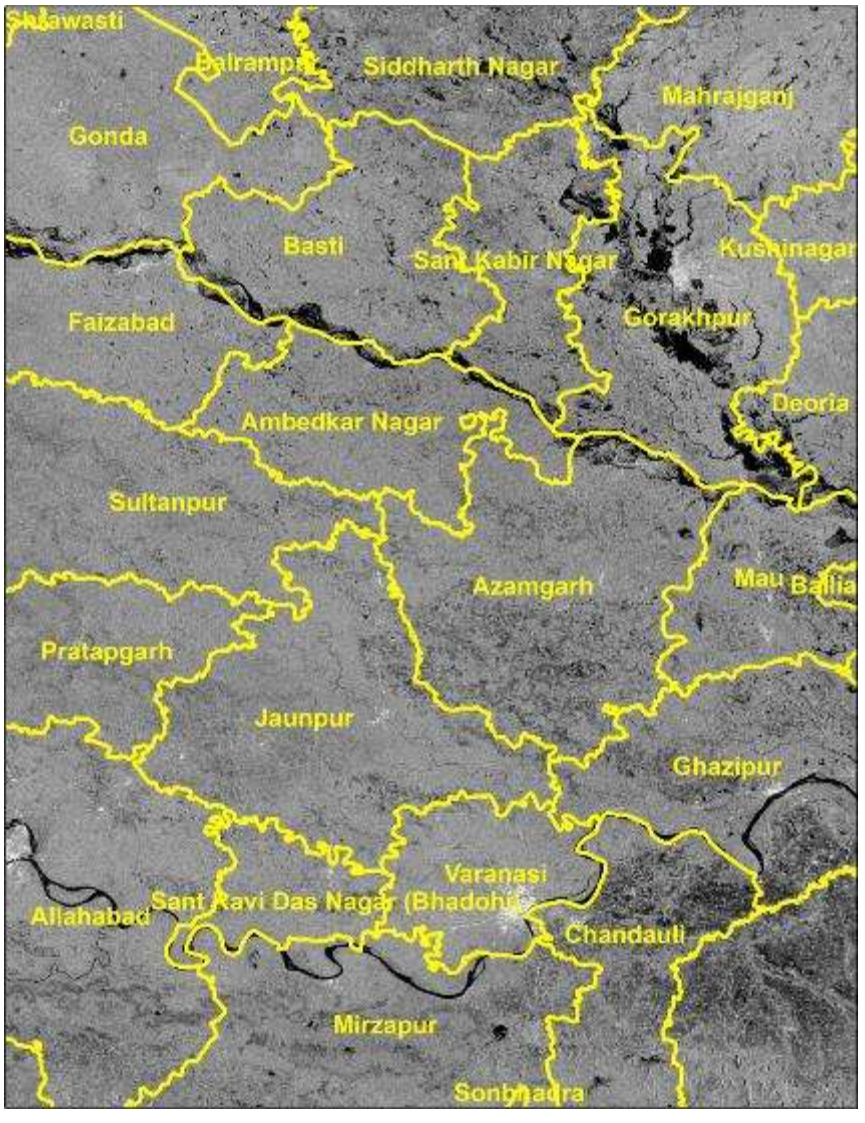
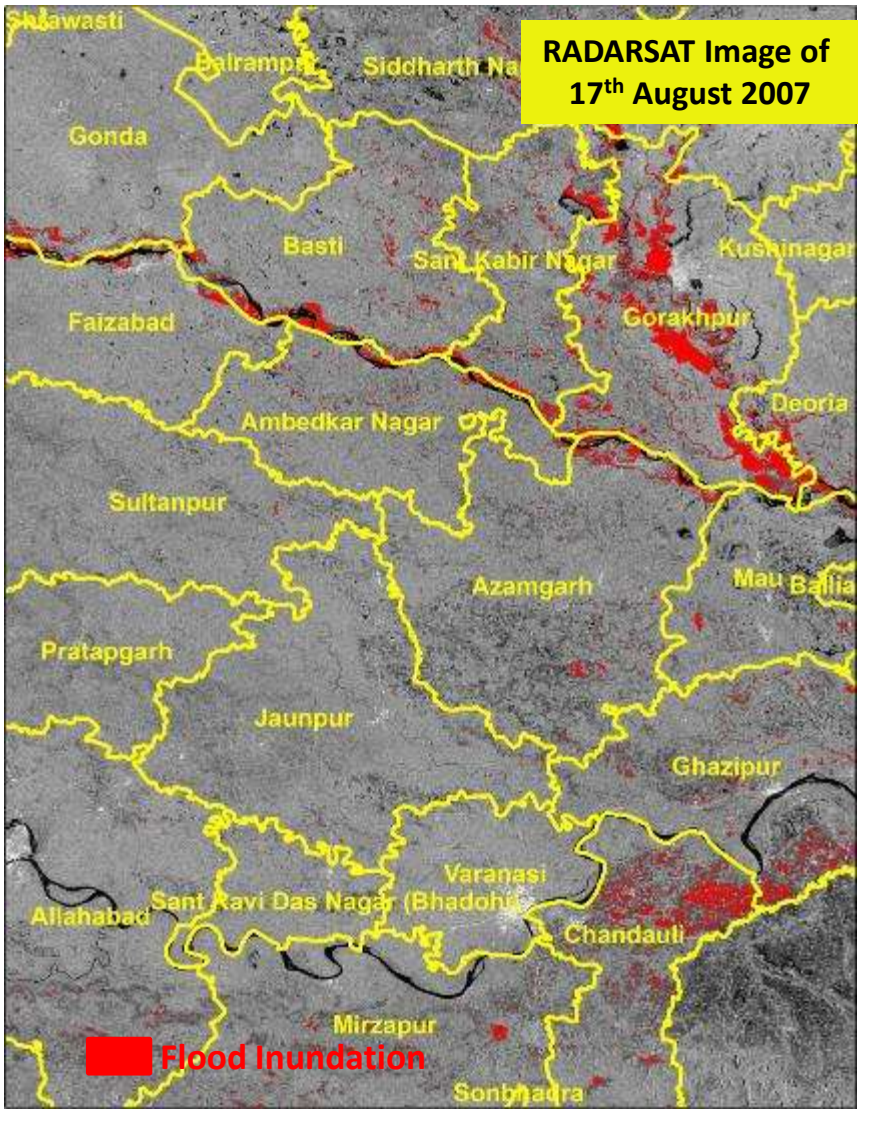
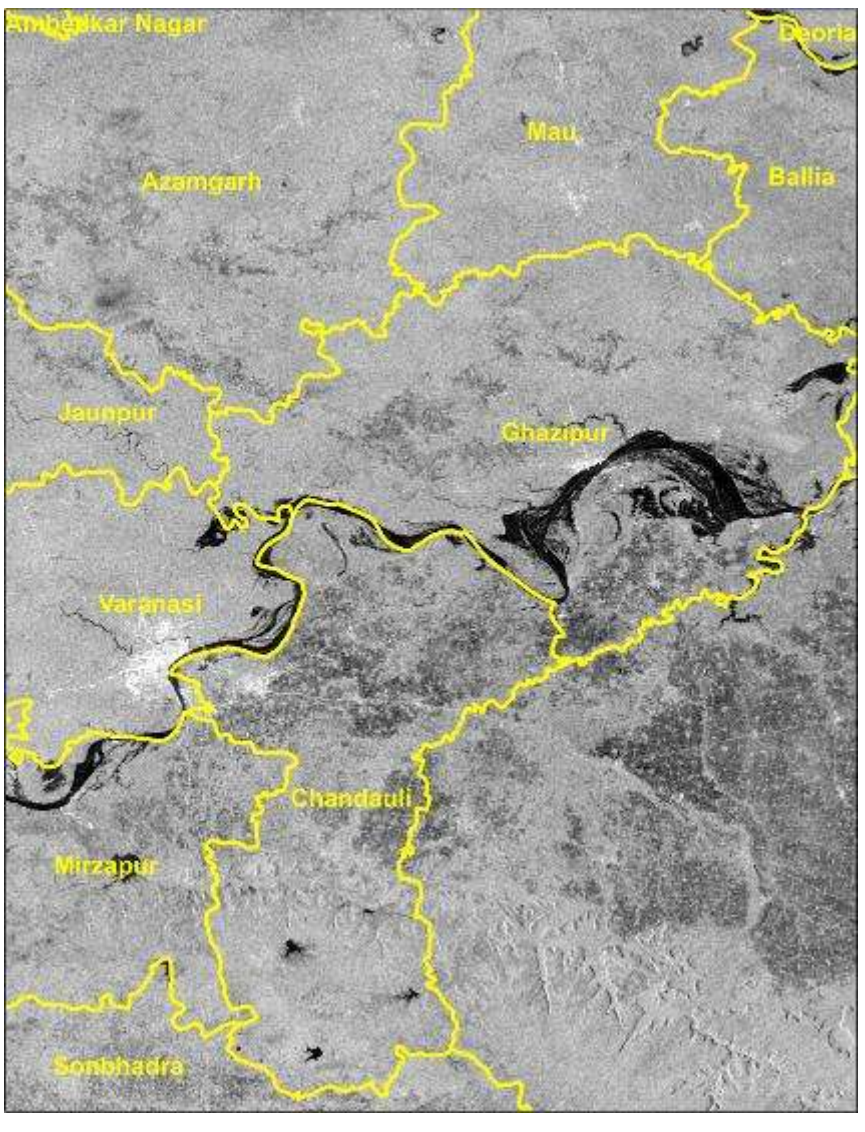
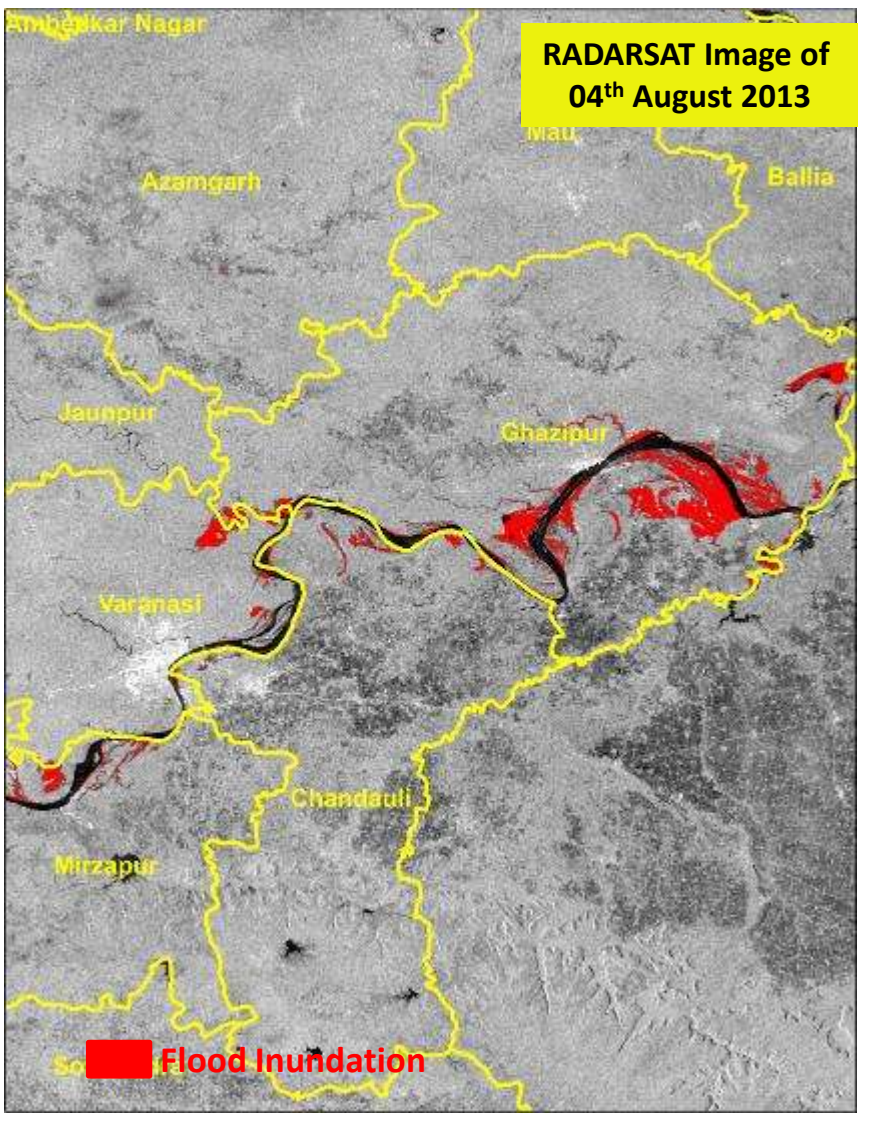


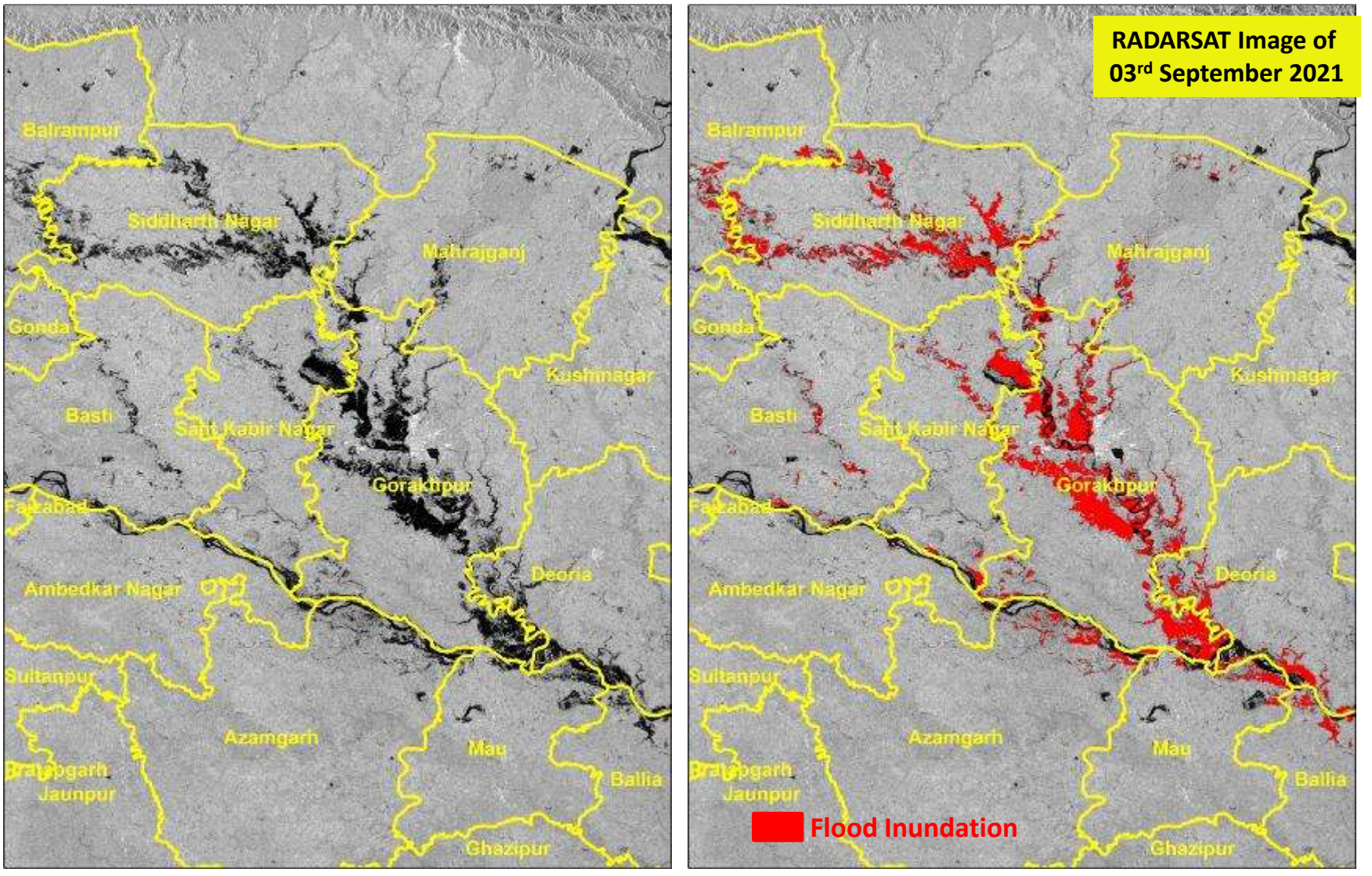
Fig.29.1 Flood affected area in Uttar Pradesh State


Gonda
Basti
Faizabad
Ambedkar Nagar
Sultanpur
Pratapgarh
Jaunpur
Azamgarh
Mau
Ballia
Ghazipur
Varanasi
Chandauli
Mirzapur
Sonbhadra
Deoria
Gorakhpur
Kushinagar
Mahrajganj
Siddharth Nagar

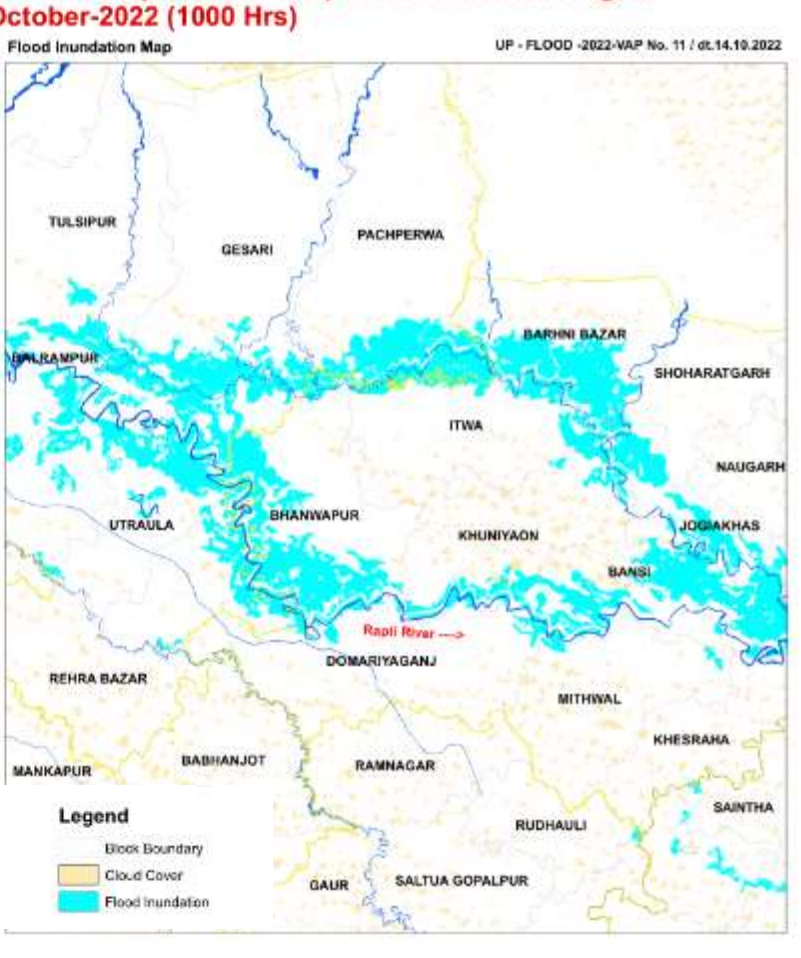

RADARSAT Image of
17th August 2007
Gonda
Basti
Faizabad
Ambedkar Nagar
Sultanpur
Pratapgarh
Jaunpur
Azamgarh
Mau
Ballia
Ghazipur
Varanasi
Chandauli
Mirzapur
Deoria
Gorakhpur
Kushinagar
Flood Inundation

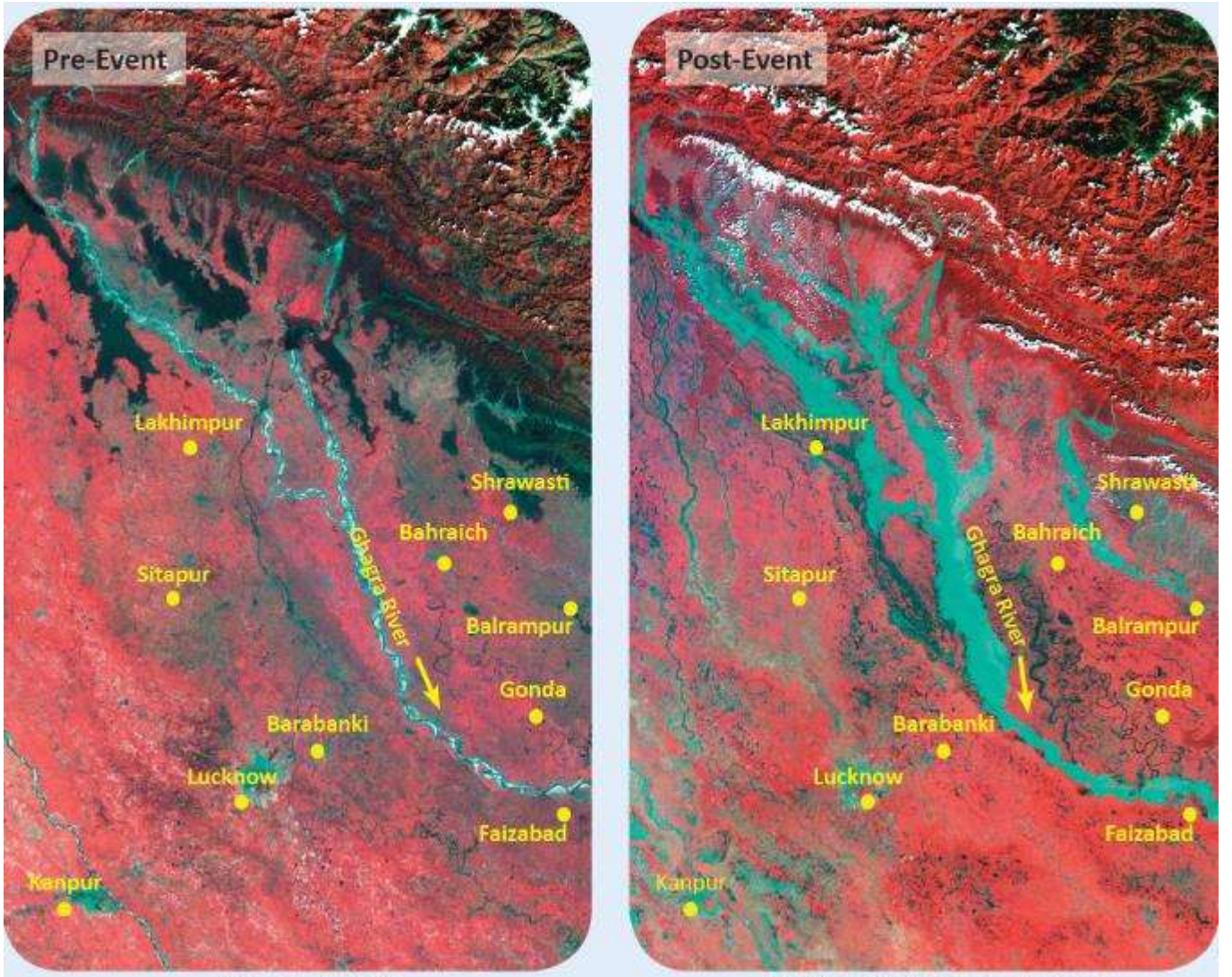

Ambedkar Nagar
Azamgarh
Jaunpur
Varanasi
Mirzapur
Sonbhadra
Deoria
Mau
Ballia
Ghazipur
Chandauli


RADARSAT Image of
04th August 2013
Ambedkar Nagar
Azamgarh
Jaunpur
Varanasi
Mirzapur
Mau
Ballia
Ghazipur
Chandauli
Flood Inundation



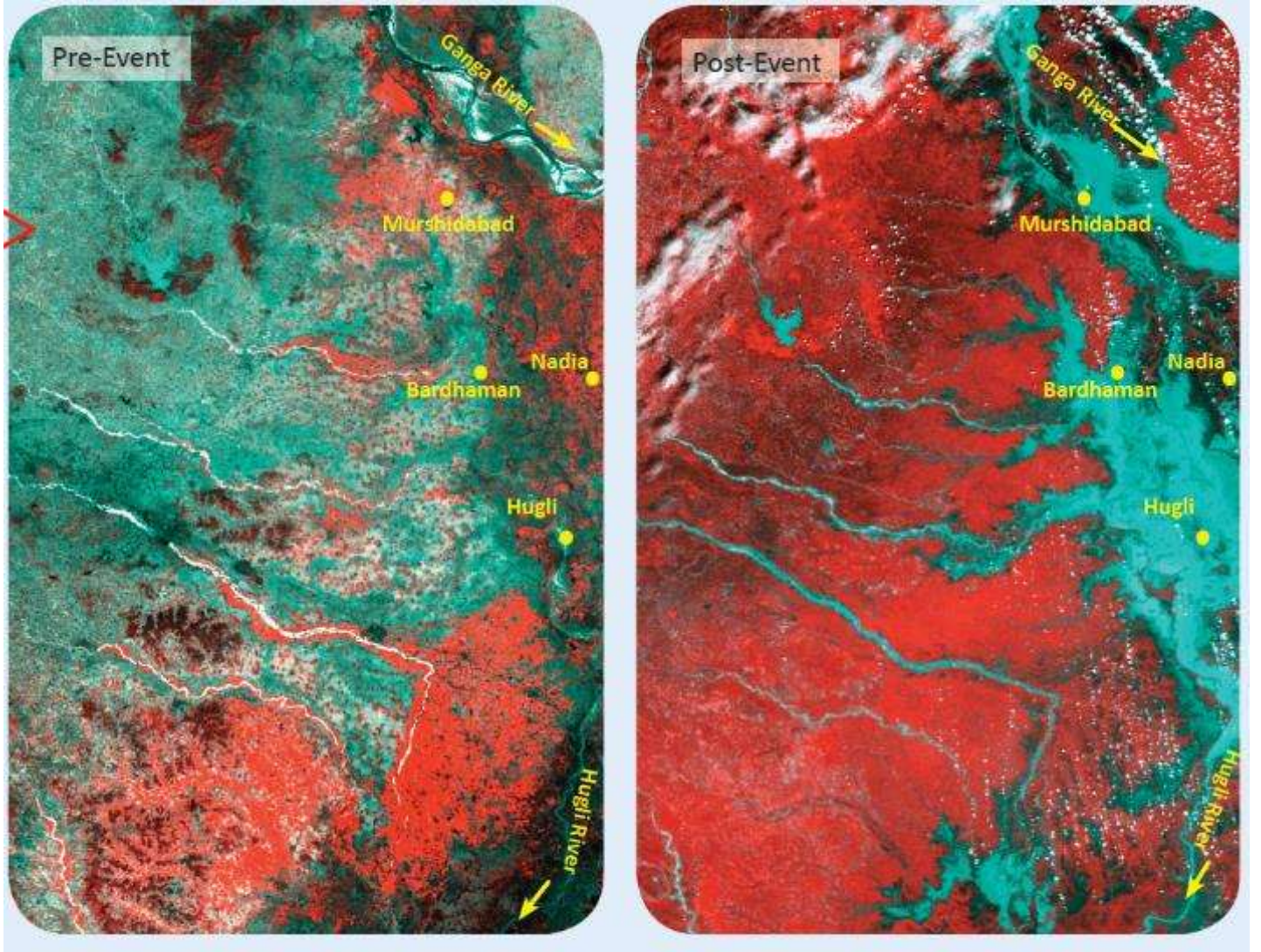
Resourcesat-2A AWiFS Satellite Image Showing Flood Inundation in part of Balrampur and Siddharth Nagar, Uttar Pradesh State as on 14-October-2022 (1000 Hrs)





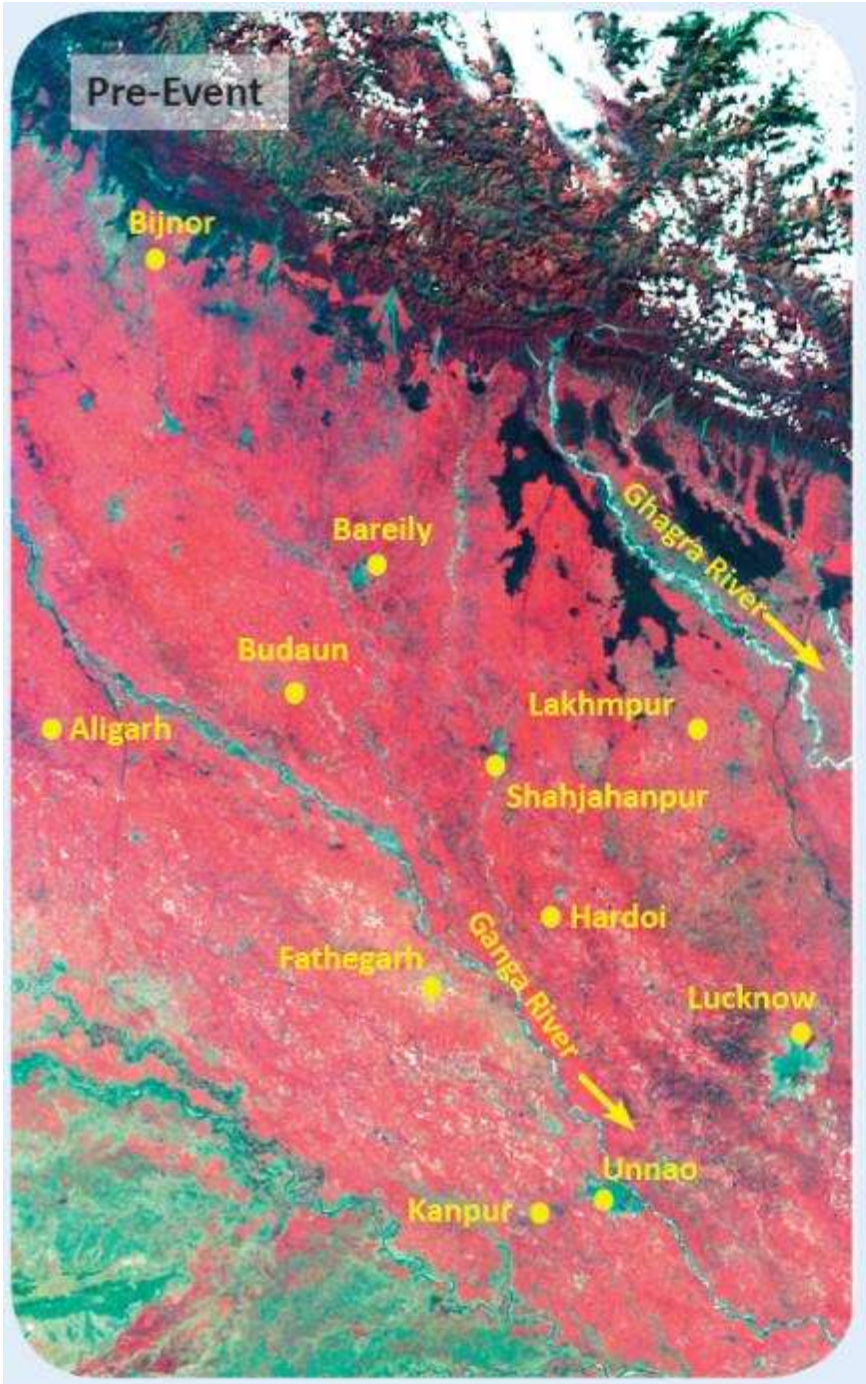
IRS-P6 AWiFS

IRS-P6 AWiFS 09 Oct-2009

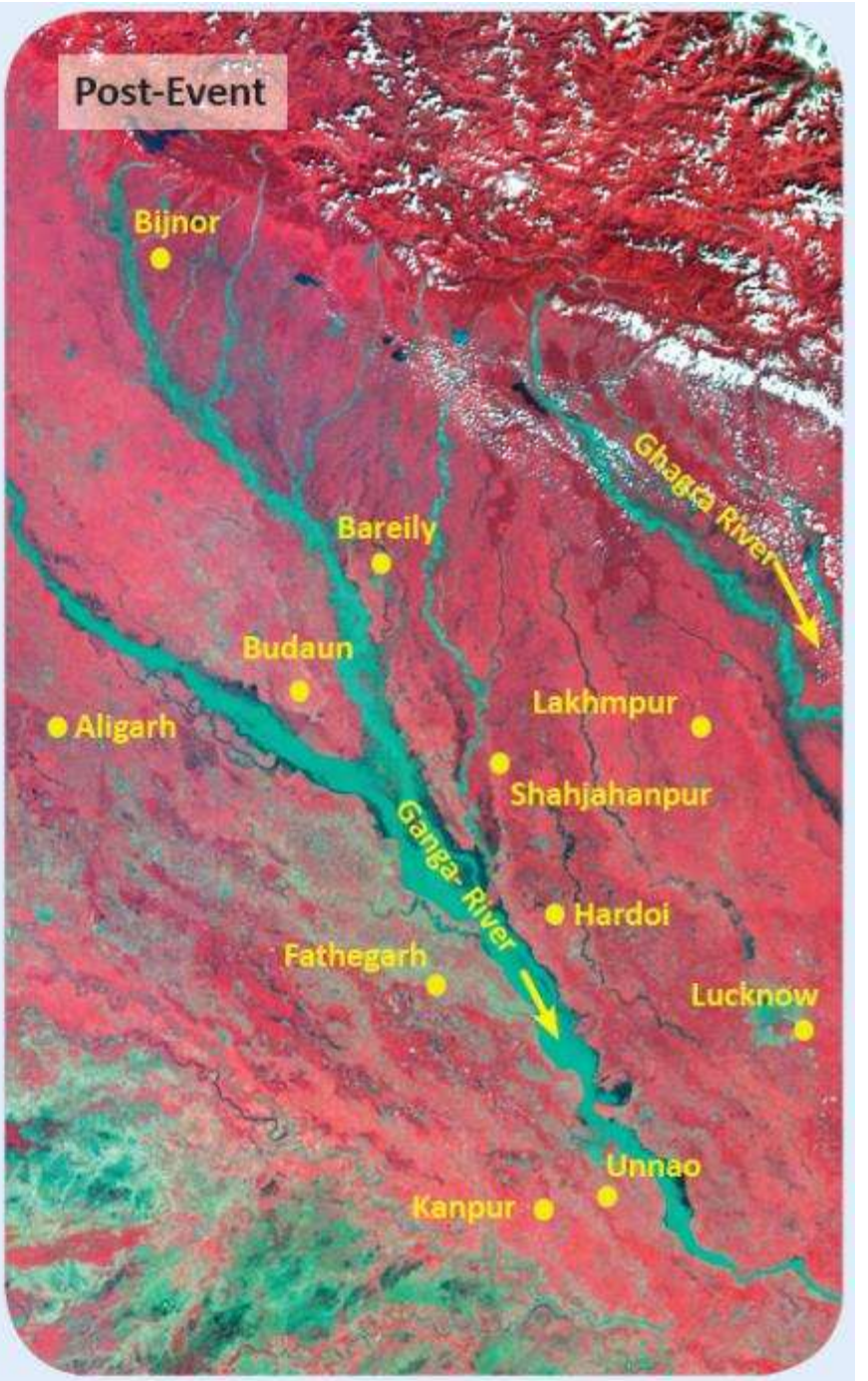


IRS-1D WiFS

IRS-1D WiFS 28 Sep-2000



IRS-P6 AWiFS



IRS-P6 AWiFS 29 Sep-2010

30. Uttarakhand

The Uttarakhand floods of 2013 were a natural disaster that occurred in the northern Indian state of Uttarakhand in June 2013. The disaster was triggered by heavy rainfall and cloudbursts that caused flash floods and landslides in the region. The floods affected several areas of Uttarakhand, particularly the districts of Rudraprayag, Chamoli, Uttarkashi, and Pithoragarh. The floods caused widespread damage to property and infrastructure, including roads, bridges, and buildings. Many people were killed, and thousands were stranded or reported missing. The floods highlighted the need for better disaster preparedness and early warning systems in the region.

30.1 Flood Problem in Uttarakhand

Kedarnath Flood 2013

In June 2013, a mid-day cloudburst centered on the North Indian state of Uttarakhand caused devastating floods and landslides, becoming the country's worst natural disaster since the 2004 tsunami.From 16 June 2013 a well-marked cyclonic circulation developed around a low pressure area over the Bay of Bengal, moving westwards, rapidly intensified due to moisture supplied from both the Bay of Bengal and the Arabian Sea, combining with intense western disturbances from the north, thus causing the Indian state of Uttarakhand and adjoining areas to receive heavy rainfall, leading to 375% of the benchmark rainfall during a normal monsoon. This caused the melting of Chorabari Glacier at the height of 3800 meters and cresting of the Mandakini River, which led to heavy floods near Gobindghat, Kedar Dome, Rudraprayag district, Uttarakhand, Himachal Pradesh and Western Nepal, and acute rainfall in other nearby regions of Delhi, Haryana, Uttar Pradesh and some parts of Tibet.

Chamoli Disaster 2021

The 2021 Uttarakhand flood, also known as the Chamoli disaster, began on 7 February 2021 in the environs of the Nanda Devi National Park, a UNESCO World Heritage Site in the outer Garhwal Himalayas in Uttarakhand state, India. It was caused by a large rock and ice avalanche consisting of material dislodged from Ronti peak. It caused flooding in the Chamoli district, most notably in the Rishiganga river, the Dhauliganga river, and in turn the Alaknanda—the major headstream of the Ganga. In satellite images, a 0.80 km scar is visible on the slopes of Nanda Ghunti, a 6,300 m peak on the southwestern rim of the Nanda Devi sanctuary, a wall of mountains surrounding the Nanda Devi massif.

Major flood events in Uttarakhand is listed in Table 30.1 for which satellite derived spatial flood inundation maps were generated and disseminated to state / central government disaster support management organizations by NRSC, ISRO.

Table.30.1 . Major flood events in Uttarakhand state

S.No	Year	Description of the flood event	Districts affected
1	2010	Floods were reported in parts of Uttarakhand due to heavy rains during the third week of September, 2010. Major rivers continued to rise with the Ganga in Hardwar	Haridwar
2	2013	Due to extreme weather conditions, heavy rainfall was reported in parts of Uttarakhand leading to flash floods and debris flow on 17-June-2013	Kedarnath surroundings
3	2022	Flash floods have occurred in Maldevta area , Dehradun on 27th Aug 2022. These flash floods have triggered damage to infrastructure	Dehradun

30.2 Flood Affected Area in Uttarakhand

Cumulative flood inundation maps were utilised for generation of map of total flood affected area in Uttarakhand and is estimated as 7,604 ha. Flood affected area map is shown in Figure.30.1 and district wise flood affected area statistics are shown in Table. 30.2. Two districts in Uttarakhand have flood affected area <10,000 ha.

Table.30.2 District wise statistics of Flood affected area in Uttarakhand

Sl. No.	District	Flood Affected Area (ha)
1	Haridwar	7170
2	Udham Singh Nagar	433
TOTAL		**7604**

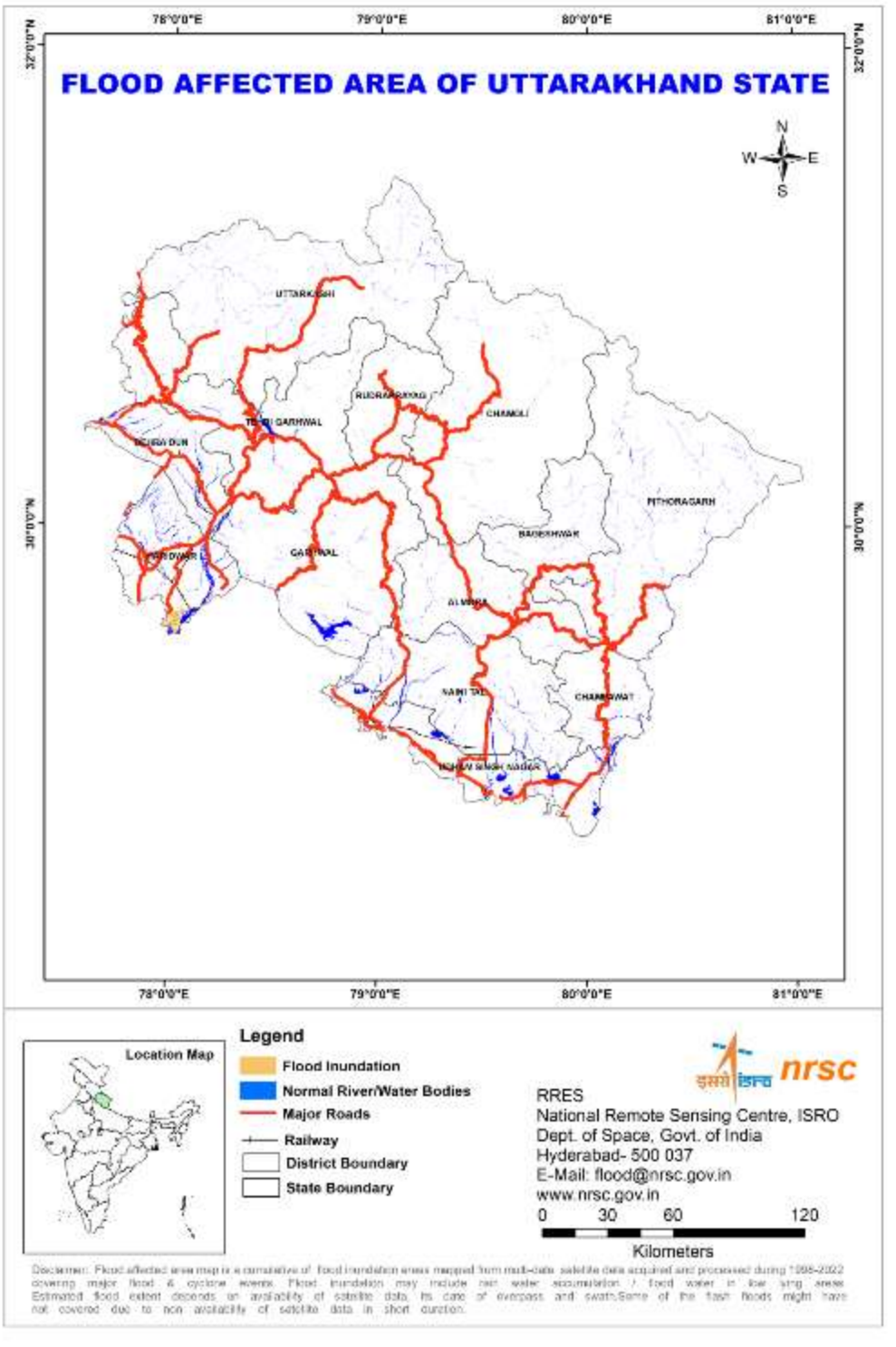
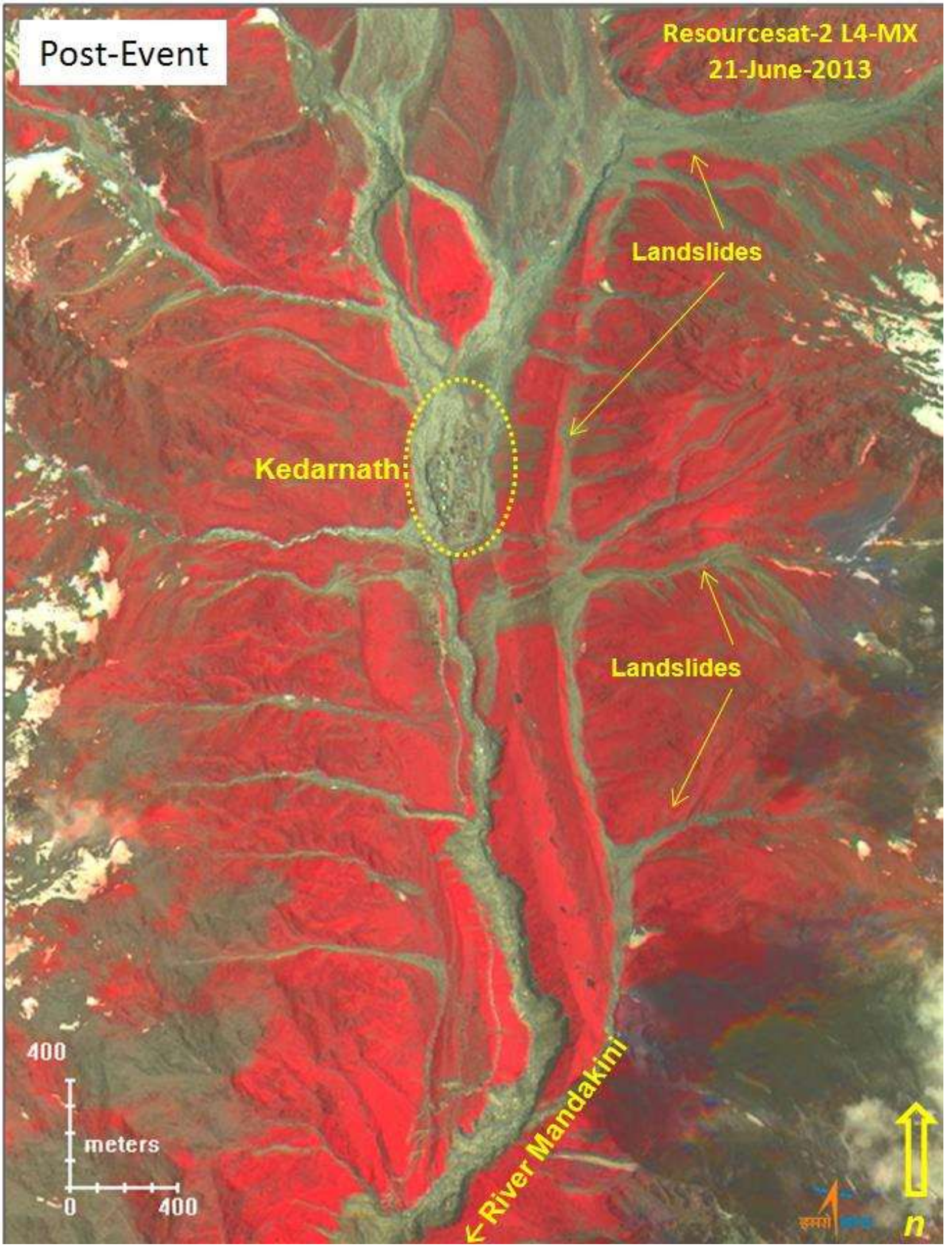


Fig.30.1 Flood affected area in Uttarakhand State

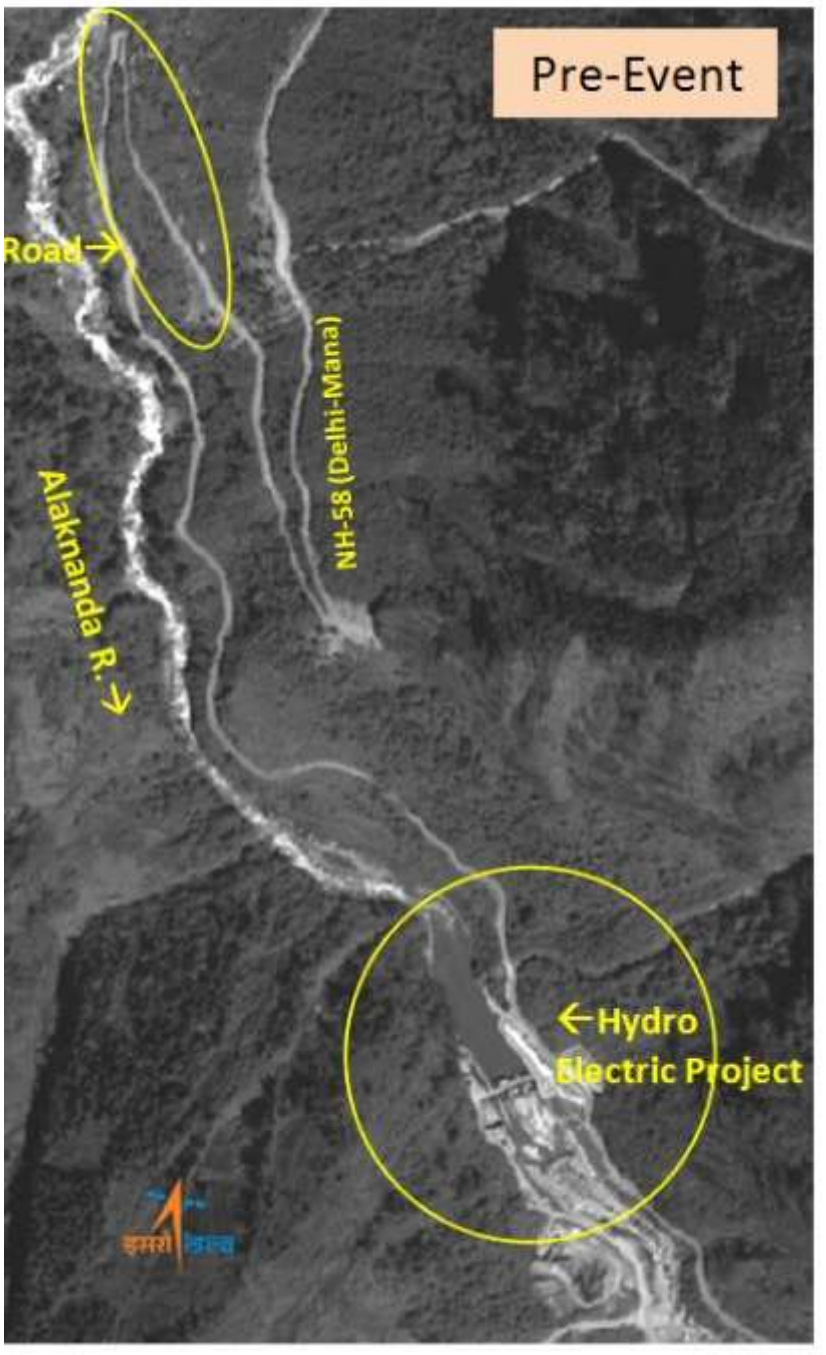
Glimpses of satellite images / flood inundation over the time period are depicted in this section.


Post-Event
Resourcesat-2 L4-MX
21-June-2013
Landslides
Kedarnath
Landslides
River Mandakini
400
meters
0
400
n

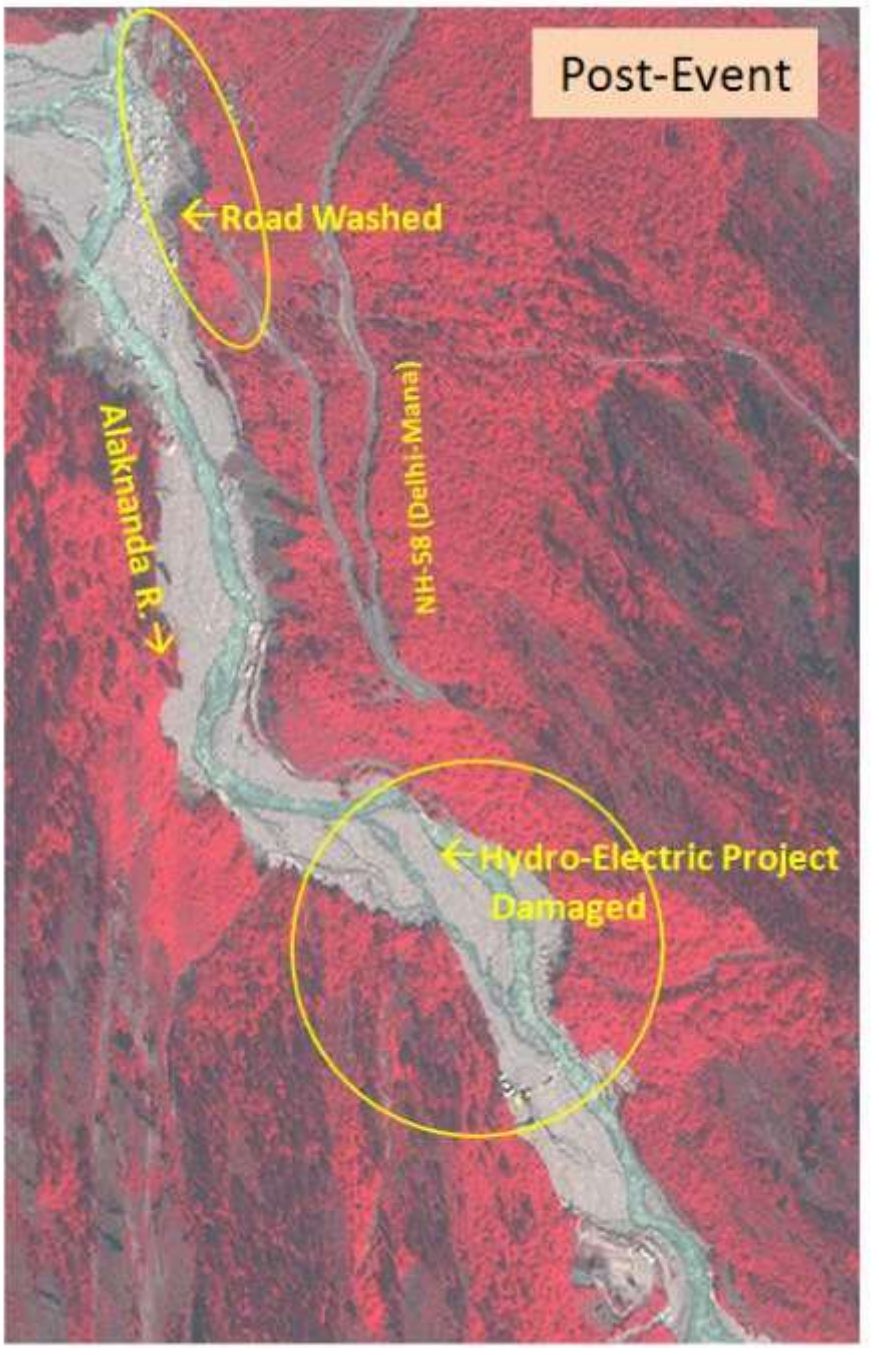

Pre-Event
CARTOSAT-1
Kedarnath
Temple
50
meters
0
50


Post-Event
CARTOSAT-2A
20-June-2013
Debris
Road
washed off
Kedarnath
Temple
Road
washed off
50
meters
0
50

Satellite images showing damage upstream of Lambada Village (Badrinath), Uttrakhand



Cartosat-1 Image (2011)



Worldview Image as on 26th June 2013

Image is acquired through International Charter

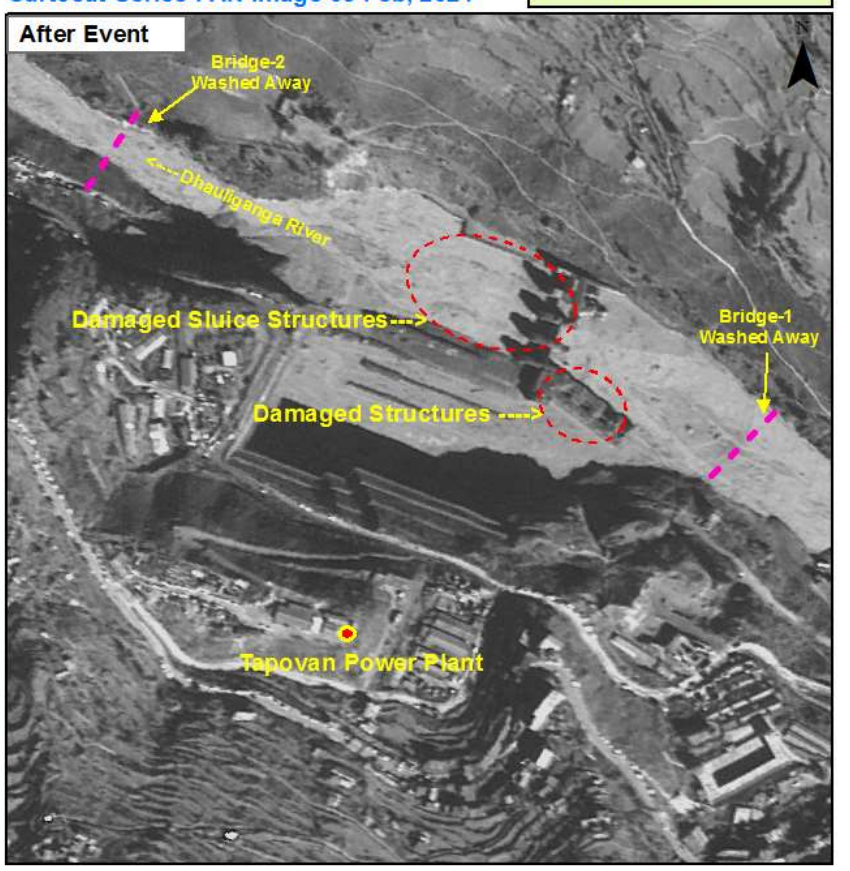
Damaged to Dam Infrastructures at Tapovan, Uttarakhand due to Flash Flood.

Date of Issue : 09.02.2021

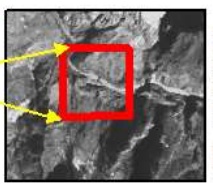
DISASTER EVENT ID: 01-FLD-2021-UK
MAP ID: 2021/01

KOMPSAT-3A Image 16 Sep, 2020

Cartosat-Series PAN Image 08 Feb, 2021



Location Map



About Event

On 07th Feb, 2021 a major rockslide/snow avalanche reportedly took place near Raini village of Chamoli district. Subsequently, flash floods were reported in Rishi Ganga and Dhauli Ganga river catchment areas causing severe loss of life and property. The power plants located at Raini and Tapovan suffered maximum damage in the current deluge.

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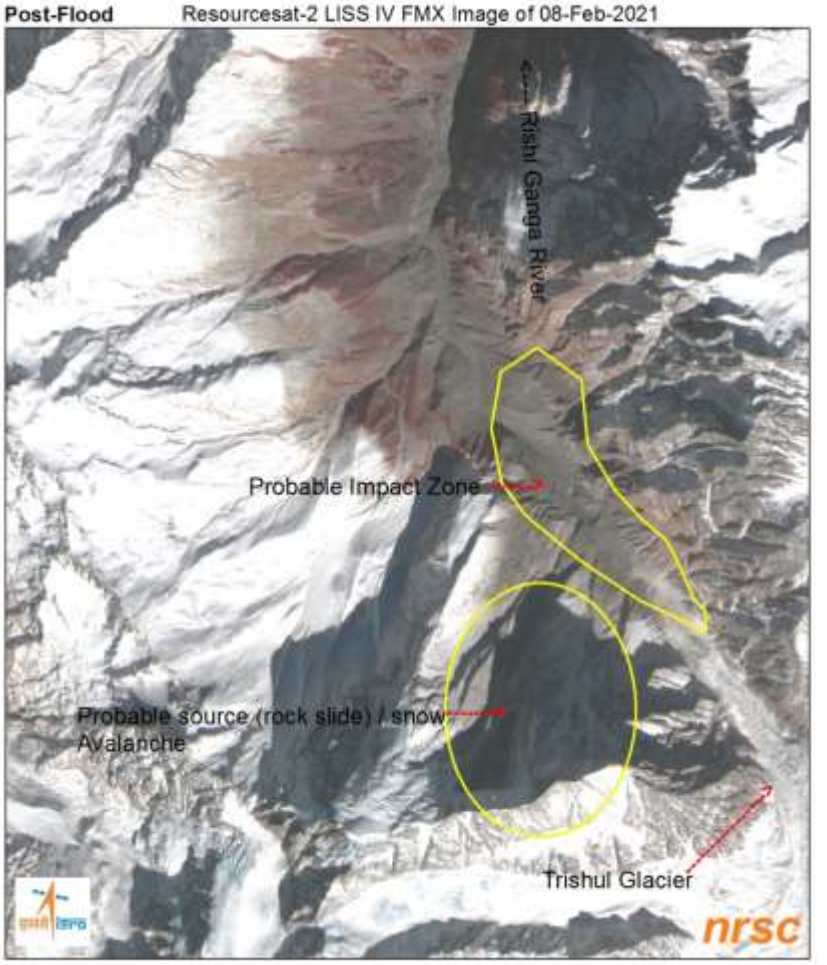
Glacial Burst Affected Areas near Trishul Glacier, Uttarakhand

Pre-Flood Resourcesat-2 LISS IV FMX Image of Oct 18, 2020

Post-Flood Resourcesat-2 LISS IV FMX Image of 08-Feb-2021



Flash flood event has damaged several roads and river channels were widened in Maldevta area, Dehradun

West Bengal

31. West Bengal

West Bengal, the fourth most populous state in India, is located in Eastern India on the Bay of Bengal. It lies between 85° 50‘ and 89° 50‘ East longitude, and 21° 25‘ and 27° 13‘ North latitude stretching from the Himalayas in the north to the Bay of Bengal in the south. The state has diverse landforms which include the Darjeeling Himalayan hill region, the Terai region, the North Bengal plains,the Rarh region, the coastal plains, the Sundarbans delta, the Western plateau and the Ganges delta. West Bengal shares international boundaries with Bangladesh in the east, Bhutan and Nepal in the north. It is bordered by Sikkim in the north, Bihar and Jharkhand in the west and Orissa in the south. The Ganges, Hooghly, Rupnarayan and Damodar are the major rivers in West Bengal, which has an area of 88,752 square kilometres (34,267 square miles). The major base of its economy is agriculture while industry and mining also have significant contributions towards the same. West Bengal may be broadly divided into two natural geographic divisions—the Gangetic Plain in the south and the sub-Himalayan and Himalayan area in the north. The Gangetic Plain is rich in fertile alluvial soil deposited by the Ganga River along with its tributaries and distributaries. It also has many marshes and shallow lakes formed out of dead river courses. Hugli (Hooghly) River is one of the western distributaries of Ganges and it contributes to the majority of water from the Ganga that flows into the sea. The state capital, Kolkata, is situated on the Hugli in the southern portion of West Bengal. The Damodar is another important river in the state and it joins the Hugli southwest of Kolkata. The elevation of the plain increases slowly toward the west; the rise is most
prominent near the Chota Nagpur plateau. The sub-Himalayan tract, known as the West Bengal Duars, or Western Duars, is a part of the Tarai lowland belt between the Himalayas and the plain. Some of the finest tea plantations of India are situated there. North of the Duars, the Himalayan mountain ranges rise abruptly along the northern boundary of the state. Mount Kanchenjunga, actually located in adjacent Sikkim, dominates the landscape of the area, particularly in Darjeeling. More than 10 % of the total area of West Bengal is occupied by forests. The region has a rich and varied flora. The delta of the Hugli constitutes the western end of the dense coastal mangrove forest called the Sundarbans. A large portion of this area is preserved as a National Park and also as a UNESCO World Heritage site. These forests are inhabited by animals like tigers, leopards, elephants, gaurs (wild cattle), and rhinoceroses among other animals, birds and reptiles of the Indian plain. Jaldapara Wildlife Sanctuary and Buxa tiger reserve are the other prominent protected natural areas in the state.

31.1 Flood Problem in West Bengal

Table.31.1 . Major flood events in West Bengal state

S.No	Year	Description of the flood event	Districts affected
1	2003	Floods occurred during 18-20 Sep 2003 due to rise of water level of Ganga and its tributaries	2
2	2004	Floods occurred during 19th Sep – 11th Oct 2004 due to rise of water level of Ganga and its tributaries	5
3	2005	Floods were occurred during 3rd week of Sep 2005 due to a deep depression over the northwest Bay of Bengal. Under its impact, heavy rains lashed coastal districts of West Bengal triggering floods.	1
4	2006	Floods occurred during 18-23rd July, 26th August – 26th Sep and in 1st week of Oct 2006 due to heavy rains	9

S.No	Year	Description of the flood event	Districts affected
5	2007	Floods occurred during 4th -8thJul, 21-28th Aug , 28th Sep -8th Oct 2007 due to heavy rains and rise in water levels in Kangsabati, Subarnarekha, Maldha and Chandi rivers.	9
6	2008	Depression in the Bay of Bengal led to heavy rains and floods in parts of West Bengal, during 20th - 30th Jun, 22nd - 24th Jul 2008.	12
7	2009	Floods have occurred during 8th - 15th, Sep 2009 in Kangshabati, Shilabati, Gandheswari and Damodar rivers.	10
8	2010	Floods were reported during fourth week of August, 2010 in Malda.	1
9	2011	Floods were reported in West Bengal during fourth week of June, 2011 due to intense depression over Bay of Bengal.	10
10	2014	Floods were reported in Jalpaiguri and Coochbihar districts of West Bengal due to torrential rain on 26th August ,2014.Teesta river was reported to be in spate.	2
11	2016	Floods occurred during 27th - 29th Jul 2016. Floods occurred during 23rd - 28th Aug 2016.	4
12	2017	Floods were reported in Birbhum, West &East Midnapore, Murshidabad, Bankura and Howrah districts of West Bengal due to heavy torrential rains during 25th – 27th July 2017. During 28th - 30th Aug 2017 heavy incessant rains followed by rise in water levels of River Ganga at Farakka gauge site in Murshidabad district has inundated many low lying areas.	7
13	2019	Heavy incessant rains lashed parts of West Bengal state during the second week of July, 2019. Significant rain induced inundation is observed. Jalpaiguri, Alipurduar, Koch Behar, Uttar and Dakshin Dinajpur are said to be affected.	3
14	2020	Heavy incessant rains lashed parts of West Bengal state during the last week of August, 2020 and one event was mapped during fourth week of October, 2020. Extremely Severe Cyclonic Storm "AMPHAN” was a very damaging tropical cyclone which struck West Bengal near Bakkhali on May 20, 2020.	14

31.2 Flood Affected Area in West Bengal

Cumulative flood inundation maps were utilised for generation of map of total flood affected area in West Bengal and is estimated as 19,69,750 ha. Major flood events in West Bengal is listed in Table 31.1 for which satellite derived spatial flood inundation maps were generated and disseminated to state / central government disaster support management organizations by NRSC, ISRO. Flood affected area map is shown in Figure.31.1. and district wise flood affected area statistics are shown in Table. 31.2. Two districts in West Bengal have flood affected between 25,000-50,000 ha, 6 districts between 10,000-25,000 ha and 12 districts <10,000 ha.

Table.31.2 District wise statistics of Flood affected area in West Bengal

S.No.	District	Flood Affected Area (ha)
1	Pashchim Medinipur	258732
2	Nadia	251576
3	Purba Barddhaman	225130
4	Murshidabad	221909
5	Purba Medinipur	215739
6	Hugli	141768
7	Maldah	115093
8	North 24 Parganas	101374
9	South 24 Parganas	98416
10	West Dinajpur	79783
11	Dakshin Dinajpur	66424
12	Haora	61059
13	Birbhum	58453
14	Jhargram	39989
15	Bankura	19102
16	Kochbihar	9169
17	Alipurduar	1969
18	Kolkata	1941
19	Jalpaiguri	1484
20	Paschim Bardhaman	639
TOTAL		**1969750**

Glimpses of satellite images / flood inundation over the time period are depicted in this section.

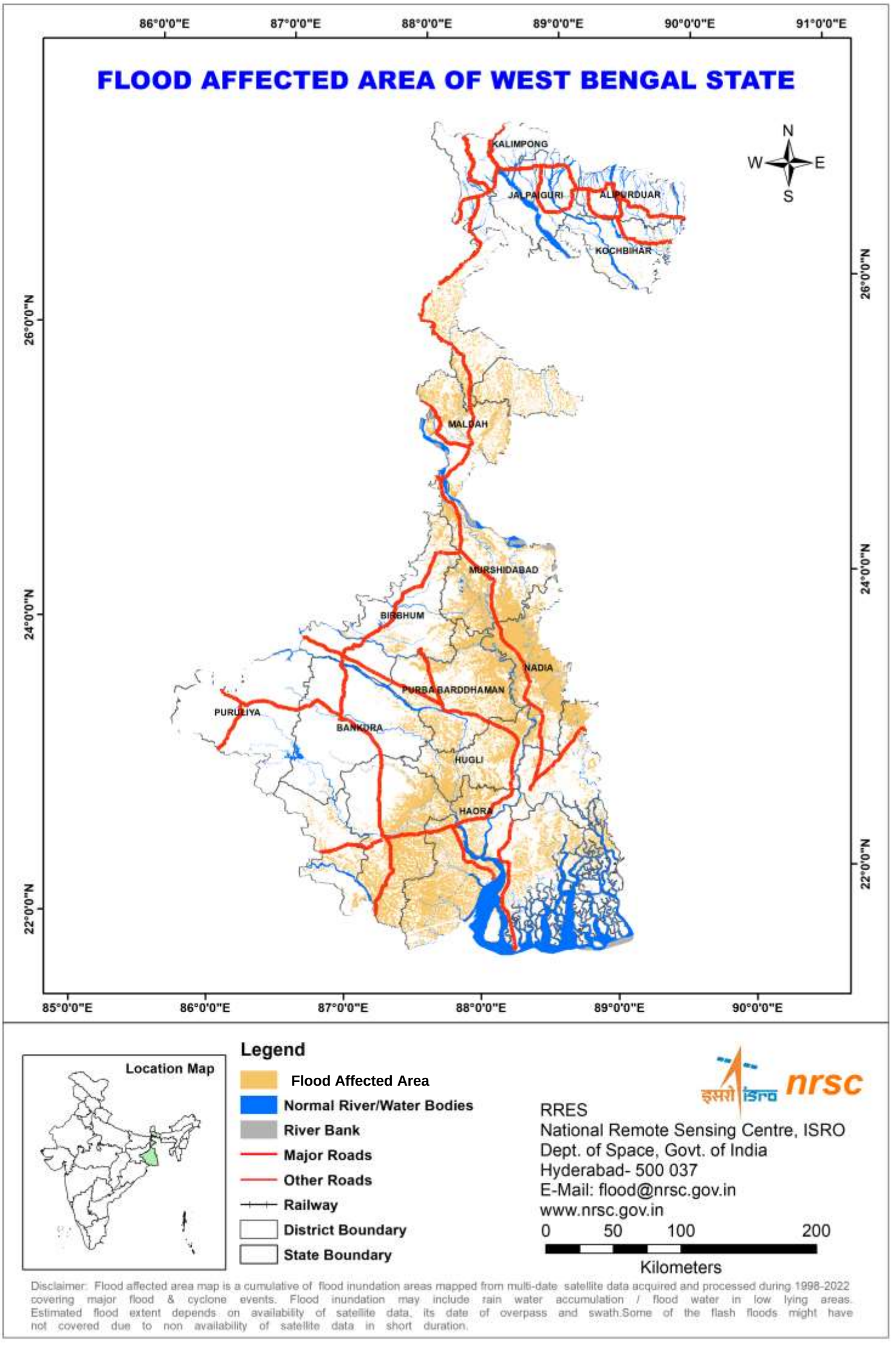
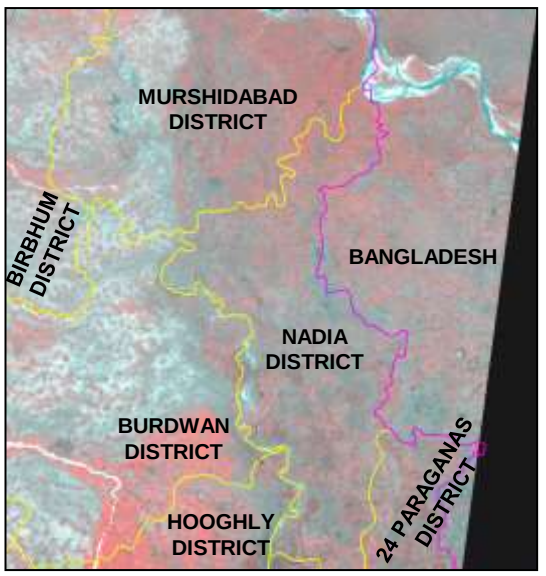


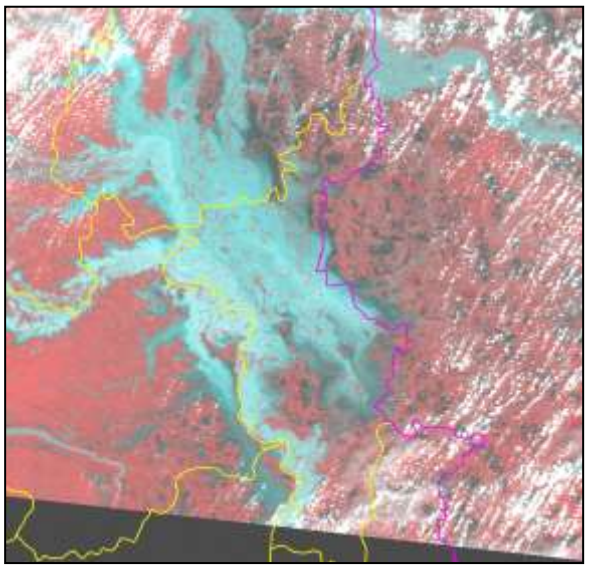
Fig.31.1 Flood affected area in West Bengal State

Progression & Recession of West Bengal Floods - 2000

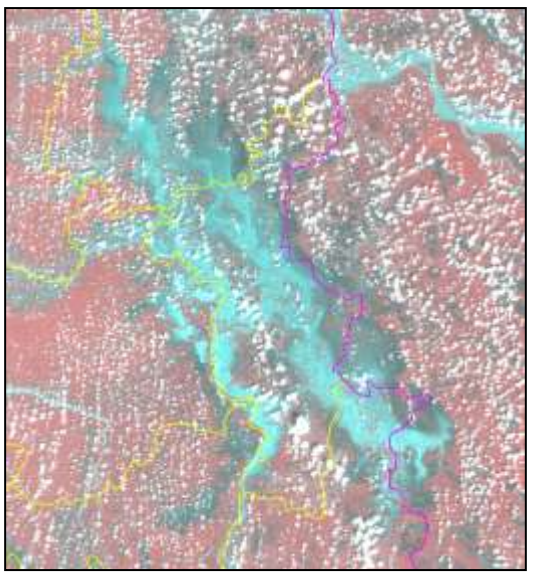
IRS 1C WiFS image of 19 Jan, 2000



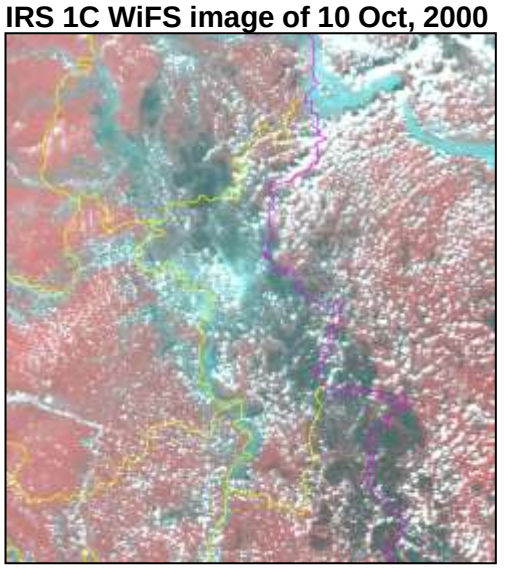
IRS P3 WiFS image of 24 Sept, 2000



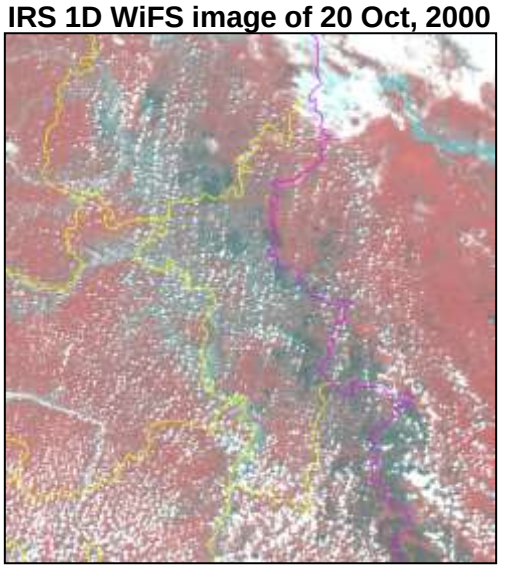
IRS 1C WiFS image of 30 Sept, 2000

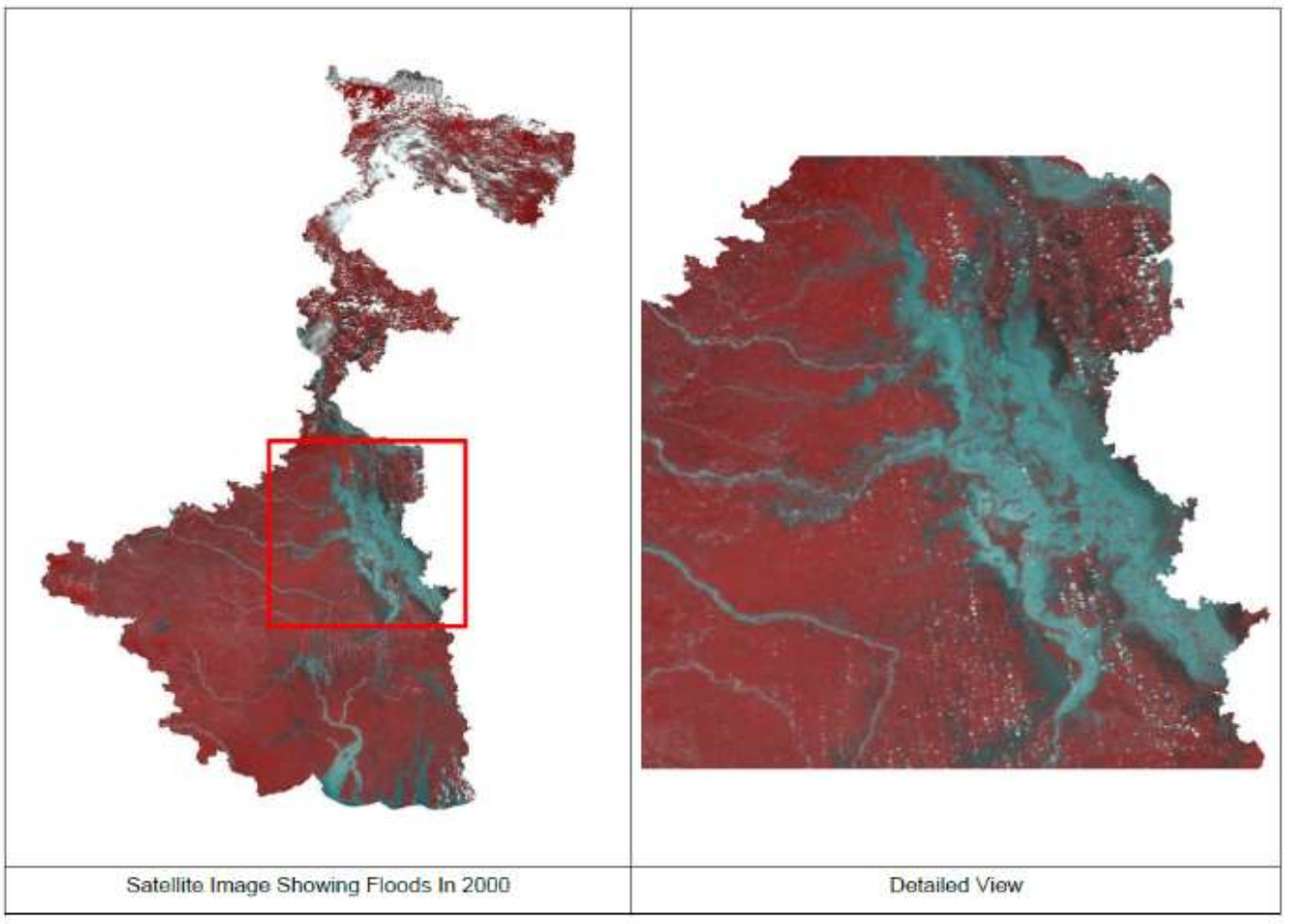


IRS 1C WiFS image of 10 Oct, 2000



IRS 1D WiFS image of 20 Oct, 2000





Satellite Image Showing Floods In 2000

Detailed View

Disclaimer : *Flood affected area map is a cumulative of flood inundation areas mapped from multi-date satellite data acquired and processed during 1998-2022 covering major flood & cyclone events.*

Flood inundation may include rain water accumulation / flood water in low lying areas. Estimated flood extent depends on availability of satellite data, it's date of overpass and coverage over flooded areas. Some of the Flash flood events could not be mapped due to non availability of satellite data in short duration. Flood affected area estimated in the study excludes river portion, permanent water bodies, salt pan and aquaculture lands in flood plains. Hence, actual flooded area may be more than the area estimated by satellite images.

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Government of India
National Remote Sensing Centre
Indian Space Research Organisation
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