

Remote sensing applications in disaster management

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सार – प्राकृतिक आपदाएँ विकासात्मक कार्यों में बहुत बड़ी बाधा है। भारत में बाढ़, चक्रवात, भूस्खलन, भूकंप आदि जैसी अनेक प्राकृतिक आपदाओं के मंडराने का खतरा सदैव बना रहता है। भारत का संपूर्ण पूर्वी तट एवं पश्चिमी तट का उत्तरी भाग मानसून ऋतु से पूर्व तथा मानसून ऋतु के बाद भीषण चक्रवातों से प्रभावित होता है। गंगा, ब्रह्मपुत्र जैसी भारत की अधिकांश प्रमुख नदियों में प्रत्येक वर्ष बड़े पैमाने पर बाढ़ आती है जिससे लगभग चालीस मिलियन हेक्टेयर प्रभावित होता है। इसके अलावा देश के लगभग दो तिहाई भाग में भूकंपनीयता की घटती बढ़ती डिग्रियों की संभावना का पता चला है। हिमालय के पहाड़ी इलाकों में मानसून ऋतु में भारी वर्षा के कारण भारी मात्रा में भूस्खलन होते हैं। हाल ही में आई कुछ आपदाएँ थीं – अक्टूबर 1999 में उड़ीसा के तट से टकराने वाला महाचक्रवात तथा जनवरी 2001 में गुजरात राज्य को प्रभावित करने वाला विध्वंसकारी भूकंप आपदाओं की घटनाओं से संबंधित आँकड़ों से आपदा संभावित क्षेत्रों में जनसंख्या और विकास के कार्यों में बढ़ोतरी के परिणामस्वरूप हो रही क्षति और आर्थिक हानि की चिंताजनक प्रवृत्तियों का पता चलता है।

सिनाप्टिक और रिपिटीटिव कवरेज से अंतरिक्ष पर आधारित प्रणालियों के आपदा की परिस्थितियों में अपनी महत्वपूर्ण सूचनाएँ और सेवाएँ प्रदान करने की क्षमता को सुस्पष्ट रूप से निरूपित किया है। भूप्रेक्षण उपग्रह वास्तविक समय में और बारम्बारता के अंतरालों में बृहत क्षेत्रों के व्यापक, सिनाप्टिक और बहुस्थानिक कवरेज प्रदान करते हैं और इसलिए ये मानीटरिंग करने के बहुमूल्य साधन बन जाते हैं। उपग्रहों के सबसे अधिक महत्वपूर्ण अनुप्रयोग भूप्रेक्षणों, डाटा रिले, नेविगेशन और संचार क्षमताओं के माध्यम से चेतावनियों का पहले से ही पता लगाना, उन चेतावनियों को प्रदान करना और जारी करना है। उपग्रह का प्रयोग विशेष रूप से सुदूर ग्रामीण और अल्प विकसित क्षेत्रों को क्षेत्रीय विशेष आपदा चेतावनी और संचार प्रदान करने के लिए किया जाता है।

अंतरिक्ष के आँकड़ों के प्रायोगिक अध्ययन और प्रचालनात्मक उपयोग के माध्यम से प्राप्त हुए अनुभव के माध्यम से आपदा प्रबंधन के लिए अंतरिक्ष से प्राप्त प्रेक्षण और संचार प्रणाली को विकसित किया गया है। सबसे अधिक महत्वपूर्ण कदम उपयोग कर्ताओं की संपूर्ण आवश्यकताओं का विभिन्न स्तरों पर और प्रभावोत्पादक रूप से सेवाएँ प्रदान कर सकने वाली डिजीटल मैकेनिज्म का मूल्यांकन करना है। अतः इस प्रकार के तंत्र के घटकों में (i) डाटाबेस डिजाइन (ii) वास्तविक समय मानीटरिंग मैपिंग (iii) माडलिंग साधन और संरचना (iv) संजाल समाधान और (v) बहुअभिकरण इंटरफेस निहित हैं। इस शोध-पत्र में अंतरिक्ष तंत्र की वर्तमान क्षमताओं और सूचना प्रणाली के प्रोटो-टाइप डिजाइन की समीक्षा की गई है।

ABSTRACT. Natural disasters are a major constraint to developmental activities. India is susceptible to several natural disasters such as floods, cyclone, landslide, earthquake etc. The entire east coast and northern part of west coast are affected by severe cyclones in the pre and post monsoon seasons. Most of the major river systems such as Ganges, Brahmaputra are prone to large-scale flooding every year, affecting over 40 million ha. It is found that almost two-thirds of the country is prone to varying degrees of seismicity. Major landslides associated with heavy rainfall in monsoon season occur in the hilly tracts of Himalayas. Some of the recent events are the super cyclone that hit Orissa coast in October 1999 and the devastating earthquake that affected Gujarat State in January 2001. The statistics of the disaster events shows the alarming trend of increasing damage and economic loss due to increasing population and development activities in vulnerable areas.

Space based systems with synoptic and repetitive coverage, have unambiguously demonstrated their capability in providing vital information and services in a disaster situation. 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 monitoring tools. The most important applications of satellites are in detecting, providing and delivering early warnings through earth observations, data relay, navigation, and communication capabilities. Satellites are particularly suited to deliver locale-specific disaster warning and communications to remote, rural and under-developed areas.

With the experience gained through pilot scale studies and operational use of space data, the concept of a space based observation and communication system for disaster management is being evolved. The most important step is to assess the overall requirements of users at various levels and the delivery mechanisms that could provide the services effectively. The elements of such a system therefore will consist of: (i) database design (ii) near real time monitoring/mapping (iii) modelling tools and framework (iv) networking solutions and (v) multi-agency interface. A review of the existing capabilities of space systems and a proto-type design of an information system is made in this paper.

Key words – Remote sensing, Satellite sensors, Disaster management, Database, Mapping, Hazard zonation.

1. Introduction

Indian landmass is prone to several natural disasters such as floods, cyclone, landslide, earthquake etc. While the east and west coasts are prone to severe cyclones, most of the major river systems such as Ganges, Brahmaputra are prone to large-scale flooding during the monsoon season. The hilly tracts of Himalayas are prone to major landslides associated with heavy rainfall. Two-thirds of the country is prone to earthquake. The damage statistics of the disaster events shows an alarming trend of increasing economic loss.

Disaster Management supports activities related to various phases such as preparedness, prediction, damage assessment and rehabilitation. Pre-disaster planning/prediction phase/preparatory phase is for preparing in advance to meet a disaster event. Rehabilitation and recovery phase consists of both short-term and long-term activities designed to return vital life support systems to minimal operating standards.

Space based systems from their vantage position have unambiguously demonstrated their capability in providing vital information and services in a disaster situation. Space based systems provide valuable inputs and are the only tools that remain unaffected by the impact of an event for assessing the vulnerability whenever a disaster event occurs over a region. The space inputs could be used in taking preventive measures through vulnerability analysis, hazard zonation and prior risk assessment at regional and local levels. Satellite based weather forecasts and advance warnings of severe weather will minimize loss of life and damage and facilitate timely and effective rescue, relief and rehabilitation of the affected population.

2. Role of satellite systems in disaster management

Towards evolving the disaster management framework, it is imperative to identify the information needs and their sources, risk assessment or vulnerability analysis, prediction and warning of disaster occurrence and rehabilitation plans. Space systems can make substantial contributions in providing vital information and services towards all three phases of disaster

management. Many of these contributions can be made with existing satellites and sensors. Earth orbiting satellites have reached an advance state of complexity and diversity. They can be conveniently grouped into four categories: communication, meteorology, remote sensing and geophysical. In this paper an attempt is made to review the status of remote sensing applications to disaster management.

3. Current capabilities of space systems

3.1. Remote sensing satellites

Remote sensing activities in India was initiated using aerial photography in early 1970's and graduated to satellite remote sensing with the experimental remote sensing satellites – Bhaskara 1 and Bhaskara – 2 launched in 1979 and 1981 respectively. Experience was gained in analyzing images at 1 km resolution from the two band TV Cameras and passive microwave sensors in 19, 22 and 31 GHz bands. The first operational Indian Remote Sensing Satellite (IRS 1A) launched in 1988 carried LISS(Linear Imaging Self Scanning) cameras employing 2048 element Charge Coupled Devices (CCD) operating in the push-broom mode to provide imageries in four spectral bands with a resolution of 72.5 and 36.25 meters. Improved resolution was achieved in IRS 1C/1 D satellites with LISS-III sensors designed to provide multi-spectral information at 23.5 m resolution, a middle infrared sensor with a resolution of 70.5 m and panchromatic imageries with 6.5 m resolution. The Wide Field Sensor (WiFS) with image swath of 770 kms in resolution of 188 m is useful for rapid monitoring of natural resources. Recent developments are in developing microwave sensors for all weather sensing. The development of active microwave systems such as imaging radars, scatterometer and altimeter add a new dimension in earth observation capability with their ability to provide imagery with a resolution approaching that of optical remote sensing, under all weather conditions.

3.2. Geophysical satellites

This class of satellites give geophysical parameters related to ocean and atmosphere. It is now possible using

TABLE 1
Key application areas of Indian satellites

S. No.	Satellite	Spatial resolution (m)/swath (km)	Repeat cycle (days)	Application areas
1	IRS-1A	LISS-I : 72.5/148	22	Earth resources, survey and management of resources in areas like agriculture, geology and hydrology
2	IRS-1B	LISS-II : 36.25/148		
3	IRS-1C	PAN : 5.8 /70.5 LISS-III : 23.6/141 : 70.8/148 WiFS : 188/774	24	Agriculture, Forestry, Urban, Land use, Soil, Geology, Terrain, Water resources, DEMs, Environment Disasters (damage assessment/relief)
4	IRS-P3	WiFS : 188/ 810 MOS-A : 1570/195 MOS-B : 525/200 MOS-C : 645/192	5	Remote sensing of earth resources, study of X-ray astronomy, periodic calibration of PSLV radar located at tracking stations
5	IRS-1D	PAN : 5.8/70.5 LISS-III : 23.6/141 : 70.8/148 WiFS : 188/ 774	24	Agriculture, Forestry, Urban, Land use, Soil, Geology, Terrain, Water resources, DEMs, Environment Disasters (damage assessment/relief)
6	IRS-P4	OCM : 360/1420 MSMR : 120, 80, 40/1360 PAN : <2.5/13	2	Systematic data for Oceanography, Coastal, Atmospheric applications
7	INSAT – 1	Visible & TIR	Continuous	Clouds, CMVs (2 level), SST, QPE, OLR
8	INSAT – 2	Visible, TIR, WV & CCD	-do-	Clouds, CMVs (3 levels), SST, WV image, QPE, OLR
9	INSAT – 3	Visible, TIR, WV & Sounder, CCD	-do-	Clouds, WV image, SST, OLR
10	METSAT	Visible, thermal, water vapour		SST, Cloud, CMVs, WV, Mesoscale

CMVs – Cloud Motion Vectors ; QPE – Quantitative Precipitation Estimate ; SST – Sea Surface Temperature ; OLR - Outgoing Longwave Radiation ; WV - Water Vapour ; DEM – Digital Elevation Model

satellite borne microwave altimeter to measure the sea height to within five to ten centimeters. Laser tracking from ground to satellites with retro-reflectors permit determination of baseline lengths to within about centimeters. The Indian satellites IRS P3 (with Modular-Optoelectronic Sensor – MOS) and IRS P4 with Microwave Scanning Radiometer - MSMR) gave observations on geophysical parameters related to atmosphere and ocean. Repeated observations of baselines in earthquake-prone regions can detect build up of strain that may indicate an impending earthquake. The microwave payloads onboard ERS and RADARSAT are providing ocean parameters such as sea surface temperature, surface wind, sea ice etc. US Navy's Global Positioning System (GPS) is being used to measure precising ground movements related to seismicity.

3.3. Meteorological satellites

Geostationary meteorological satellites have a distinct advantage over low earth orbiting satellites because of their capability to image on a continuous basis over large areas, which is particularly important for tracking cyclones and measurement of wind vectors derived from the displacement of specific cloud features in successive imageries. Many of these satellites have also incorporated data collection platforms that can periodically interrogate meteorological information from unattended platforms located in inaccessible and remote areas and transmit them to a central location. The INSAT systems in operation over the past two decades are giving meteorological observations over Indian region through the Very High Resolution Radiometer operating in visible and thermal

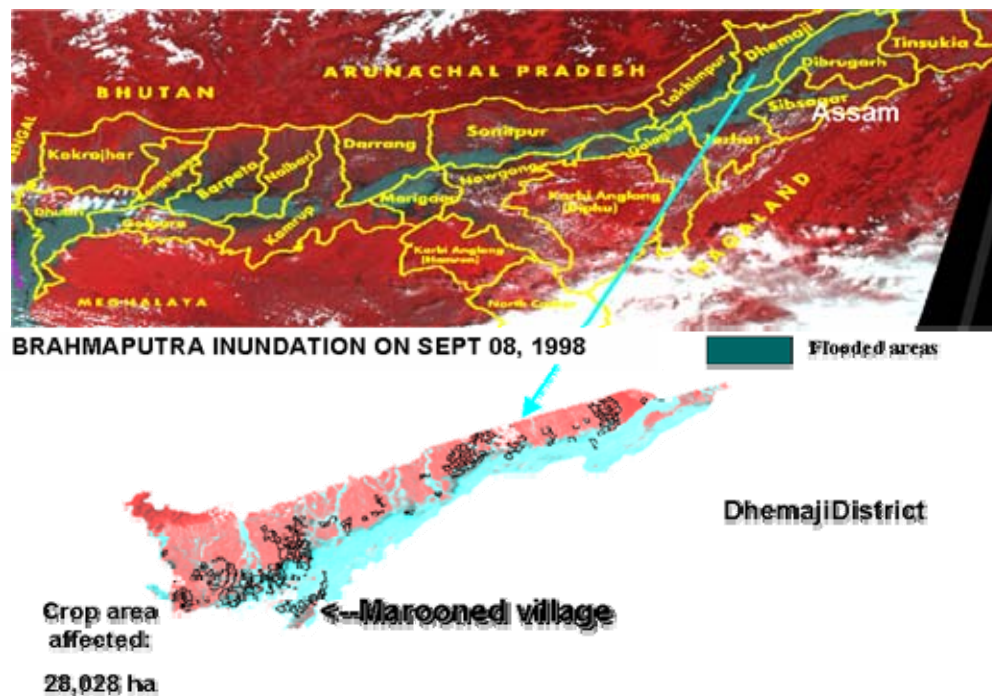


Fig. 1. Monitoring of Brahmaputra floods in Assam

channels. The observations include cloud cover, Cloud Motion Vectors (at 3 levels), Sea Surface Temperature, Outgoing Long Wave Radiation. Several polar-orbiting meteorological satellites are in operation such as NOAA series and DMSP. The capabilities of the Indian satellites in terms of diverse applications are given in Table 1.

4. Potential applications of remote sensing data

In more ways than one, remote sensing is ideally suited for disaster management. First of all it provides a database from which the evidences left behind by disasters that have occurred before can be interpreted, and combined with other information to derive hazard maps. Satellite images give a synoptic overview and provide very useful geomorphologic information, for a wide range of scales, from entire continents to details of a few meters. Secondly, many types of disasters, such as floods, drought, cyclones, volcanic eruptions, etc. will have certain precursors. Satellites can be used to detect the early stages of these events as anomalies in a time series. Images are available at regular short time intervals, and can be used for the prediction of both rapid and slow disasters. Then, when a disaster occurs, the speed of information collection from satellites and the possibility of information dissemination with a matching swiftness make it possible to monitor the occurrence of the disaster.

Many disasters may affect large areas and no other tool than remote sensing would provide a matching spatial coverage. Remote sensing also allows us to monitor the event during the time of occurrence while the forces are in full swing. The impact and departure of the disaster event leaves behind an area of immense devastation. Remote sensing can assist in damage assessment and aftermath monitoring, providing a quantitative base for relief operations. Finally, satellite data can be used to map the new situation and update the databases used for the reconstruction of an area, and to prevent that such a disaster might occur again (Kasturirangan *et al.*, 1995). Following sections give a brief summary of various applications of satellite data for operational disaster management.

4.1. Cyclone monitoring and warning

Meteorological satellites are valuable for monitoring and forecasting of cyclones. INSAT/VHRR images are being used to identify cloud systems over the oceans, where no observational data is available, as well as for cyclone tracking, intensity assessment and prediction of storm surges, etc. They need to be supplemented by ground meteorological observations and radar data for accurate assessment of rainfall intensity. An innovative use of INSAT has been in the implementation of the unique, unattended, locale specific Cyclone Warning

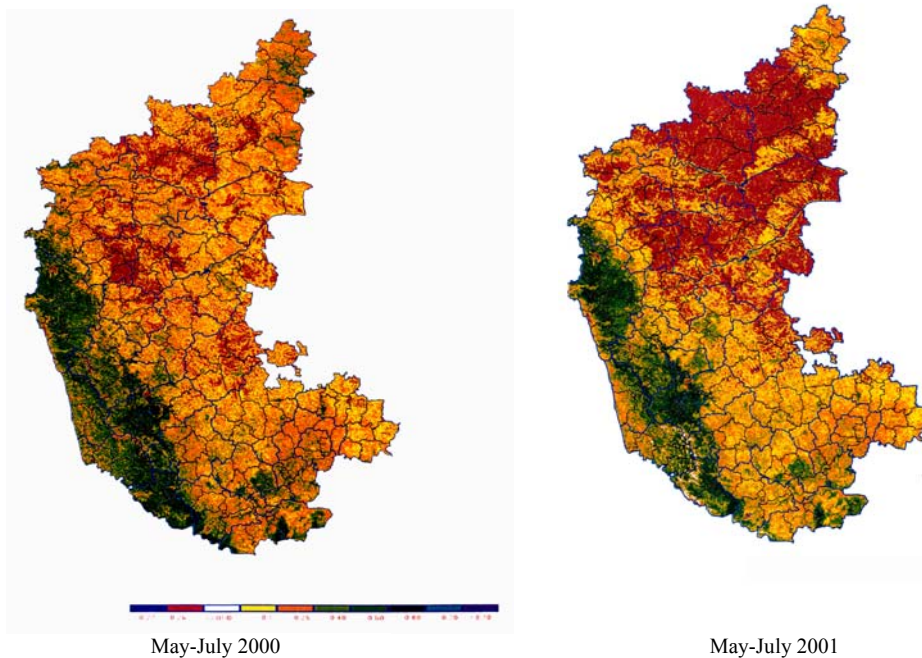


Fig. 2. Severe drought in Karnataka – monitoring through Vegetation Index

Dissemination System (CWDS) consisting of over 250 disaster warning receivers installed in cyclone prone areas of the country, designed to provide warning to coastal villages about an impending cyclone. Since the commissioning of DWS and its first operational use for disaster warning in 1987, CWDS has become a vital disaster mitigation mechanism. Current research around the globe is concentrating on use of meso-scale models with satellite data inputs to improve the cyclone intensity and track prediction.

4.2. Flood management

Despite limitations of cloud cover and long revisit period, satellites have been providing vital information towards (i) precipitation forecast and warning (ii) inundation mapping and damage assessment and (iii) flood plain management. Recent advances in using microwave data, especially to address the persistently cloud affected areas have enhanced the potential use of remote sensing by virtue of its all weather capability. Besides providing inputs for quantitative estimation of precipitation, geo-stationary satellites have become increasingly helpful for collection of data on rainfall, river stages, etc., for remote, uninhabited locations over the land using DCPs.

4.3. Inundation mapping and damage assessment

Mapping of flood-affected areas is one of the most successful applications of satellite remote sensing in flood management. Because of the unique spectral signature, it is possible to map areas under standing water, areas from where flood water has receded, submerged standing crop areas, sand casting of agricultural lands, breaches in the embankments, marooned villages and towns, etc. Using multi-date satellite imageries, the extent of damage due to crop loss, destruction of infrastructure facilities etc., can be assessed. Near real time monitoring and damage assessment of all major flood events are being carried out operationally. Global Positioning System (GPS) is being used to aid in the development of a Digital Elevation Model (DEM) for a flood prone area in Andhra Pradesh, to enable assessment of spatial inundation at different water levels in the river. When satellite derived land use/cover and ancillary ground based socio-economic data is draped over the DEM, flood vulnerability can be assessed to provide location specific flood warnings. Remote sensing data are evaluated for integration with existing forecasting models. Also microwave data from RADARSAT is used in conjunction with optical data to overcome the limitation of cloud cover.

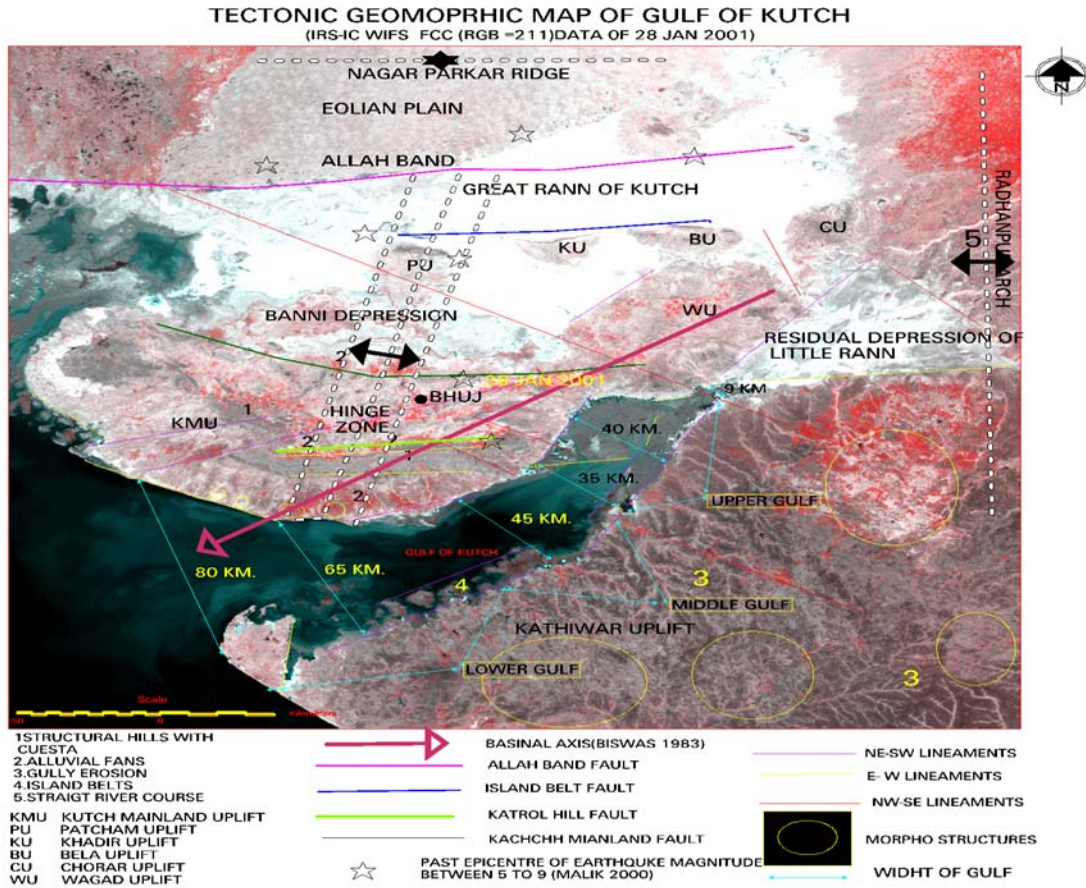


Fig. 3. Tectonic Geomorphologic map of Gulf of Kutch [Courtesy : Geosciences Division, National Remote Sensing Agency]

A pilot scale study was initiated by ISRO to design a proto-type system that will integrate space inputs with conventional data (Venkatachary *et al.*, 2001). The study area selected was Brahmaputra floods in Assam. The system consisted of comprehensive database design, space-based near real-time monitoring tools, modelling framework, networking and user interface. With appropriate synthesis of these core elements, flood monitoring and damage assessment was carried out during 1998-2001 for selected districts in Assam. A typical satellite based flood map at district level showing marooned villages is shown in Fig. 1.

4.4. Drought management

Drought management involves development of both short term and long term strategies. Short-term strategies include early warning, monitoring and assessment of

droughts while long-term strategies aim at drought mitigation measures through proper irrigation scheduling, soil and water conservation, cropping pattern optimization, etc. Early warning of drought is useful for on-farm operations and to arrive at an optimal local water utilization pattern. Rainfall anomalies as observed from geo-stationary/meteorological satellites are being used for early warning of drought in several African countries, which is yet to be fully operationalized. Indian studies have indicated that large-scale meteorological phenomena such as El Nino are associated with the failure of the southwest monsoon, resulting in severe droughts.

Monitoring and assessment of drought is required for taking corrective measures at appropriate times to minimize the reduction in agricultural productivity in drought prone areas. Satellite derived Normalised

ANNEXURE

Space inputs & user applications

Management Phases	Information needs	Space based inputs	End users & potential use of space inputs
Floods			
Mitigation & Preparedness	Vulnerable areas, Drainage network & flow	Close-contour data from airborne ALTM surveys for flood-plain zoning Use of Data Collection Platforms (DCPs) for observations from remote areas River migration study using multi-date satellite data for flood-protection measures Use of advanced flood forecast models with satellite inputs on landuse, terrain, geomorphology etc.	Central Water Commission for (i) real-time data collection on water level/rainfall in major basins using DCPs, (ii) use of close-contour data for flood-zoning, (iii) upgradation of current flood forecast models to use satellite inputs, (iv) improved communication links for data collection State Relief Commissions /Flood Control Boards for (i) use of river migration data for flood protection planning, (ii) regulations on use of flood-plains for developmental activities
Response	Rainfall in catchment areas Water level in river/streams Run-off prediction Terrain relief and slope Extent of affected areas damage assessment	Monitoring/mapping of flood-inundated areas Damage assessment of agricultural crops Marooned villages	State Relief Commissioner /Disrict Collector for (i) use of flood inundation information for planning rescue/relief operations, (ii) use of damage estimates for preparation of flood memorandum for Central Relief Commissioner for alternate source of information on flood damage and impact
Recovery	Flood resilient landuse Drainage structures Long-term measures for flood reduction	Identification of safe areas for rehabilitation Locations for flood-protection measures	State Relief Commissioner for implementation of (i) regulations in flood plains, (ii) flood protection measures, (iii) optimal rehabilitation site selection.
Forest fires			
Mitigation & Preparedness	Forest-fire-prone area identification Monitoring and warning network	Mapping of fire-prone areas (through indicators such as vegetation cover, dryness, temperature etc.)	Forest Survey of India / State Forest Depts. to identify priority areas for planning fire prevention / fighting measures Use of satellite data for regular monitoring of high risk areas
Response	Identify affected areas Assessment of damage	Extent of burnt-areas and damage assessment	State Govts. / Forest Depts. to use damage assessment data for appropriate relief
Recovery	Regeneration of forests	Mapping of water sources / land potential to identify potential regeneration sites	State Govts. for planning regeneration strategy
Cyclones			
Mitigation & Preparedness	Vulnerable areas Cyclone resilient measures Wind loads and structure interaction models	INSAT VHRR based monitoring on continuous basis and assessment of intensity Cyclone warning dissemination through INSAT-Cyclone Warning Dissemination Systems (CWDS) Use of satellite-derived parameters (sea surface temperature, wind, cloud types, liquid water content etc.) in numerical weather prediction model for improved cyclone prediction	India Meteorological Department for use of NWP models with satellite derived parameters for improved forecasts State Governments for use of CWDS with proper maintenance back up and identified personnel
Response	Cyclone track & intensity Prediction of time & location of landfall Dissemination of warning messages to affected areas Damage assessment	Emergency communication for rescue/relief operations Information/maps on flood inundation due to cyclonic rains Damage assessment to crops	State Relief Commissioner /District Collector for use of emergency communication tools for rescue/relief State Relief Commissioner for use of damage statistics for memorandum of relief
Recovery	Cyclone resilient engineering structures	Planning of rehabilitation /reconstruction with ortho-photos from aerial data	

ANNEXURE (Contd.)

Management Phases	Information needs	Space based inputs	End users & Interface needs
Drought			
Mitigation & Preparedness	Vulnerable areas of History of recurrence/ intensity	Monitoring of crop condition using NDVI data from satellites Integrated surveys for drought combating on long-term basis	State Relief Commissioner / State Agriculture Department for planning mitigation measures in terms of drought combating
Response	Rainfall anomalies and vegetation condition assessment Areas affected & severity assessment of damage	Assessment of likely damage/ yield loss to crops	Central/State Relief Commissioners & Agriculture Deptts. for updating information on drought situation ; planning relief measures
Recovery	Drought combating/ proofing Soil conservation measures Water harvesting schemes	Long-term planning of drought combating (soil/water conservation, check dams, water harvesting structures, ground water development)	State Governments for long-term measures to achieve drought proofing
Landslides			
Mitigation & Preparedness	Seismic zonation/ vulnerability Guidelines for engineering structures Risk assessment framework	Geology/ tectonic studies of regions	State Governments to use zonation / risk assessment data for development planning and enacting building regulations/codes
Response	Monitoring strain accumulation Seismic observation network Areas affected by earthquake Damage assessment	Emergency communication support with Space systems Damage assessment through aerial surveys of worst-affected areas	State Relief Agency to use the aerial data (large-scale maps) and emergency communication facility for effective rescue / relief operations
Recovery	Earthquake resilient structures	Identification of safer locations for rehabilitation	State Govts. for rehabilitation planning using the scientific data and reconstruction with earthquake resilient structures

Difference Vegetation Index (NDVI) – a ratio of red and near infrared radiances- is sensitive to moisture stress and is being used to monitor drought conditions on a real time basis. A remote sensing based National Agricultural Drought Assessment and Monitoring System (NADAMS) using data from IRS satellites (IRS WiFS data) has been established for countrywide monitoring in India (Fig. 2).

Monthly drought assessment reports are being generated under NADAMS. With the operationalization of IRS-1C WiFS and SWIR bands, in season agricultural drought monitoring capability has been further improvised.

Drought proofing requires an integrated approach taking into account the multi-dimensional inter-linkages between various natural resources and environment on one hand and the mutual inter-dependencies of natural resources on the other. Satellite remote sensing based Integrated Mission for Sustainable Development (IMSD) is a unique Indian experience to evolve action plans towards combating droughts in the backdrop of socio-economic conditions of watershed. The integrated approach of utilizing the existing conventional data with satellite remote sensing data assumes greater importance in order to develop operational methodologies in basic resource mapping and management to formulate long-

term drought mitigation measures. With the integration of remotely sensed data and conventional information through GIS, site-specific solutions are evolved. The implementation of these action plans have resulted in (i) reducing the runoff loss by about 50% (ii) rise in ground water table from 0.9 to 5 m due to the impact of check dams and percolation tanks and (iii) enhanced agricultural productivity.

4.5. Earthquakes

Earthquake risk assessment involves identification of seismic zones through collection of geological/structural, geophysical (seismological) and geomorphologic data and mapping of known seismic phenomena in the region (mainly epicentres with magnitudes). Satellite imagery could be used in delineating neotectonic structures and to clarify seismo-tectonic conditions in earthquake risk zones. Accurate mapping of geomorphologic features adjoining lineaments reveal active movement or recent tectonic activity along faults. Studies carried out earlier have highlighted the correlation between major lineaments and the seismic activity in Latur area in Maharashtra, India. It was observed that between 1967 and 1977, about 100 earthquakes (86 in Koyna region alone) of intensity 4 or above on Mercalli scales have occurred in Southern Peninsula. Most of these have been found to occur in the vicinity of NNE-SSW to NW-SE trending mega lineaments. The geotectonic settings of the Gujarat earthquake of January 2001 was studied by National Remote Sensing Agency using IRS data (Fig. 3).

4.6. Landslides

Satellite data and aerial photographs have been used to develop appropriate methodologies for terrain classification and preparing maps showing landslide hazard zonation. Using GIS techniques, the thematic layers on geology, soils, slope, landuse/cover etc. are suitably integrated to arrive at relative classes of landslide hazard zonation. Such work has been carried out for Garhwal Himalayan region, Nilgiri Hills in Southern India and in the Sikkim forest area. In the Tehri dam reservoir periphery, these imageries have helped in identifying 71 potential landslide areas. The studies are to be supplemented by aerial photographs for high-resolution contour mapping with intervals of better than 2m. Recently the landslide zonation was carried out for 2000 kms stretch of pilgrimage route in upper Himalayas.

4.7. Forest fires

Satellite imagery in infrared region and ground/aerial photographs has been employed to map areas damaged by

forest fires and assess the extent of area that needs to be reclaimed. Thermal infrared sensors on board the NOAA/AVHRR and IRS have been used for monitoring moisture conditions and assessment of forest fire prone areas. The normalized difference vegetation index (reflectance ratio of NIR and IR) were the most suitable to map burnt areas.

5. Space-based disaster management support

With the vast experience gained through pilot scale studies and operational use of space data, the concept of a space based observation and communication system for disaster management is being evolved in the country. The most important need is to assess the overall requirements of users at various levels and the delivery mechanisms that could provide the services effectively towards monitoring, forecasting, warning, assessment, prediction and reduction of losses due to natural disasters. The information required by disaster managers in each of the critical phase of disaster management, which includes mitigation and preparedness, response and recovery/relief need to be met with (Annexure). The elements of such a system therefore will consist of : (i) database design (ii) near real time monitoring/mapping (iii) modelling framework (iv) networking solutions and (v) multi-agency interface.

The future thrust areas are improved disaster forecasting through use of models, networked systems for on-line decision support and advanced communication systems for warning and relief. The emerging requirements from the satellite systems are :

- (i) Capability for imaging the whole country at frequent intervals (say, once in 4-6 hours) at resolutions of about 100-200 m (in 3-4 bands in visible, near infra-red and thermal);
- (ii) Capability to observe the disaster affected areas (soon after occurrence) at high-resolutions (5-10 m, multi-spectral) under all-weather conditions towards damage assessment;
- (iii) Capability to observe the localised areas of disasters (groups of settlements, habitation) at about < 1 m resolution for assessing infrastructure damage and for relief/rehabilitation work;
- (iv) Capability to detect micro-movements of the crustal plates (using satellite GPS) for earthquake forwarning;
- (v) Data Collection Platforms and Ocean Data Buoys to fill gaps in observation network.

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