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MANAGING THE NATURAL DISASTERS FROM SPACE TECHNOLOGY INPUTS

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ABSTRACT

Natural disasters, whether of meteorological origin such as Cyclones, Floods, Tornadoes and Droughts or of having geological nature such as earthquakes and volcanoes, are well known for their devastating impacts on human life, economy and environment. With tropical climate and unstable land forms, coupled with high population density, poverty, illiteracy and lack of infrastructure development, developing countries are more vulnerable to suffer from the damaging potential of such disasters. Though it is almost impossible to completely neutralise the damage due to these disasters, it is, however possible to (i) minimise the potential risks by developing disaster early warning strategies (ii) prepare developmental plans to provide resilience to such disasters, (iii) mobilize resources including communication and telemedicinal services and (iv) to help in rehabilitation and post-disaster reconstruction.

Space borne platforms have demonstrated their capability in efficient disaster management. While communication satellites help in disaster warning, relief mobilisation and telemedicinal support, Earth observation satellites provide the basic support in pre-disaster preparedness programmes, in-disaster response and monitoring activities, and post-disaster reconstruction. The paper examines the information requirements for disaster risk management, assess developing country capabilities for building the necessary decision support systems, and evaluate the role of satellite remote sensing. It describes several examples of initiatives from developing countries in their attempt to evolve a suitable strategy for disaster preparedness and operational framework for the disaster management using remote sensing data in conjunction with other collateral information. It concludes with suggestions and recommendations to establish a worldwide network of necessary space and ground segments towards strengthening the technological capabilities for disaster management and mitigation.

1.0 INTRODUCTION

"The greatest exploiter for all of us are floods today, droughts tomorrow, earthquake some times and all of these multiply our trauma of deprivation, pains of poverty and hunger. These disasters take away not only our crops, shelters, lives of our families, friends cattles, but also destroy our hopes and dreams of the future. Is there any event event comparable to these which causes so much human sufferings and injustice?".

This is the cry in bewilderness of a common farmer of Koshi River basin, Bihar (India) in the midst of recurrent floods and droughts. The agony of this common man reflects the urgency with which the issue of disaster management needs to be addressed.

It is a sad testimony of the nature that the geological and climatic extremes causing disasters have the greatest impact on the poorest people of the developing countries. With high population density, poor infrastructure development, poverty and illiteracy, the developing countries are more vulnerable and less equipped to withstand the damaging effects of the hazards. These disasters are also formidable physical constraints in our overall efforts to develop and utilise the natural resources on a sustainable basis. In view of these, Disaster Management efforts call for utmost priority at all the levels so as to neutralise the immense damage potential of the disasters atleast to a certain extent.

The real strategy to disaster management should address issues related to mitigation, preparedness, response and recovery. Towards evolving this strategy, it is imperative to identify, disaster-by-disaster, the crucial information needs in order to work out the risk appraisal including vulnerability analysis of a particular terrain, prediction, warning and prevention of the disastrous events. Disaster management measures also entail examination of the probability of occurrence and the consequences, understanding of the total processes in relation to the cause and effect, identification of preventive measures and implementation of rescue strategies. While the International Decade for Natural Disaster Reduction (IDNDR) provides a broad framework for assessment of risk worldwide, individual countries must concentrate on (i) identification of hazard zones (ii) risk assessment, (iii) creation of awareness at various levels (iv) evolving systems for monitoring, prediction and warning, (v) designing long-term preventive measures (structural and non-structural) and short-term protective measures and preparedness, (vi) early intervention measures, (vii) education, training, public information, (viii)transfer of technology, and (ix) research on improved technology and disaster management. Space technology offers tremendous potential to accomplish these tasks globally and nationally. While communication satellites could address the issues related to mass awareness, warning, education and training, remote sensing and meteorological satellites help in formulating the mitigation measures by synoptic weather and terrain assessment and monitoring, vulnerability analysis and for understanding the very scientific basis of the processes leading to the occurrence of the disasters themselves.

2.0 DISASTER - A GLOBAL CONCERN

Even as great scientific discoveries and technological innovations take place across the world, it is ironical that the number of disasters has been on the rise with the number of people killed/affected per disaster also showing an increasing trend (Table-1). No region is really free from the disasters and their impact. The recent earthquake in Kobe (Japan) demonstrated vulnerability of even developed society despite high technology and its application in everyday life. The countries in South Asia have diverse agroclimatic regions- high mountains, perennial rivers, arid and semi-arid regions, coastal belts and dry sub-humid regions and extensive forest covers with a high degree of biodiversity. While long coastal regions are prone to cyclones and arid and semi-arid regions to persistent droughts, the Himalayan mountain terrain and parts of the continental crust are prone to earthquake and landslides. The region's near perennial rivers are subject to periodic floods. Unfortunately the development process itself leads to immense pressure on the poor, who are forced to migrate to areas that are more vulnerable to disaster. According to US overseas Development council, six out of every ten of the World's poor are being pushed by unsustainable agricultural practices and high population growth into marginal lands that are more vulnerable to disasters (Prakash, 1994).

Many are driven by slow man-made calamities such as over population, economic inequalities, personal and national debt burdens and civil wars. The impact of natural disasters has been severe on the population and economy of developing countries, which lack capability to deal with such calamities due to their vulnerability coupled with poverty, illiteracy, and inability to undertake mitigative or timely ameliorative measures.

Over 60% of all the reported major natural disasters have occurred in the developing countries which have the least capacity to sustain heavy losses. Generally, capability of a nation to take up relief and disaster preparedness is closely connected with the wealth and living conditions of a country. Statistics on disasters in the past twenty years show, that while high economic damages occurred in highly developed countries, more people lost their lives and economic consequences were more severe in the developing countries. Major disasters since 1900 have caused over 45 million deaths and affected over 3.7 billion people globally (Paratesi, 1991) resulting in massive damage and destruction of property and infrastructure. Highly populated and vulnerable Asian continent has been the largest victim of such disasters accounting for over 60% of deaths and 85% of affected people globally. Of all these disasters, drought (including famine) and flood are responsible for largest number of deaths (over 53%), causing irreparable damage and economic loss. According to recent estimates, roughly 44% of the damage in 1991 due to the natural disasters world wide is attributed to floods alone (Rao, 1996). The impact of recurring disasters due to storm surges is even more devastating as evidenced from the number of people killed in Bangladesh. About 60% of all deaths due to storm surges have occurred in the low lying coastal areas of the countries bordering the Bay of Bengal and the adjoining Andaman Sea, with Bangladesh alone accounting for about 40% of the casualties. The occurrence of severe drought during 1984-88 in Ethiopia, major grain producing provinces of Canada, Asia, Australia and other African countries is still fresh in human memory.

Practically all the developing countries, being primarily agrarian, are very much dependent on the vagaries of seasonal rainfall and climatic conditions. The picture of erratic rainfall causing floods in certain areas and droughts in other parts of the country resulting in widespread famine conditions is a common occurrence in the developing countries. For example, Narmada River of India which is not considered a perennially flood-prone river, has peak discharge time just for a limited period (June to Sept.) during the monsoon while there is minimum discharge during the remaining part of the year **(Fig-1)**. Deforestation, extension of agricultural activities in vulnerable areas coupled with increased soil erosion and degradation of catchment areas have led to frequent flash floods through reduction in natural storage capacity **(Fig-2)**. The flood-prone area in India has been increasing dramatically. The National Flood Commission has estimated in 1978 that the flood-prone area has increased from about 25 million hectares at the end of the 1960s to about 40 million hectares by the mid-1970s and to about 65 mha now - an extraordinary increase in just a couple of decades since 1978. On an average, statistics indicate that severe drought occurs once every five years in most of the tropical countries, though often they occur on successive years causing untold misery to human life and livestock. The unprecedented drought during 1987-88 in India resulted in a reduction of 15 million tones in its annual food grain output. Studies show that more than 500 million people live in the drought prone areas of the world and 30% of the entire continental surface is affected by droughts or desertification processes (Rao, 1996). The historic anomalies in our overall model of growth and development have made majority of the population especially in developing countries more vulnerable to the natural disasters. It is really an unfortunate paradox that most of the developing countries like India, in spite of their remarkable achievements in terms of green revolution, industrial revolution, enhancing the per capita income and overall quality of life, have turned more vulnerable to the natural disasters and these disasters are causing more damage and destruction now than ever before **(Fig-3)**. With green revolution, environmental integrity got diluted. With industrial revolution, urban slums got proliferated and in our overall quest for radical socio-economic transformations, poverty, illiteracy and inequity got perpetuated. As a result, these hazards and disasters have directly hit the poorest and most deprived sections of our society. These so called natural disasters invariably become social disasters ultimately. In case after case, it has been found that the natural disasters almost choose their victims by class-the poorest of the poor living on the margins of the environment **(Fig-4)**. Thus disasters destroy the life, economy, infrastructure, environment and society because all are interlinked and damage the human civilization as a whole.

3.0 DISASTER MANAGEMENT

Considering the tremendous and frequent destructive potential of the disasters, it is imperative to evolve a suitable strategy for efficient disaster management. Towards accomplishing this task, the most important requirement is to first identify, disaster-by-disaster, the information required by disaster managers in each of the critical activities of disaster management, which includes **mitigation, preparedness, response** and **recovery/relief.** Responses are pre-and-post-disaster activities designed to provide for evacuation, to provide for emergency assistance to casualties, to reduce the probability of secondary damage, and to speed recovery operations. Recovery operations are short-term post-disaster activities (rehabilitation) designed to return vital life-support systems to minimize operating standards; and long-term post-disaster activities (reconstruction) designed to return life to normal or improved levels **(Fig-5)**. The basic requirement of evolving suitable measures for mitigation and preparedness is vulnerability analysis of a particular terrain/Ecosystem to the disasters. The vulnerability of an area is determined by its inherent natural and man-made environmental conditions, climatic behaviour, and also its political, social, physical and economic structures to withstand and respond to natural hazard events **(Fig-6)**. In addition, certain groups of people, types of physical assets and forms of economic activity can be particularly vulnerable to damage. Looking at the information requirements for each disaster management activity for each type of disaster, including an understanding on the sequence of physical processes leading to a natural disaster **(Fig-7)**, it seems quite obvious that space technology inputs are crucial for disaster management. While satellites perform a complementary role to field surveys, reconnaissance level surveys, and ground data collection platforms in obtaining some of this information, they offer the best means of obtaining critical information in many disasters and in many situations. Space technology is the only means to obtain needed real time information, in remote and inaccessible areas.

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 occur over a region **(Table-2)**. Space inputs could be used in taking preventive measures through vulnerability analysis, hazard zoning and a 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 affected population. Satellites are particularly suited to deliver locale specific disaster warning and communication to the remote, rural and underdeveloped areas. Satellites play an important role in providing (i) reliable estimates of the damage, (ii) location of hazardous areas, and (iii) assessment of post-disaster situation. Satellite communication provides an efficient means of providing timely aid and coordinating rescue efforts by central relief management agencies **(Fig-8)**. Though the information needs on the diverse time scales can be met by spaceborne systems **(Fig-9)**, a strong initiative for integrating information derived from different sources is called for to address the crucial issues of disaster management in a coordinated manner. There is a possibility of linking Earth Observation and Communication and Navigation Satellites to develop global information infrastructure which could offer viable solutions to many of the problems related to disaster management; but it can be enhanced only with international cooperation.

3.1 Flood Management

Space technology with appropriate ground support systems such as, Disaster Warning System (DWS), Data Collection Platform (DCPs), emergency terminals, etc., is being widely used to provide valuable information and services towards flood forecast, relief and management measures. For scientific planning and execution of various management measures, it is necessary to obtain reliable information about watershed characteristics and river configuration and its behaviour to effectively utilise the same to understand flood situation. Despite limitations of cloud cover and long revisit period, satellites, have been providing vital information towards (a) precipitation forecast and warning ; (b) inundation mapping and damage assessment ; and (c) flood plain management. Recent advances in using microwave data, especially to address the persistently cloud infected areas have further enhanced the potential use of remote sensing, by virtue of its all weather capability.

3.1.1 Flood Warning

The FAO has developed satellite remote sensing techniques to improve the surveillance and forecasting capabilities in Africa. A system called the Africa Real-Time Environmental Monitoring Information System (ARTEMIS) has been developed using Meteosat thermal infrared data for estimating rainfall. Working jointly with the Bangladesh Water Development Board, SPARRSO has developed a nationwide flood forecasting and warning service by integrating satellite derived `cloud signatures' with field data. Significant achievements have been made in satellite based precipitation forecast and flood management by China. All weather and quasi-real time satellite based flood monitoring systems have been developed for major river basins. In Nepal, NOAA/AVHRR images were used for flood warning for the entire region. Besides providing inputs for quantitative estimation of precipitation, geostationary satellite have become increasingly helpful for collection of data on rainfall, river stages, etc., for remote uninhabited locations over the land using data relay transponders (DRT) and data collection platforms (DCP) (Rao, 1994). The communication satellites could also be effectively used in disseminating warning information. The successful launching and operationalisation of the second generation INSAT satellites in India,have greatly improved space technology applications for weather monitoring and disaster warning. The secondary data utilisation centres at various forecasting centres of the India Meteorological Department receive processed cloud pictures, facsimile charts and conventional meteorological data transmitted from INSAT Meteorological Data Processing System.

3.1.2 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 clear difference in the spectral signatures, it is quite possible to map areas under standing water, areas from where flood water had 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 infrastructural facilities etc., can be assessed.

In Brazil, remotely sensed data is being used for mapping flood affected areas since 1981. Flood monitoring and damage evaluation for the lower reaches of the Yellow river is one of the successful projects being implemented by the Chinese Academy of Sciences. In Thailand, after the devastating floods of 1988, satellite data is being successfully used for damage assessment and flood plain management., Space technology for flood monitoring and management have been successfully operationalised in India. Near real-time monitoring and damage assessment of all major flood events are being carried out operationally. Satellite remote sensing and Geographic Information System (GIS) technique have been integrated in Brahmaputra river basin to provide information on flooded area and damage to croplands, roads and rail-tracks. Global Positioning System (GPS) is being used to aid development of Digital Elevation Model (DEM) of a flood prone area in Andhra Pradesh State, to enable assessment of spatial inundation at different water levels in the river. When the satellite derived land cover/use and ancillary ground based socioeconomic data is draped over DEM, flood vulnerability can be assessed to provide location specific flood warnings. Remote Sensing data are being evaluated for integration with existing forecasting models. Also microwave data from ERS-1 is used in conjunction with optical data to over come the limitation of cloud cover.

3.1.3 Flood Plain Management

Though flood forecasting and warning, mapping the flood affected areas and damage assessment are important, the thrust should be for the effective management of flood plains as this alone can bring long lasting solution and reduce the loss burden. Identification of flood prone river basins, assessment of expected risk levels, and selection of suitable land and water management measures are the major components of integrated river basin development where remote sensing plays a vital role. Analysis of multidate satellite data can lead to flood risk zone maps, which is very much essential to regulate the use of flood plains in a planned manner. For example, in India, satellite derived inputs are being used to arrive at integrated river basin development plans for major river basins **(Fig-10)**. Also, erosion prone areas along river bank could be identified and monitored for protecting the land and habitats. Maps prepared from remotely sensed data showing drainage congested areas could be used effectively to avoid flooding.

Though the occurrence of floods cannot be prevented, their disastrous effect can very well be mitigated to reduce the loss. Clogging of drainage channels with sediment and debris, meandering of streams and changes in the condition of the vegetative cover such as deforestation may result in excess runoff and overtaxing of the established drainage channels. Continuous monitoring of our river basins using satellite data can provide vital clues about these aspects. The potential of remotely sensed data in estimation of sediment yield, river migration studies and monitoring vegetation cover change is well established (Rodriguiz, 1992, Rao, 1989 and Rao, 1996). The most efficient flood prevention structural practice is flood water retarding dams, which not only control the excess runoff but also provide an excellent opportunity as a reservoir that can meet the water requirement at a later stage. These retention dams also act as ground water recharging structures (Gilard 1996). In certain areas, where periods of intense precipitation is seasonal, it is thus possible to make multiple use of the retention storage. Besides runoff estimation and hydrograph analysis based on watershed characteristics, inputs derived from satellite data could be effectively used to identify not only suitable locations based on land cover and soil characteristics for various structural measures but also to identify the vulnerability of a particular river basin to the floods **(Fig-11).** For example, thick forests with porous soil medium enable to reduce the 'Peaks' in the hydrograph and result in less run-off. Thus, an integrated approach towards land and water management with proper conservation measures can significantly reduce the damage due to floods.

3.2 Drought Management

Drought management involves development of both short term and long term strategies . Short term strategy includes early warning, monitoring and assessment of droughts whereas long term strategies aim at droughts mitigation measures through proper irrigation scheduling, soil and water conservation, cropping pattern optimization, etc.

3.2.1 Early Warning of Drought

Early warning of drought is useful for on-farm operations and to arrive at an optimal local water utilisation pattern. Rainfall anomalies as observed from geostationary/ meteorological satellites are being used for early warning of drought which is yet to be fully operationalised. Studies have indicated that certain large scale meteorological patterns are associated with the failure of the summer southwest monsoon, which is the main cause of droughts in Indian subcontinent (Rao, 1988). Factors that can provide early indication of possible droughts include upper air winds over the India, the development of hot low-pressure areas over southern Asia, and the El Nino/Southern Oscillation phenomena in the Pacific Ocean. Other factors that can be observed by satellite and which are related to rainfall patterns are sea surface temperature, snow cover, cloud patterns, wind velocity and direction, and atmospheric temperature/ humidity profiles. Geostationary and polar orbiting low earth orbit satellites provide an excellent means of deriving most of these information on regional and global scales. Research is underway to develop more accurate models involving the atmospheric, marine and land factors and in particular to forecast monsoon development and even more importantly the break in monsoon which results in the drought. These efforts may possibly lead to timely droughts/floods forecast.

In Africa NOAA/AVHRR data are used to estimate the vegetation conditions, with the help of the ARTEMIS system. ARTEMIS regularly distributes data products describing rainfall probability and actual precipitation derived from Meteosat and also timely information on crop conditions and food shortage due to droughts, desert locust, etc., through NOAA/AVHRR derived Normalised Difference Vegetation Index (NDVI). The early drought warning systems in Malaysia relies primarily on the Agro Ecological Zonation and Agricultural Rainfall Index (ARI) methods. Besides these two conventional methods, the use of satellite remote sensing for droughts preparedness is being developed under the Agro-climatic Impact Assessment Project (AGROCIA).

3.2.2 Assessment and Monitoring

Monitoring and assessment of droughts are required for taking corrective measures, at appropriate times, to minimise the reduction in agricultural productivity in drought prone areas. Monitoring and assessment of droughts also provide objective information on the prevalence, severity level and persistence of drought conditions in a time-effective manner which will be helpful to the resource managers in optimally allocating scarce resources to where and when they are most needed.

The satellite derived vegetation index (VI) which is sensitive to vegetation stress is now being used continuously to monitor drought conditions on a real-time basis, often helping the decision makers initiate strategies for recovery by changing cropping patterns and practices (Rao, 1992). The use of meteorological satellite data to assess the spatial and temporal inadequacies of rainfall at critical crop stages and subsequent assessment of crop status/condition based on VI anomalies provide an excellent drought monitoring mechanism. However, spaceborne measurements have to be integrated with computed aridity anomaly based on field measurements of rainfall, and crop calendars to bring out real time drought conditions of a region.

A remote sensing based National Agricultural Drought Assessment and Monitoring System (NADAMS) for countrywide monitoring in India has been developed and is being used for operational monitoring. In the first phase of NADAMS integrates the rainfall and aridity anomaly with VI data set to provide realistic assessment of droughts. Initially, biweekly drought bulletins for 246 drought prone districts of the country were issued to concerned user agencies at all levels for necessary action. Based on the user feedback, the second phase of NADAMS was launched in 1992 which includes detailed monthly drought assessment in terms of spatial variability and impact on crop/fodder production. With the operationalisation of IRS-1C WiFS and IRS-P3 WiFS and SWIR bands, in season agricultural drought monitoring capability has improved further (Fig-12).

3.2.3 Drought Combating/Proofing

While the construction of large reservoirs to ensure irrigation and drinking water contributed to a large extent towards mitigation of droughts in different countries, the poor and inefficient management of land and water resources in respective command areas have resulted in massive land degradation like salinity/alkalinity, waterlogging, etc., and thus causing serious concern to our conventional model of drought mitigation. Remote sensing inputs on land degradation, landuse changes, and changes in ground water fluctuations along with ecological impact form the basis of efficient land and water resources management in the command areas. For example, in India satellite data is used to delineate waterlogged and saline areas and for ecological impact studies to find solutions to these problems.

Drought proofing calls for 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 back-drop of socio-economic conditions of watershed. The integrated approach of utilising 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 droughts mitigation measures (Rao, 1993). With the integration of remotely sensed data and conventional information through geographical information system, site specific solutions are evolved according to the land capability class (having similar climatic and productivity figures of merit), which is further divided into micro level units depending upon the kind of soil limitations, climatic characteristics, erosion, moisture holding capability, etc., and suitable conservation/management practices are suggested for their development (Rao et.al, 1989). The locale-specific action plans, to illustrate, include (i) water harvesting structures, (ii) soil conservation through terracing and contour bunding, (iii) afforestation, agro-forestry and agro-horticulture, (iv) fuelwood and fodder development, (v) sand dune stabilization, etc. Preliminary results of the implementation of IMSD action plans in a few perennially drought prone watershed show significant improvements. For example, Ananthpur, a droughtprone district in the rain shadow zone in the Peninsular India is characterised with just 300 mm of average annual rainfall, which is the second lowest in the country. The climatic anomalies along with unsustainable agricultural practices over the years has forced the local inhabitants in some parts of the district to migrate to other areas. The implementation of action plans have resulted in (i) reduce the runoff loss by about 50%, (ii) rise in water level from 0.9 to 5 metres due to impact of check dams and percolation tanks and (iii) enhance the agricultural productivity by 2 to 5 times (Kasturirangan, 1995). Similarly, in a typical drought prone of Uma Gani watershed of Chandrapur District, India, these action plans were implemented with the active involvement of District officials, farmers and NGOs. There has been a remarkable change in the overall status of watershed **(Table-3)**. Such efforts demonstrate that the mission of drought proofing/mitigation is accomplishable with the help of remotely sensed data properly integrated with other colateral information.

3.3 Earthquake

Earthquake risk assessment involves identification of seismic zones through collection of geological/structural, geophysical (primarily seismological) and geomorphological data and mapping of known seismic phenomena in the region, (mainly epicentres with magnitudes). Such a map calls for considerable amount of extrapolation and interpretation on the basis of the available data. There is also a tendency for earthquakes to occur in "gaps", which are in places along an earthquake belt where strong earthquake had not previously been observed. The knowledge of trends in time or in space helps in defining the source regions of future shocks (Karnik and Algermissen 1978). Satellite imagery could be used in delineating neotectonic structures and to clarify seismotectonic conditions in earthquake risk zones. Accurate mapping of geomorphological features adjoining lineaments reveal active movement or recent tectonic activity along faults. Satellite imagery of the North-Anatolian fault zone was used to delineate fault systems of potential earthquake risk which were not mapped by ground surveys. Studies carried out by Rao et. al (1993) 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 area alone) of intensity 4 or above on Mercalli scale have occurred in Southern Indian Peninsula. Most of these have been found to occur in the vicinity of NNE-SSW, to NW-SE trending mega lineaments.

Space techniques have overcome the limitations of ground geodetic surveys/measurements and have become an essential tool to assess the movement/ displacements along faults/plate boundaries to even millimeter level accuracy. Using Very Long Baseline Interferometry (VLBI), it has been possible to record accurately the plate movement of the order of centimeter along baseline of hundreds of kilometer. Similarly, Satellite-based Global Positioning System (GPS) has emerged as a powerful geodetic tool for monitoring (geological) changes over time which is the key for understanding the long term geodynamical phenomena. GPS has been particularly useful in measuring the more complex deformation patterns across plate boundaries, where large and regional scale strain builds up. Plate movements, slips along faults etc., have been measured using differential GPS to an accuracy of sub centimeter (Hoffman et. al 1992).

The SAR interferometry is now proving to be a valuable source of information regarding the three-dimensional position of a target. Differential SAR Interferometry (D-INSAR) can provide useful information on Crustal Dynamics. The computation of co-seismic and post seismic displacement fields for a major earthquake provides important clues in understanding the source mechanism. The technique has already been validated for long term survey of slow moving faults (typically 10 mm/per year) (Chauhan, 1994). Spectacular results have been obtained using differential ERS-1 SAR interferometry for the estimation of the small terrain motions. Progress has also been reported in non-differential interferometry for the estimation of the elevation of the terrain (Rocca and Coulson 1993). Areas rocked by Lander's earthquake (South California) of magnitude 7.3 were studied using ERS-1 SAR Interferometry which matched extremely well with a model of the earth's motion as well as the local measurements (Massonnet and Advagna 1993, Massonnet et.al.1993). The Landers earthquake, because of its large and clear surface rupture of over 75 km, provided a positive validation of the use of radar interferometry for measuring co-seismic displacements.

3.4 Volcanic Risk Assessment

In the last three decades, aircraft and satellite based thermal infrared (TIR) remote sensing techniques have been used extensively to detect and monitor many of the active volcanoes around the world. The repetitive coverage, regional scale, and low cost of thermal IR images from satellites make this an attractive method for monitoring volcanoes. Although the spatial resolution of NOAA environmental satellite is too coarse to record details of surface thermal patterns, the plumes of smoke and ash from volcanoes are detectable. The ability to monitor size and distribution of volcanic plumes is useful in planning the rehabilitation of areas covered by ash.

Volcanologists are particularly interested in minor ground movements for the purpose of forecasting imminent volcanic activity. Previous studies have shown that the upward migration of magma from the earth's crust just before eruption, inflates the volcanic cone. Such premonitory signs can easily and quickly be detected with the aid of differential SAR Interferometry. This requires radar data of only 3 passes of which two must follow each other after a slightly longer period, when image pairs (1+2) and (2+3) are processed to produce two SAR interferograms. The differences between them clearly show the (average) relief changes for each pixel. Extensive calibrations in a variety of test areas have shown that by using this technique, changes on the earth's surface can be detected to centimeter accuracy.

Remote sensing based volcanological research has so far concentrated on using high spatial resolution sensors. Francies and Rothery (1987) and Rothery et al. (1988) have drawn attention to the potential use of Short Wavelength Infrared (SWIR) region (1.0 to 3.0 μ m) for detecting and monitoring thermal events including volcanoes. They have shown that thermal anomalies less than 30 m in size at temperatures of 150°C and above can be detected by using the TM SWIR bands. Barren Island volcano in the Andaman & Nicobar islands erupted in March 1991 and in January 1995, was monitored using Landsat TM & IRS LISS-II data. This study proved the utility of remote sensing techniques in monitoring/studying volcanoes (Reddy et. al 1993). Analysis of night-time SWIR data of the Barren Island volcano provides clear evidence and further validates the capability of TM SWIR bands for detecting and monitoring thermal anomalies associated with active volcanoes although the location of areas on night-time data is difficult. However, it has advantages over daytime data in determining more accurately the thermal anomalies and associated radiant fluxes.

3.5 Vulnerability Analysis of landslides

A number of studies have been carried out in India using satellite data and aerial photographs to develop appropriate methodologies for terrain classification and preparing maps showing land hazard in the Garhwal Himalayan region, Nilgiri hills in South India and in Sikkim forest area. In the Tehri dam reservoir periphery, these imageries have helped in identifying 71 potential landslide areas . The exercise carried out in Niligiris has helped in delineating landslide hazard zones and identifying areas least prone to this hazard, where house building activities can be taken up. All such exercises have so far primarily depended on aerial photographs, because of their high resolution enabling contour mapping with intervals of better than 2 m in height. The availability of 1m resolution data from the future satellites can easily help in delineating contour levels at 2m intervals making space remote sensing a highly cost-effective tool in this regard.

3.6 Cyclone Monitoring and Warning

Meteorological satellites are particularly valuable for monitoring and forecast of cyclones. INSAT/VHRR images are being used in identifying cloud systems over the oceans, where no other observational data is available as well as for cyclone tracking, intensity assessment and prediction of storm surges, etc. They need to be supplemented by the ground meteorological observations and radars for the accurate assessment of rainfall intensity. An innovative use of INSAT has been in the implementation of the unique, unattended, locale specific Disaster Warning System (DWS), consisting of over 150 disaster warning receivers installed in selected cyclone prone areas of the country, designed to provide warning to coastal villages about an impending cyclone. Since the commissioning of DWS and its fist operational use for disaster warning in (Rao, 1996) 1987, DWS has become a vital disaster mitigation mechanism. Most memorable use of DWS system was during the cyclone that hit the Andhra Pradesh coast on May 9, 1990, enabling the Government to evacuate over 1,70,000 people, thus saving thousands of lives and livestock in this area. Additional DWS units are being established to cover the entire coastal areas of the country. Cyclones in the Southern Hemispheric Indian Ocean are also regularly monitored by INSAT and advices are issued to various countries of this region.

3.7 Crop Pests and Diseases

One of the successful programs where space technology has been used in risk assessment from crop pests/diseases is the Desert Locust Satellite Applications Project of the UN/FAO for the International Desert Locust Commission (Heilkema, et al. 1986). Temporal and spatial distribution of desert vegetation and rainfall derived from NOAA-AVHRR data have been used to identify the potential locust breeding grounds. Indian Phytopathologists have demonstrated the capability of satellites in monitoring stratus-type cloud movement from Niligiris and Palani hills of South India to Central India which is associated with the outbreak of rust diseases in the northern wheat belt. An integrated system based on data collected by aerial remote sensing, low earth observing satellite systems (like the IRS, Landsat,etc.) and meteorological satellites (NOAA, INSAT) has been suggested to be evolved for crop pest/disease forecasting and crop condition monitoring. Realisation of such a system based on remote sensing techniques involves (a) investigation of large number of case studies to establish the relationship between the weather and pest/disease development,(b) an understanding of the spectral responses associated with damage symptoms, (c) evaluation of suitable spectral bands and crop "windows", and (d) development of specific algorithms for data analysis and a data dissemination system in a cost effective manner.

3.8 Forest fires

Satellite imagery in the infrared regions and actual ground/aerial photographs have been employed to map areas damaged by forest fires and assess the extent of area that needs to be reclaimed. The thermal infrared sensors on-board the NOAA/AVHRR, Landsat-TM, etc. have been found to be useful for detecting fires as well as for monitoring moisture conditions that could aid in anticipating the forest fires. Garcia and Caselles (1991) used Landsat-5 TM data to study a number of forest fires and concluded that the normalised difference in reflectance between near IR and middle IR (2.08-2.35 μ m) were the most suitable to map burnt areas. Multi-date satellite imagery from Landsat and IRS are now routinely employed by resource scientist in India, Thailand, Australia and South America to detect forest fires, monitor their progress and make assessment of total biomass loss.

3.9 Land degradation and Problem Soils

Remotely sensed data from satellite platforms have been used for identification of existing and potential erosion prone areas through a transformation of spectral data into major principal components. The perpendicular vegetation index and soil brightness index which are indicative of the green cover and surface soil exposure have been used in assessing the crop cover and land use patterns which are important components in the Universal Soil Loss Equation. Geographic Information System with a capability to integrate multiple layers of spatial data produced by remote sensing system has been found to be an excellent tool in assessing the land capability and soil erosion hazard **(Fig-13)**. Satellite remote sensing is already providing operational services in many countries towards monitoring land degradation especially soil erosion, salinity, alkalinity & waterlogging (Rao, 1991).

3.10 The COSPAS-SARSAT System

The international program COSPAS-SARSAT is aimed at locating vessels and aircraft in distress. The system composition has been set out in the agreement together with space and ground segments and emergency radio beacons **(Fig-14)**. The ground segment includes Local User Terminal (LUT) and Mission Control Centre (MCC) which can be located in any where in the world. At the present time there are a total of 22 COSPAS-SARSAT LUTs in operations. Their visibility zones covers practically the whole of the Northern hemisphere and about more than 50% in the southern hemisphere. By 2000 AD, it is expected that they would cover almost the whole of the World's land mass and most of the water.

According to the data of the COSPAS-SARSAT secretariat for the period Sept. 1982 to June 1991 the system was used in 762 search-rescue operations and helped to save 2030 lives (Zurabov, 1993) about 446 operations were in conjunction with aircraft accidents (1009 lives saved), 281 operations were carried out in conjunction with sea accidents (911 lives saved) while on 35 occasions the system was used for disaster on land (110 lives saved). INSAT has an onboard component of search & rescue which along with the low earth orbiting COSPAS/SARSAT provides unique operational services. At the present time there are plans under consideration for augmenting the COSPAS-SARSAT space segment with more geostationary satellites. With the augmentation of the system, it is quite possible that in near future that it will become the real means of emergency radio signaling for sea vessels, aircrafts and other types of transport. It will also be used in emergency situations in remote areas where there is no modern communication facilities.

3.11 Teleservices

The recognition of teleservices has now been emerging as a major application of communication satellite systems especially during the occurrence of natural disasters. The most successful example of the use of space based telemedicine is the implementation of Space Bridge in December'88 to facilitate interactive consultation between identified US Medical Centres and Physicians in Armenia, following the severe earthquake which resulted in 25,000 deaths and 125,000 casualties. The use of two way audio and one way full motion colour video between Armenia and US for 12 weeks following the disaster, enabled physicians to address various medical problems of thousands of Armenians affected by the earthquake. There are many more successful case studies of space based telemedicine through Space Bridge experiments which have firmly established the need and utility of a worldwide operational telemedicine service.

4.0 Linking Earth Observation and Communication Satellites

Though the inherent speed and efficiency of Earth Observation by Satellites and the demonstrated, rapid global information connectivity provided by communication satellites seem to be natural capability enhancer for disaster management there are several issues which need be addressed at all levels including an operational system of the Global Information Infrastructure (GII). The GII, using integrated terrestrial/satellite facilities in such a way as to take advantage of the timeliness and economic merits that satellites have in providing services to people and institutions located anywhere on the Earth, offers unique solutions to the problems related to disaster management. The key advantage of satellite communications is its "Wireless" nature over long distances. This characteristic makes satellite communications affordable and applicable for such diverse functions as telecommunications for rural areas, ships at sea, aircraft in flight, and communications networks in developing nations. With little to no ground based infrastructure satellite communications support such services as medical and environmental emergency information dissemination, health and medical services, distance education and learning, training and technical assistance and economic development in the diverse areas of the world from the south Pacific Islands to the Arctic. However, interconnection of the Earth Observation satellites with communication satellites calls for building the capability to transmit a large volume of data very quickly, with a very low bit-error rate. These capabilities are essential for such tasks as handling Earth Observation data for disaster observations, mitigation and recovery, communication satellite data for warning, response etc. as well as other data applications such as graphics, still pictures and video which could be used in such areas as medical diagnosis, city planning, or any of myriad of additional applications requiring timely evaluation and action on data received from a remote source.

One initiative to link remote sensing and disaster warning is being pursued as part of the Japan US-Cooperation in Space Project (JUSCSP) (G.Moore, 1995), with special emphasis on disaster management. A Disaster Observation Satellite Working Group (DOS WG) has also been formed to address the requirements for an international, global satellite system with the capability of providing faster disaster warning and other services, to be made operational by early 21st century. The DOSWG proposes a multi-agency satellite based system with visibility of the entire globe in order to provide a near continuous stream of observed data which then must be evaluated in a timely fashion and then distributed rapidly, in an easily usable form. Based on the feedback from DOSWG, recently the Satellite Communications Working Group (SCWG) of JUSCSP has developed technological framework, called the Trans-Pacific High Data Rate Satellite Communications Experiments which includes the modules (i) ATM-LAN interconnection at 45 Mb/s, (ii) Telemedicine at 45 Mb/s (iii) High definition Video program delivery at 140 and 155 Mb/s, (iv) High Definition Video post-production processing at 45, 140 and 155 Mb/s, (v) Earth Observation System, Data & Information System data visualization experiment, (vi) Satellite/fibre Optic capable comparision tests, and (vii) Multi-node network tests involving Asia-Pacific and European countries. The experimental demonstrations of some of these modules have proved its feasibility while demonstrations for the other modules are in progress. These experiments further call for evolving an appropriate way to facilitate the type of international cooperation and interaction required to turn the concept of a global disaster warning, control and mitigation system into a reality.

The Committee on Earth Observation Satellite (CEOS) comprising major space agencies as measures and observes, and international scientific organisation as affiliates, is also working on development of a earth observation satellite based information network that would provide data and information to meet the needs of scientific, operational, disaster monitoring, and commercial user communities. The recently formed CEOS Working Group on Information Systems and Services is expected to further enhance and interconnect the data directories, inventory, browsing services between the member countries through appropriate network. Realising the global need to develop better disaster prediction, response awareness, communication and education through the use of satellite technology, many countries are currently working on the development of operational framework towards linking EOS and communication satellites. As these systems become functional over the next decade, several issues of disaster management will find better solutions.

Before the advent of a meaningful global partnership towards disaster management, there is a need to build the national/regional capacity with the established interlinkages both bottom-up and top-down (Kasturirangan et al. 1995). Some of the disasters like desertification, desert locust, acid rains and marine oil spills are of global scale in their occurrence. Therefore a global disaster assessment and early warning system is required. This system could depend on existing and planned satellites for data acquisition and transmission having telecommunication links with major ground stations, say, via Internet, Intelsat link etc **(Fig-15)**. International organisations involved in disaster management such as the FAO, WMO, WHO etc will be greatly benefited and they will be primary users. National & State Relief Commissions will be secondary users. R & D organisations, NGOs etc. will be the tertiary users of the system. The system, in fact, links the national capacity of disaster management to the GII to offer the permanent solutions in this regards.

5.0 CONCLUSIONS

Vulnerability to the natural disasters especially of the poor and deprived societies of developing countries are increasing, in spite of the rapid economic developments coupled with great scientific innovations and technological progress taking place all around the World. Disasters, both having geological and climatic origins, are becoming more frequent and also more damaging. While the scientific uncertainties still exist towards predicting and understanding real causes of most of the disasters, certain crucial issues related to disaster management are addressable on near real time basis using space technology inputs.

Space systems have a unique role to play in evolving the suitable disaster management plans. Remote Sensing & GIS offer tremendous potential towards vulnerability analysis of a terrain or ecosystem to the natural disasters. There has been a number of case studies all around the developing and developed countries using space technology as a tool towards reducing the damaging potential of disasters. While Earth Observation Satellites are being used to evolve the suitable measures to deal with the issues related to mitigation & preparedness, response and recovery-the integral components of disaster management, Communication satellites are being used for information dissemination, disaster warning, telemedicine including search & rescue. Disaster management is a global issue which calls for a global mission of linking not only EOS & communication satellites but also suitably integrating space inputs along with other relevant information. However, as of today only a handful of the countries have means of using operationally the benefits of space technology towards achieving the national goals of disaster management. Here is a need to build the national capacity with appropriate space & ground segments to address the above issues. Global Information Infrastructure containing the suitable modules for disaster management is the important initiative at this moment through appropriate international coordination and cooperation in the true spirit of humanity and towards protecting this Planet from harmful effects of the disasters.

6.0 References

Chandrasekhar, M.G.(1994), Remote Sensing for Sustainable Development, Proc.UN/IAF Symp. on Space & Rural Development, IAF Congress, Jerusalam.

Francies, P.W., and Rothery, D.A., (1987), Using the Landsat Thematic Mapper to Detect and Monitor active volcano, Geology, 15, 614-617

Heilkema, J.V., et al (1986), Assessment of Ecological Conditions associated with the 1980-81 desert locust plague upsurge in West Africa using environmental satellite data, Int.Jour. Remote Sensing, 7, 1609

Hoffman, B., et al., (1992) GPS Theory and Practice, Springer Verlg Wien, New York
Jayaraman, V., Chandrasekhar, M.G., and Rao, U.R., Remote Sensing for National Development: Implementing Results Achieved in the National Indian Satellite Programme; UN Workshop, 44th IAF Congress, Graz, Austria, Oct. 16, 1993

Karnik, V., and Algermissen, S.T, (1978), Seismic Zoning- Chapter in the Assessment and Mitigation of Earthquake Risk, UNESCO, Paris pp 11-47.

Kasturirangan, K., Chandrasekhar, M.G., P.P.Nageswara Rao, Srivastava, S.K, Raj, Ganesh.K., & Sebastian, M. (1995), The Role of Space Technology in Developing National Assessment of Risks from Natural Hazards, UN/IAF Symp. September 28-October 1, 1995, Oslo, Norway.

Kasturirangan, K. (1995), The challenges of Space Technology - Possibilities to Enhance the Quality of Life, Special Plenary Session, IAF, 46th Congress, Oslo, Norway.

Massonnet, D., et al (1993), The Displacement Field of the Landers Earthquake mapped by radar interferometry, Nature, Vol.364.

Moore. G., (1995). Linking Remote Sensing and Disaster Management, Earth Observation Quarterly. May 1995, pp37-39.

Mosonnet, D., & Advagna, F (1993), A Full-scale Validation of Radar Inerferometry with ERS-1: The Landers Earthquake - Earth Observation Quartersly, NO.41.

Nageswara Rao, P.P., V.Jayaraman and M.G.Chandrasekhar, (1991): Application of remote sensing in plant protection, ISRO-NNRMS Rept.89-91.

Nageswara Rao, P.P. and V.Jayaraman, (1992): Satellite remote sensing in disaster management, Natural Resource management, (ed.) R.L.Karale, NNRMS Pub.Bangalore, India

Paratesi, S.R.G.D., (1992): Hazards and Disaster: Concepts and challenges; Remote Sensing for hazard monitoring and disaster assessment; Barett, E.C. et al., Beach Science Publishers, Paris.

Prakash, India (1994), Disaster Management, Rashtra Prahari Prakashan (Ed.)., Gaziabad, India.

Rao, U.R., (1989): Space and drought management; Proc.IAF Congress, Bangalore.

Rao, U.R., (1989): Space and flood management, Proc.IAF Congress, Malaga, Spain.

Rao, U.R., (1993): Space and Environment. Proc.IAF Congress, Austria, Graz.

Rao, U.R., et al., (1993) Latur earthquake - selection of sites for rehabilitation of the affected villages in Latur and Osmanabad districts of Maharashtra, India, Current Science. 65. 772.

Rao, U.R.(1996) Space Technology for Sustainable Development, Tata McGraw-Hill Publishing Company Ltd. New Delhi, India.

Reddy, C.S.S. et al (1993) Night tiem TM short wavelength infrared data analysis of Barren Island Volcano South Andaman, India. Int. Jour. Remote Sensing, Vol.14, No.4, pp 783-787

Roderiguez, C.R. and U.R.Rao, (1994): Space and disaster warning in developing countries, space safety and rescue, (ed.) G.W.Heath, AAS Publication, 84, 167.

Rottery, D.A., et al (1988), Volcano Monitoring using short wavelength infrared data from satellites, Jour Geophysical Research, 93, 7993-8009

Smith, B.D., Williams, D.F., Fujita, A. (1994), Satellite Missions, Global Environment, and the Concept of a Global Satellite Observation Information Network: The Role of the CEOS, Acta Astronautica Vol.34. pp 195-203, 1994.

Srivastava, S.K., Jayaraman, V., Nageswara Rao P.P., and Chandrasekhar, M.G., Sustainable Development, Scientific Issues and Satellite Remote Sensing; Asian-Pacific Remote Sensing Journal, Vol.6, No.2, January 1994, pp139-148

State of India's environment, (1992): A Citzen's report, (eds.) A.Agarwal, and S.Nandan, Centre for Science and Environment, Delhi.

Thiruvengadachari,S., (1988) : Space and drought management, . Proc.IAF Congress, Bangalore, India.

Zurabov, Y.G. (1993) the COSPAS-SARSAT System: Results and Prospects, Earth Space Review, Vol. 2 (4), 1993.

Table-1 Some major Disasters since the Start of IDNDR

Year	Hazard	Country	No.of Dead	Damage Estimate (million US$)
1990	earthquake tropical	Philippines	1,660	920
	cyclone tropical	South Pacific	8	
	cyclone	Philippines	503	
				119
				720
1991	earthquake	Georgia	270	1,700
	Volcano	Philippines	932	260
	cyclone & flash flood	Philippines	4,899	
	tropical cyclone	Bangladesh	138,866	1,780
	river flood	China	2,470	21,000
	cyclone	USA/Caribbean		20,000
	earthquake	India	2,000	
	tropical cyclone	South Pacific	12	331
1992	tsunami	Indonesia	2,080	100
	tsunami	Nicaragua	116	25
	earthquake	Turkey	547	
	mudflow	Philippines	333	320
1992-93	drought	Southern Africa	-	-
1993	river flood	United States	-	20,000
	earthquake/tsunami	Japan	122	
	31 typhoons tropical	Philippines	514	
	cyclone earthquake	Fiji	21	134
	flood	India	10,000	
		Western Europe	7	hundreds of million
1994	earthquake	United States		20,000
	earthquake/mudslide	Colombia	271	
	volcano	Papua New Guinea	100,000 affected	
	flood	China	1,400	
	flood	India	2,001	
1995	earthquake	Japan	5,500	100,000
	earthquake	Russia		

Table-2 Remote Sensing for vulnerability information

DISASTERS	METHODOLOGY	VULNERABILITY INFORMATION
Earthquakes		
Structural Geology	Lineament Analysis	Structural weakness of the crust
Geomorphology	3D Modelling GPS	Slope steepness and lithotype
Neotectonics	Interferometry	Recent movements
Volcanic eruptions		
Structural Geology	Lineament Analysis	Structural weakness
Geomorphology	3D Modelling, GPS/	Volcanism evolution
Neotectnics	Interferometry	Recent movements
Gas monitoring	Absorption band, thermal	Pre-eruptive warning
Thermal monitoring	infrared classification	pre-eruptive warning
Lava flows		Lava-debris flowing hazard
Flood		
Structural Geology	Lineament Analysis	Soil permeability
Geomorpholoy	3D Modelling	Slope steepness
Drainage analysis	Infrared absorption	Run-off modeling
Land analysis	Infrared absorption	Hydrologic classification
Weather parameters	Optical & thermal bands	Climate conditionss
Warning	Communication payloads	Early Warning
Landslides		
Structural Geology	Lineament Analysis	Structural weakness of lands
Geomorphology	3D Modelling	Slope steepness
Neotectonics	Photointerpretation	Recent movements
Land analysis	Infrared absorption	Hydrologic classification
Displacements	Interferometry	Ground deformation
Droughts		
Vegetation Index	Vis & NIR absorption	Crop water stress
Aridity Index	Optical and thermal data	Evaporative demand of Atmos
Precipitation	Microwave, radar	Stress Severity
Geomorphology	Optical and Microwave data	Ground water targetting/
Soil Moisture	Optical and Microwave data	Recharge Stress detection
	3D modelling	
	Microwave data	

contd.

Table-2 Remote Sensing for vulnerability information (contd.)

DISASTERS	METHODOLOGY	VULNERABILITY INFORMATION
Cyclones		
Cloud system	Optical and thermal	Probability of Cyclone
Cyclone pattern	Scatterometer data	Depression
Wave heights	Altimeter data	Tracking of Cyclone
Sea surface Temperature	Microwave Radiometer data	Origin of Cyclone
Wind Circulation	Scatterometer data	Origin of tracking
Warning	Communication payloads	Early warning
Crop Pests/Diseases		
Desert Locust	Optical & microwave	Migration of
Pest/Disease infestation	Optical	Desert Locust
Weather Conditions	Meteorological payloads	Damage Assessment
		Pest outbrust
Forest Fires		
Occurence of Fire	Middle IRs band	Fire detection
Destruction of Forest	Optical data	Damage Assessment and Identification of fire prone areas.
Land Degradation		
Soil Conditions	Optical data	Erosion, Salinity & Alkalinity
Land Use & slope	Optical data, DEM & Interferometry	Erosion hazard

Table-3 : Implementation of Action Plans for the Drought Mitigation - Uma Gani Watershed, Chandrapur District, Maharastra, India

	Before	After (%)
Cropping Intensity %	107	147
Horticulture	5	20
Pulses (M.Tonnes/Yr)	-270	100
Cereals (M.Tonnes/yr)	-430	1000
Fuel Wood (M.Tonnes/yr)	-1199	1000
Fodder (M.Tonnes/yr)	-135651	Self Sufficient
Runoff (%)	80	40
Groundwater Reserve (%)	14	30
Consumptive use (%)	6	30
Milk production (Lit/day)	4,000	15,000
Culturable land:Man ratio	0.264	0.320
Tankerfed villages	4	Nil

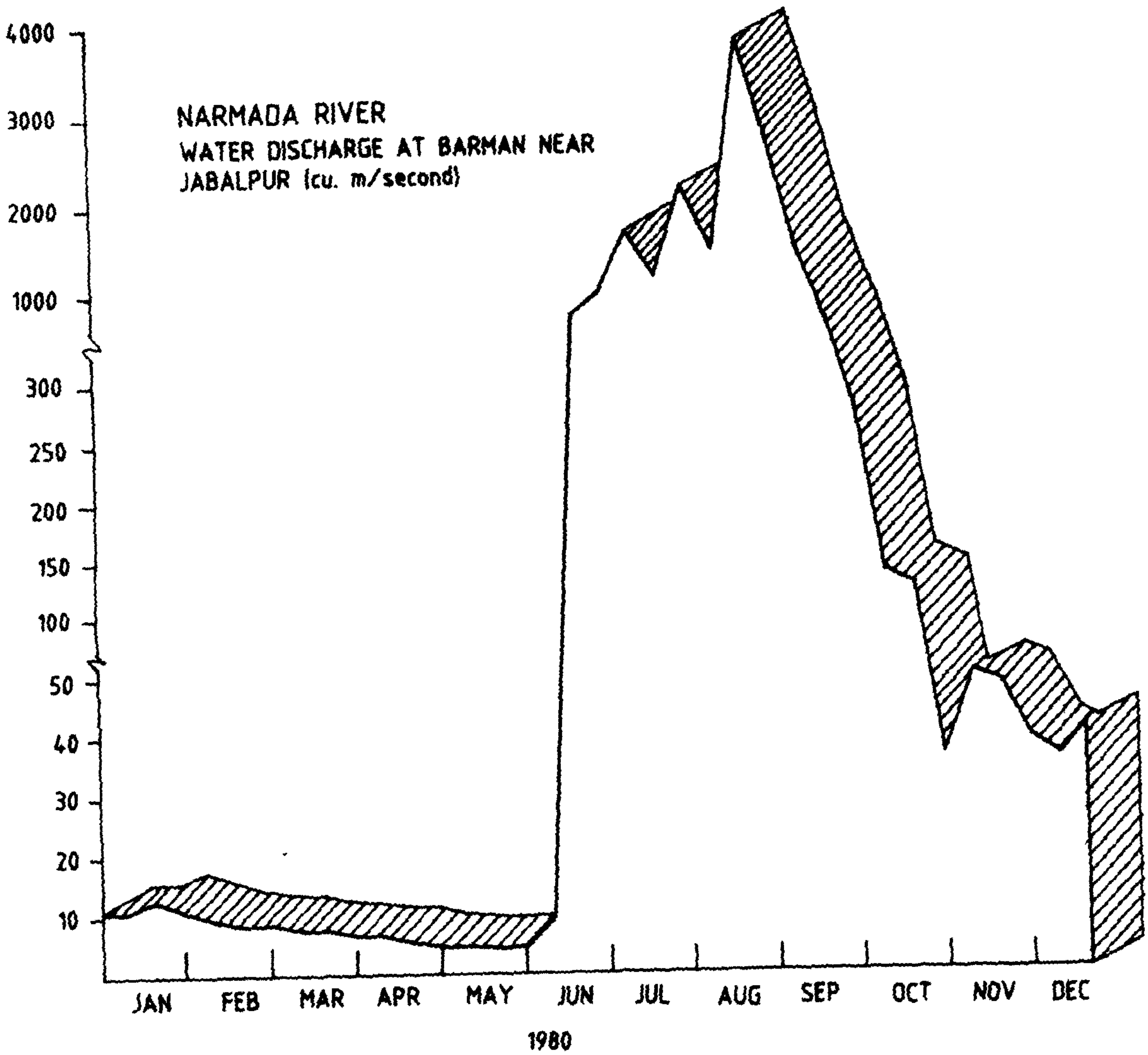


Fig. 1 : Yearly profile of water discharge in a typical river basin

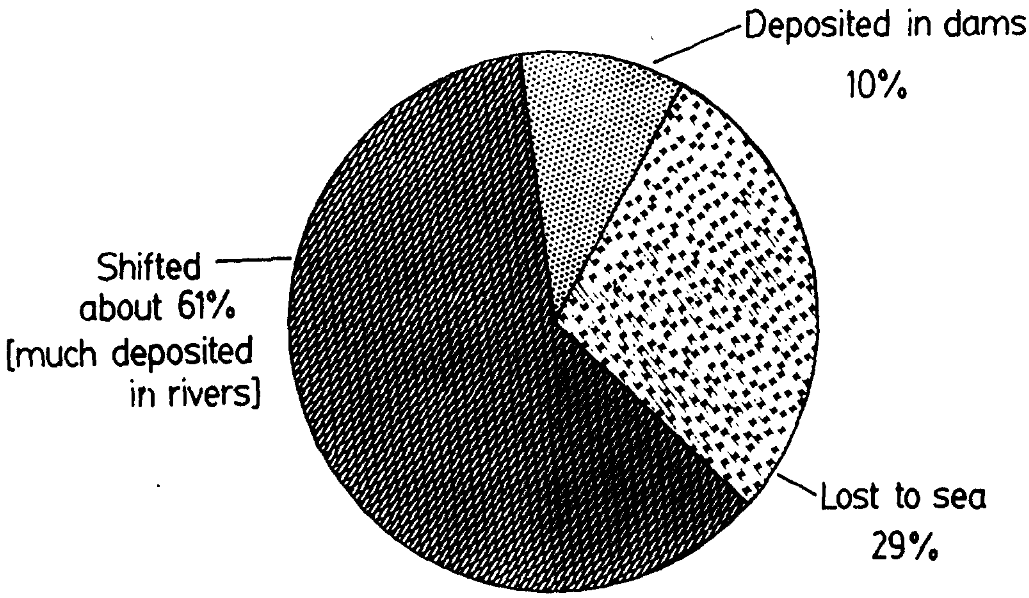


Fig. 2 : India's annual soil loss - 5,334 million tonnes

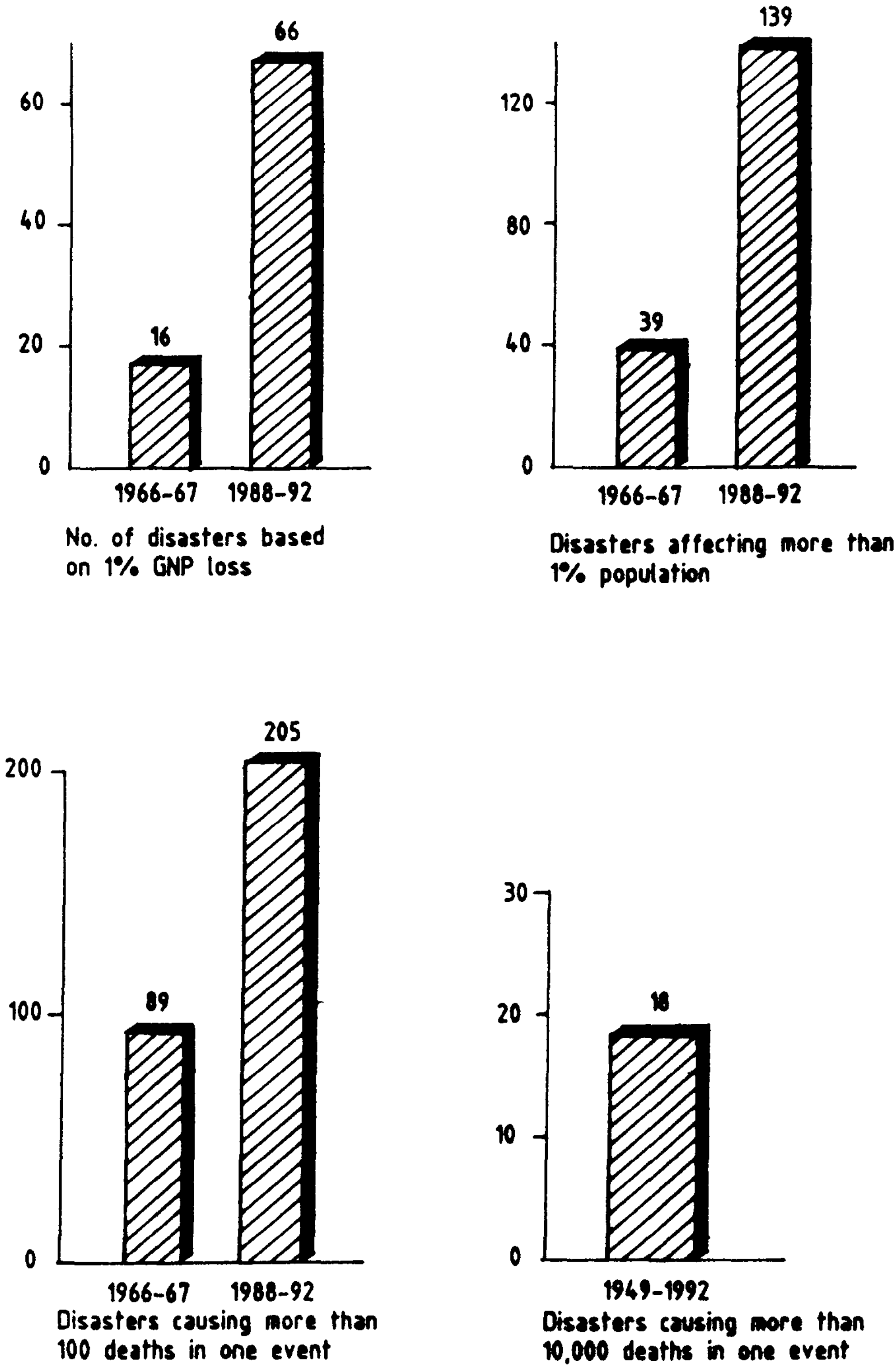


Fig. 3 : Increasing damaging potential of disasters in India

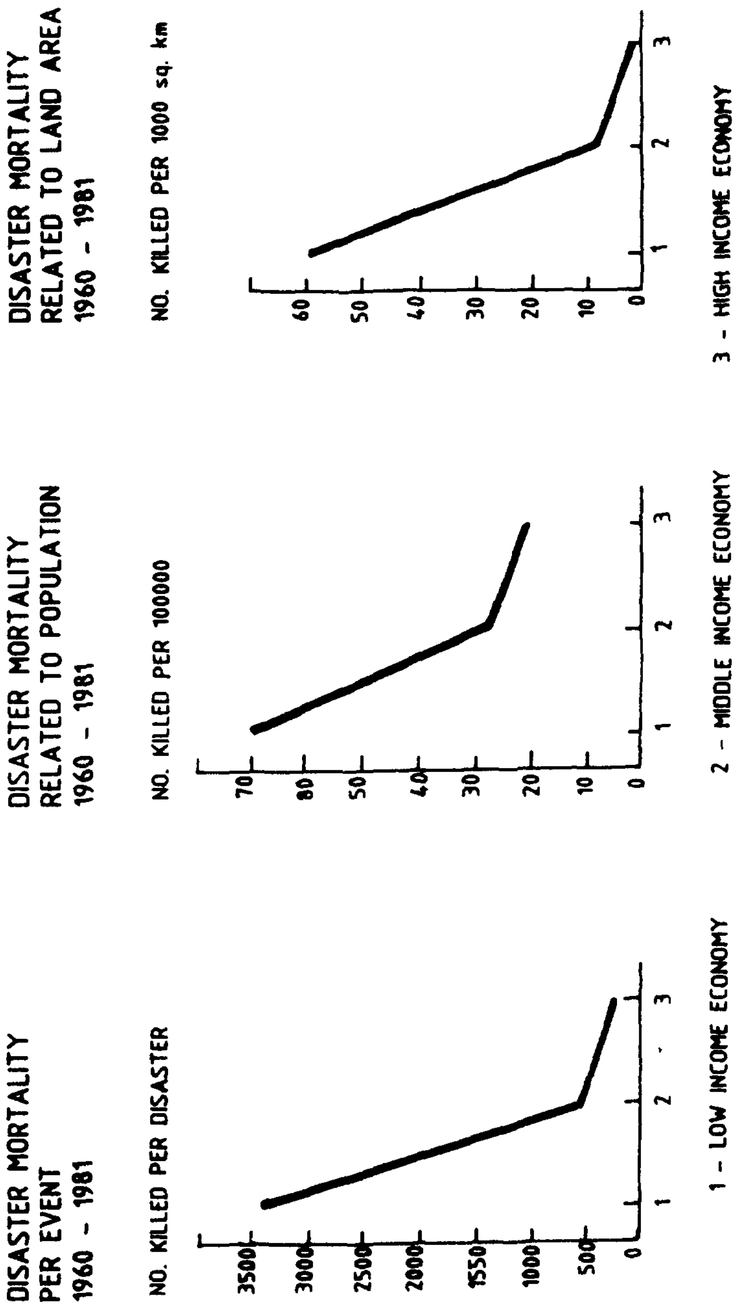


Fig. 4 : Consequences of disaster on various classes of people

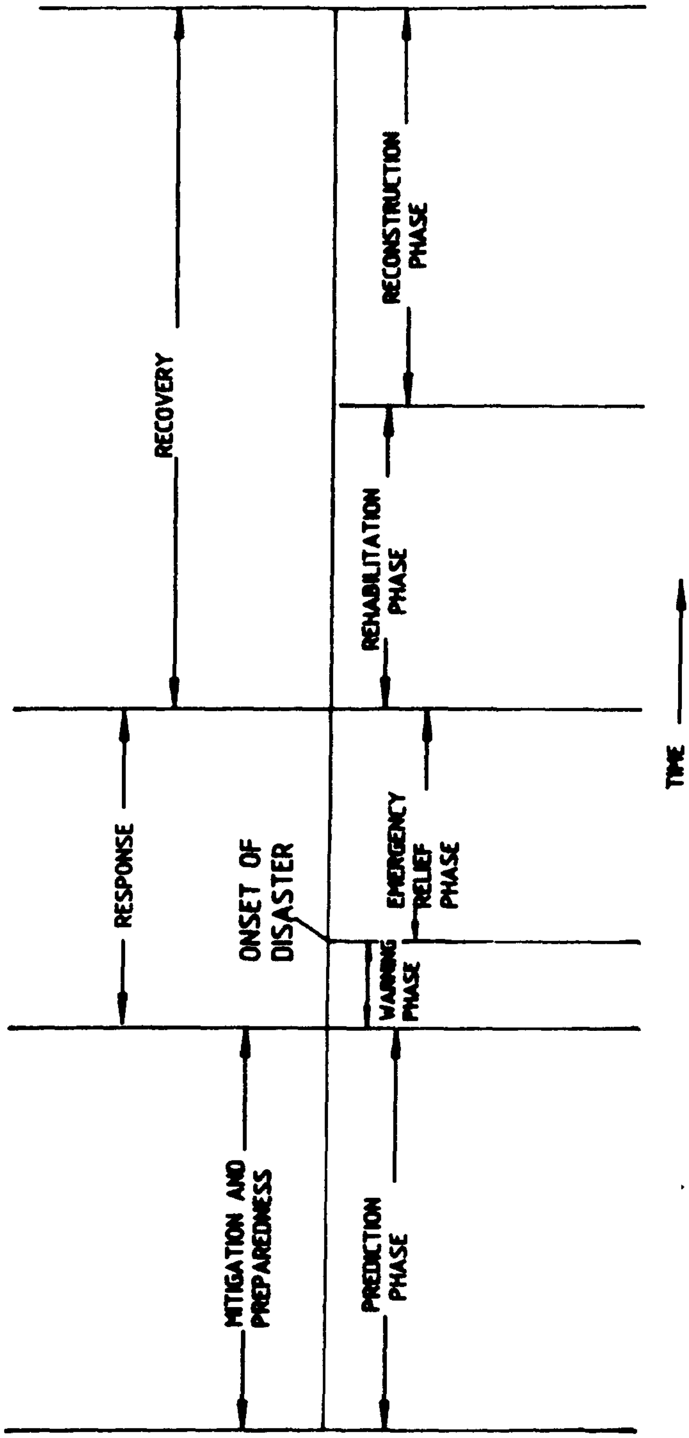


Fig. 5 : Timing of critical activities and phases in disaster management

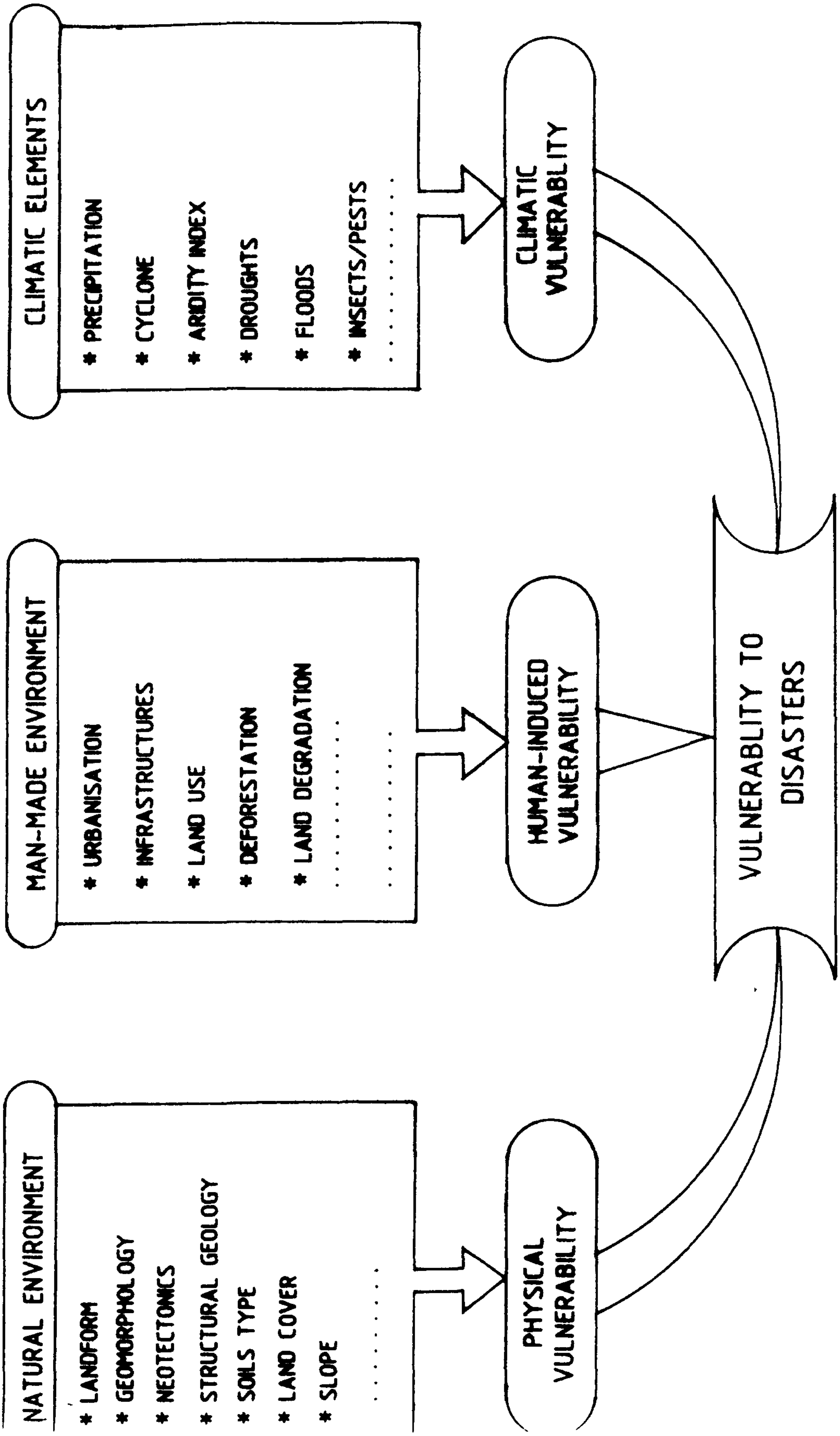


Fig. 6 : Components of vlunerability of a typical Terrain/Ecosystem to disasters

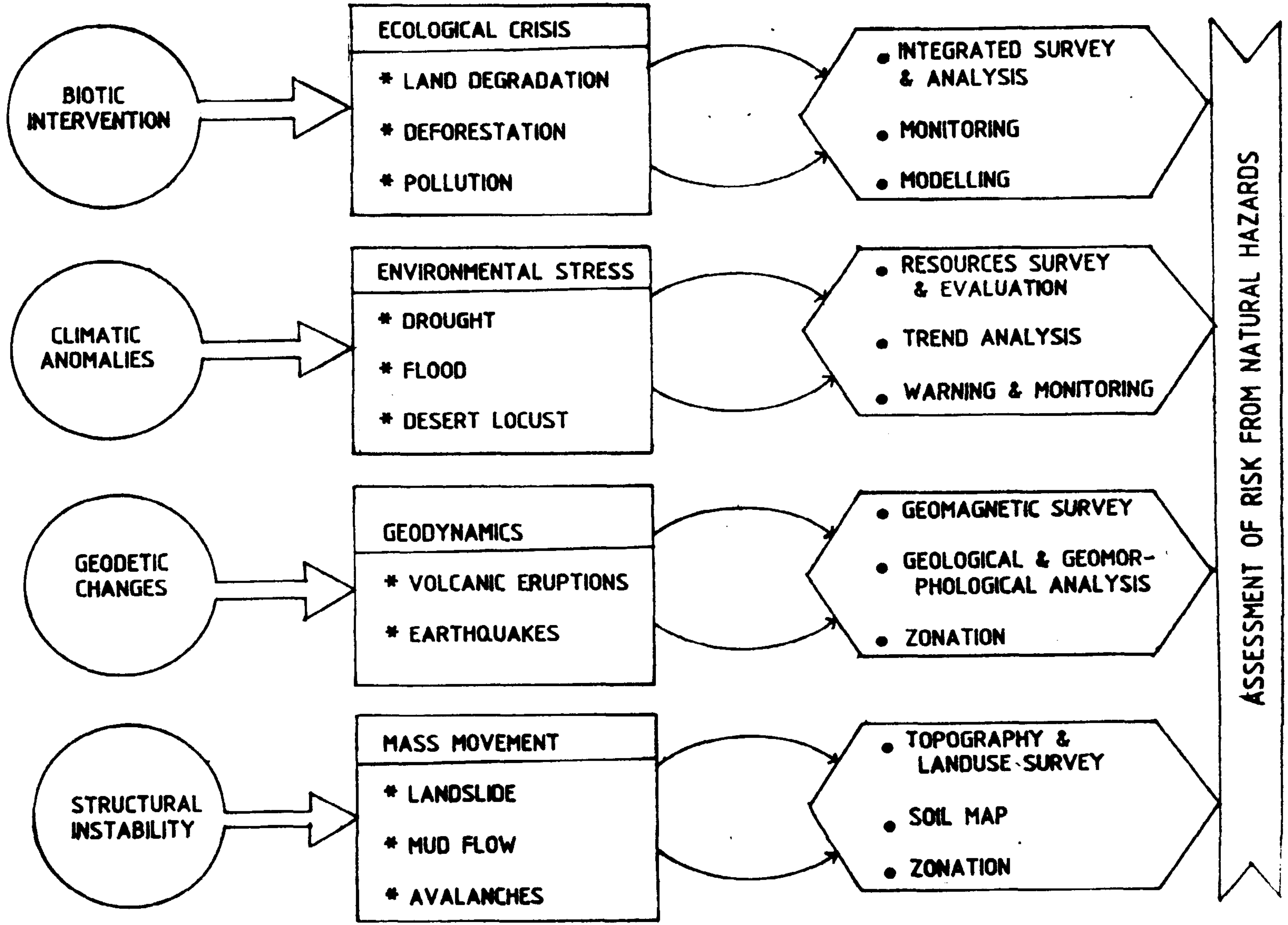


Fig. 7 : An appraisal on causes, effects and approaches to risk assessment

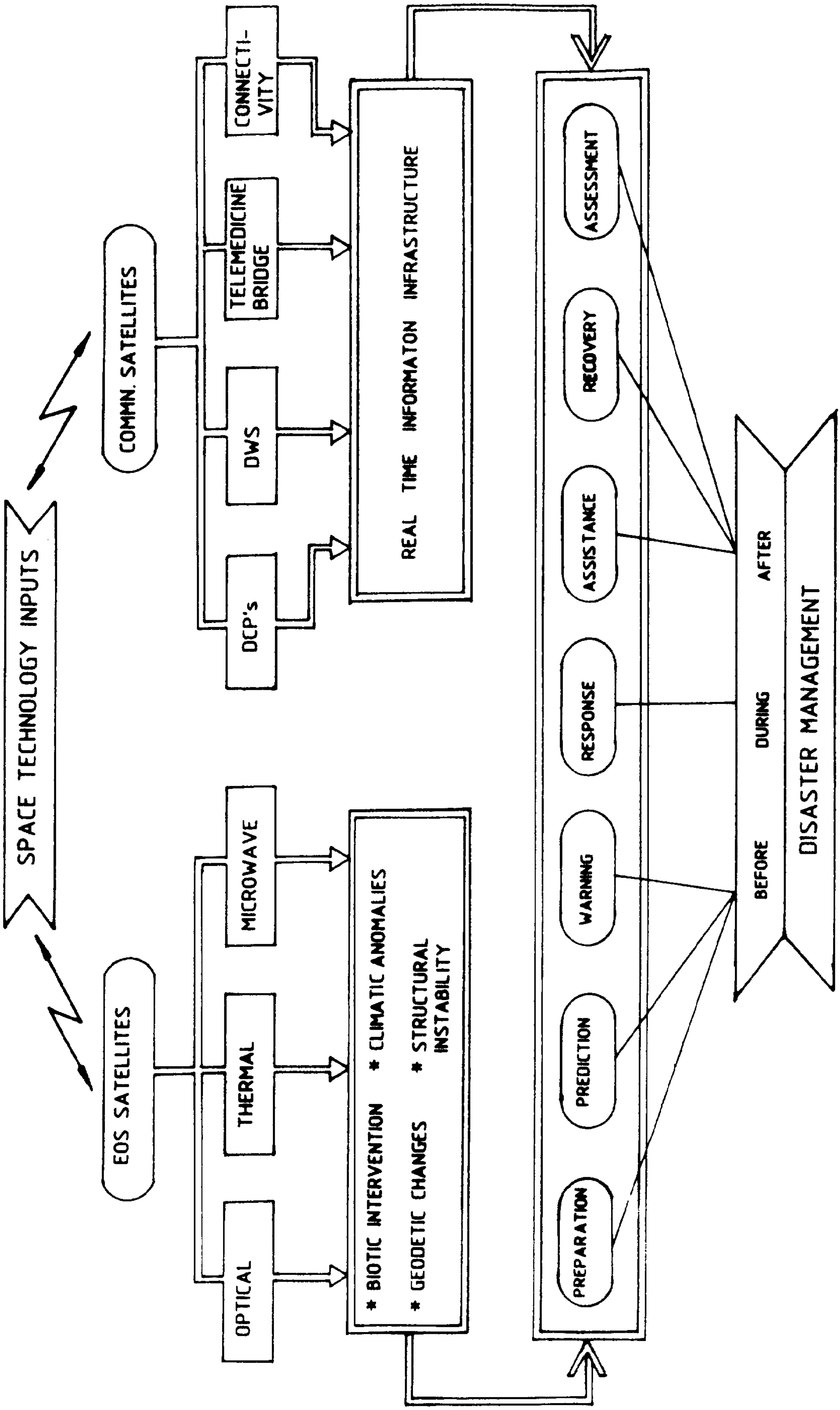


Fig. 8 : Space technology inputs for disaster management

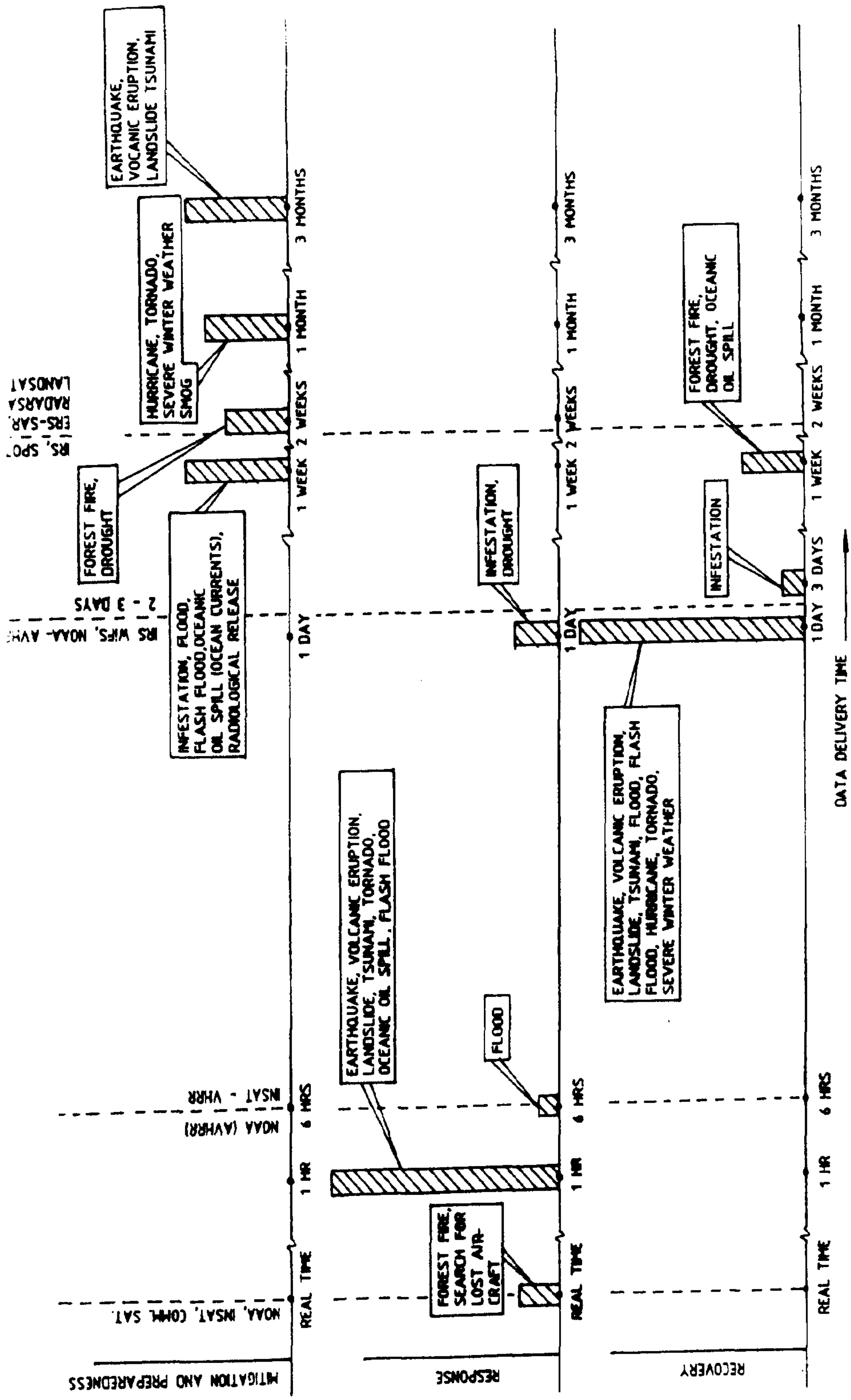


Fig. 9 : Data dlivery requirements of space borne systems

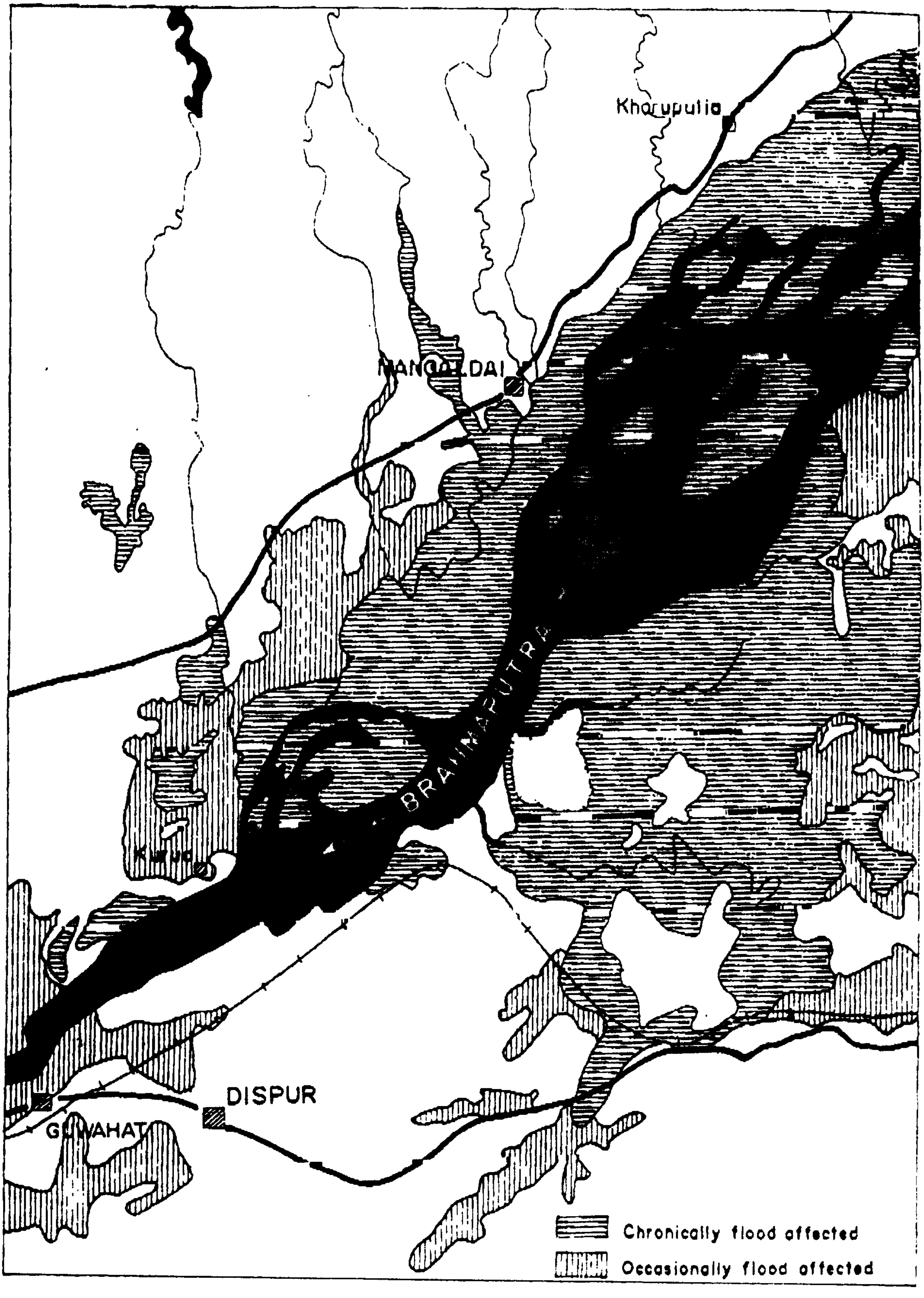


Fig. 10 : Flood risk zone map of Brahmaputra (Guwahati Area)

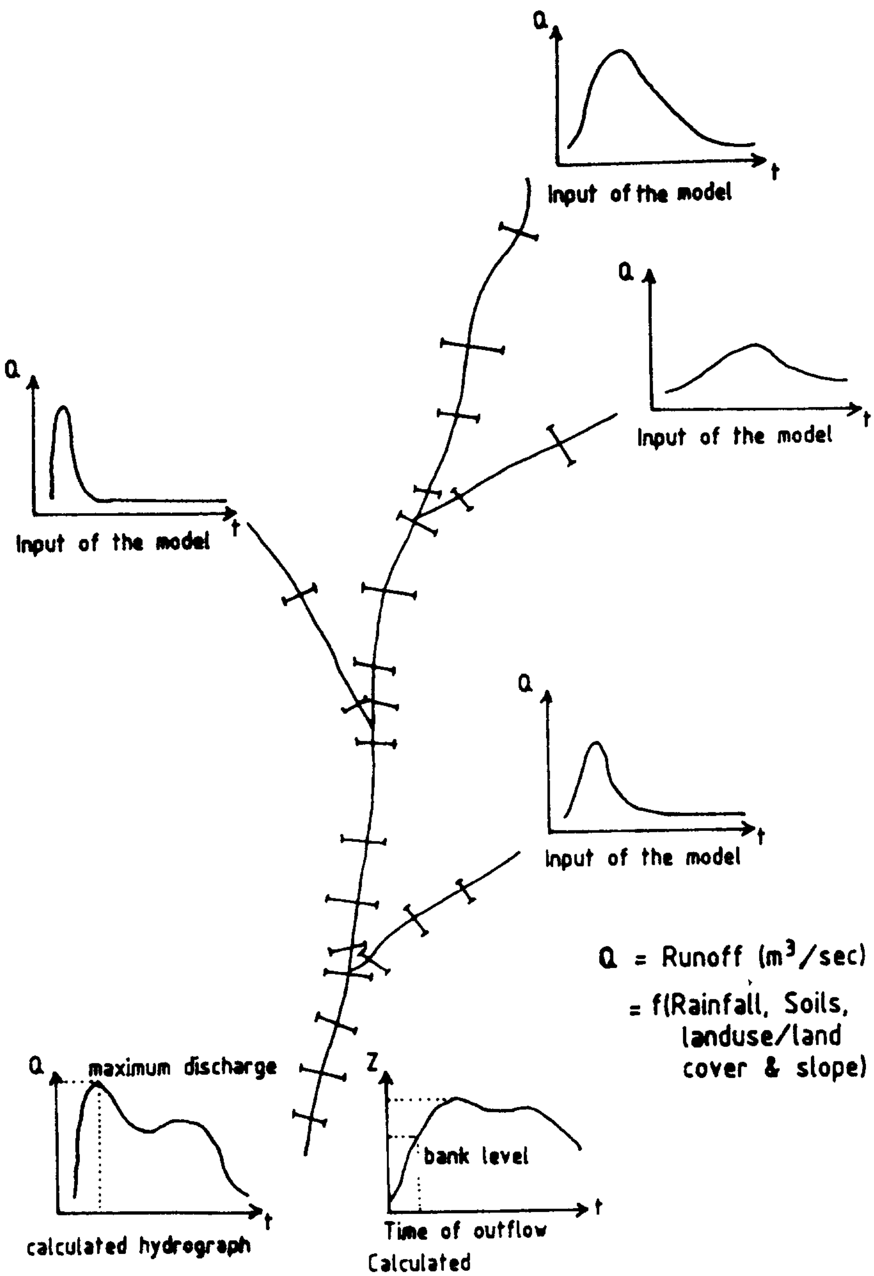


Fig. 11 : Remote sensing based Hydrograph analysis to (i) build retention dams for flood controls and also (ii) vulnerability analysis

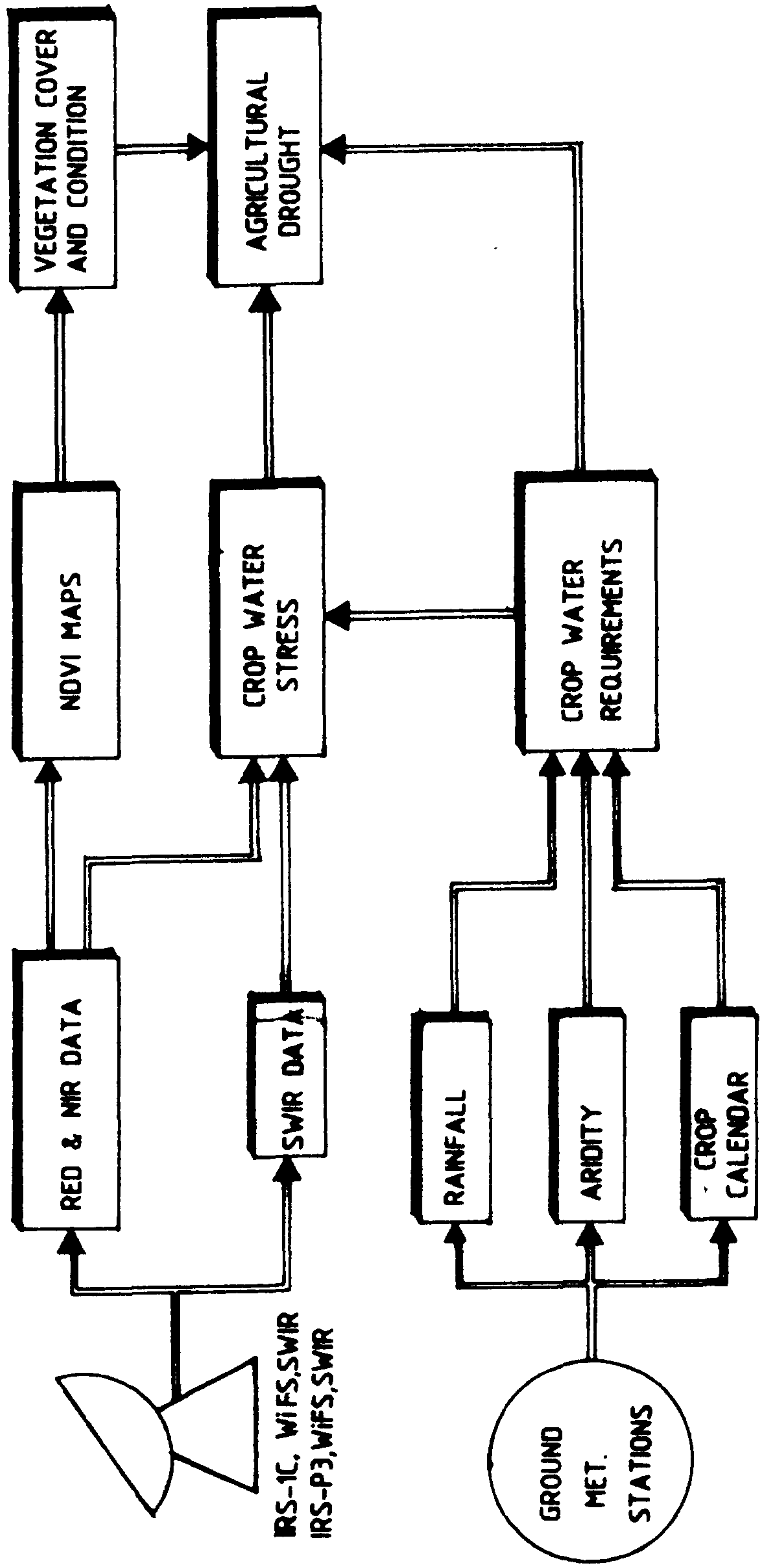


Fig. 12 : Agricultural Drought Monitoring System in India

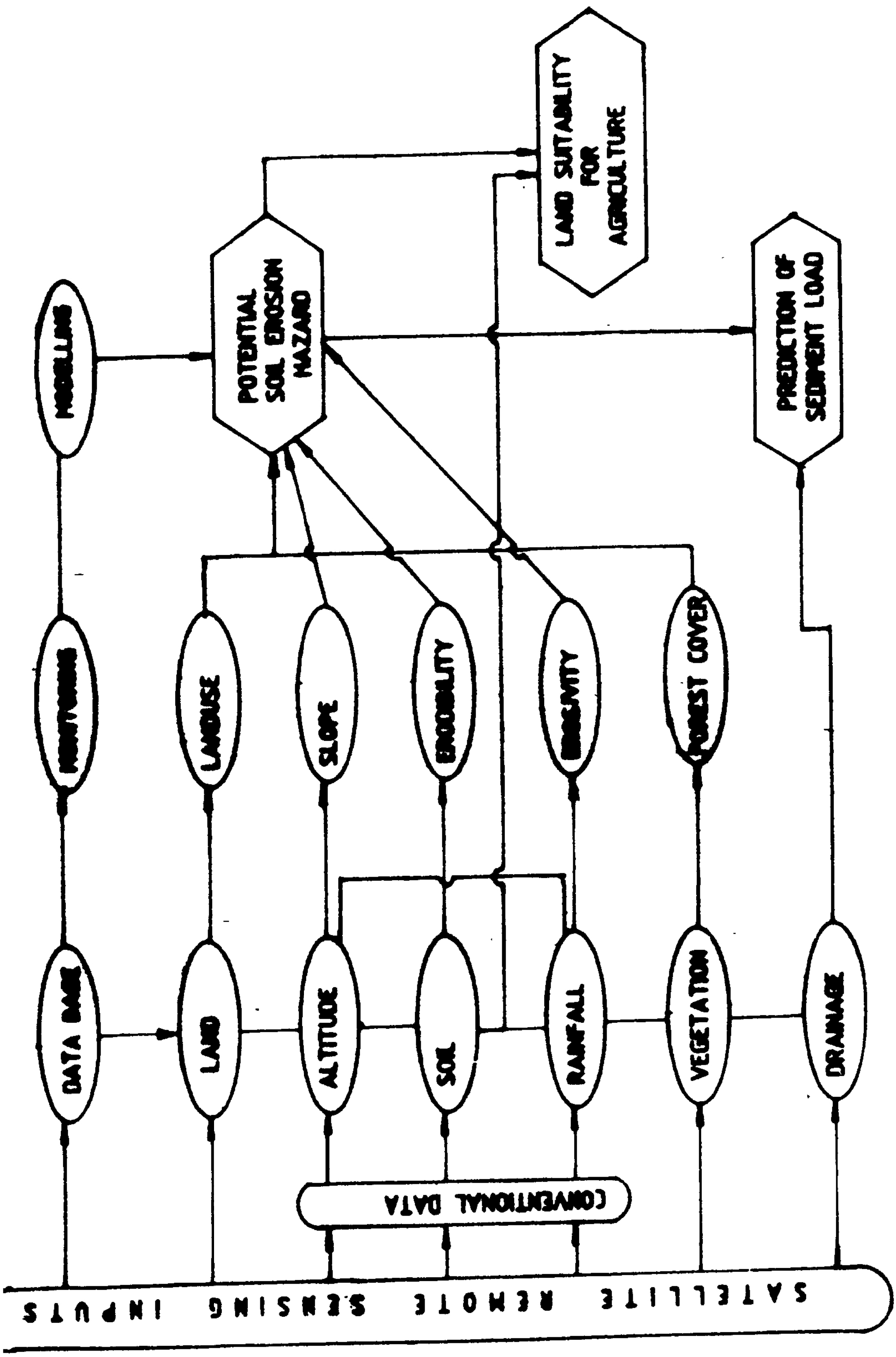
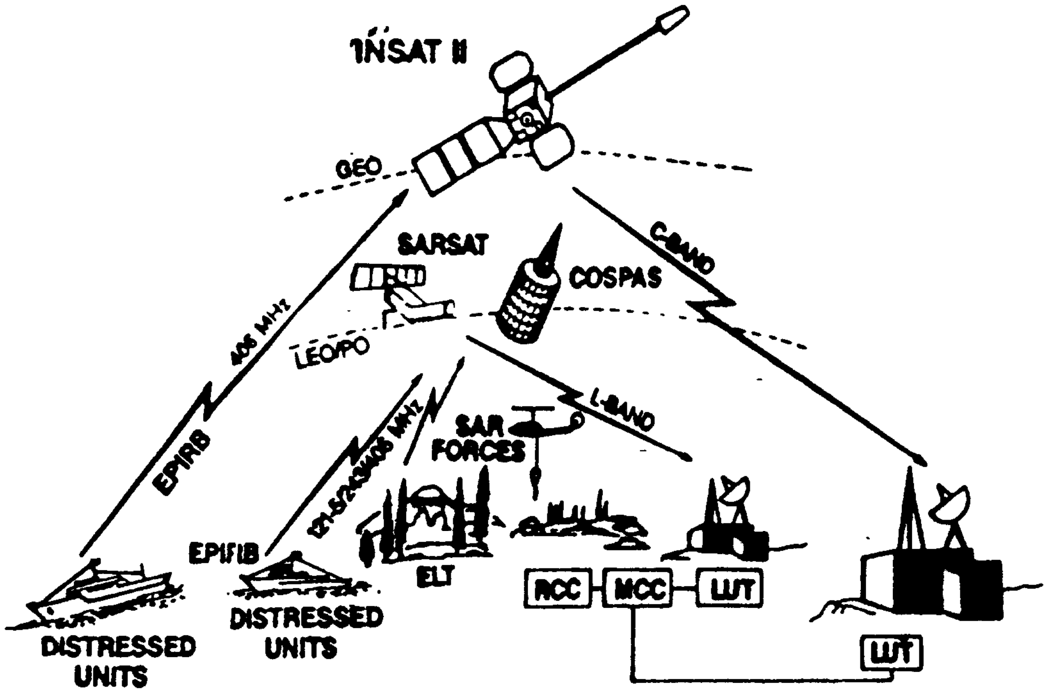
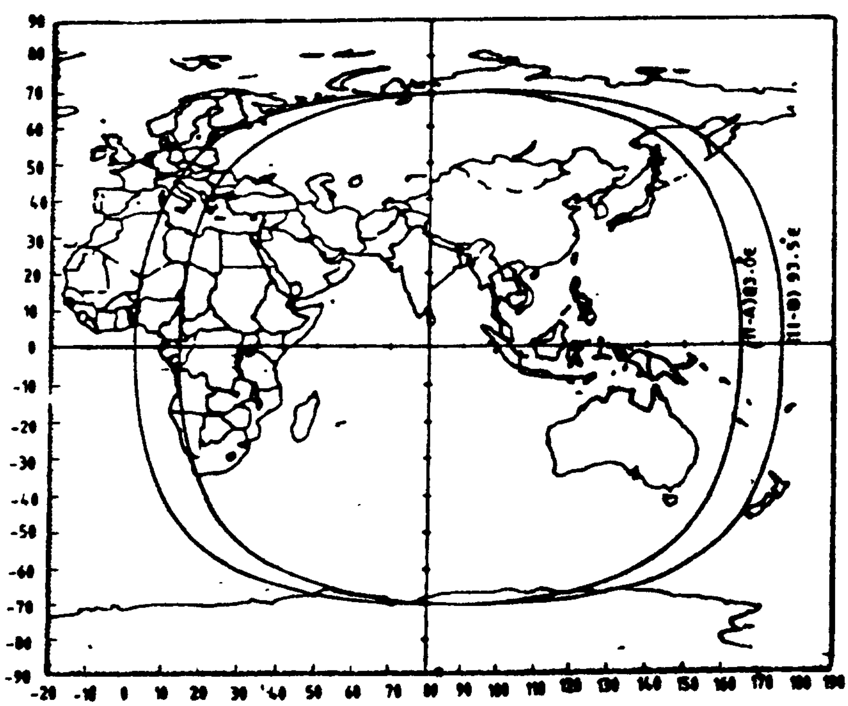


Fig. 13 : Remote sensing for predicting soil erosion and evaluating land suitability for agriculture



SATELLITE-AIDED SEARCH AND RESCUE



406 MHz S&R Coverages of INSAT-II

Fig-14

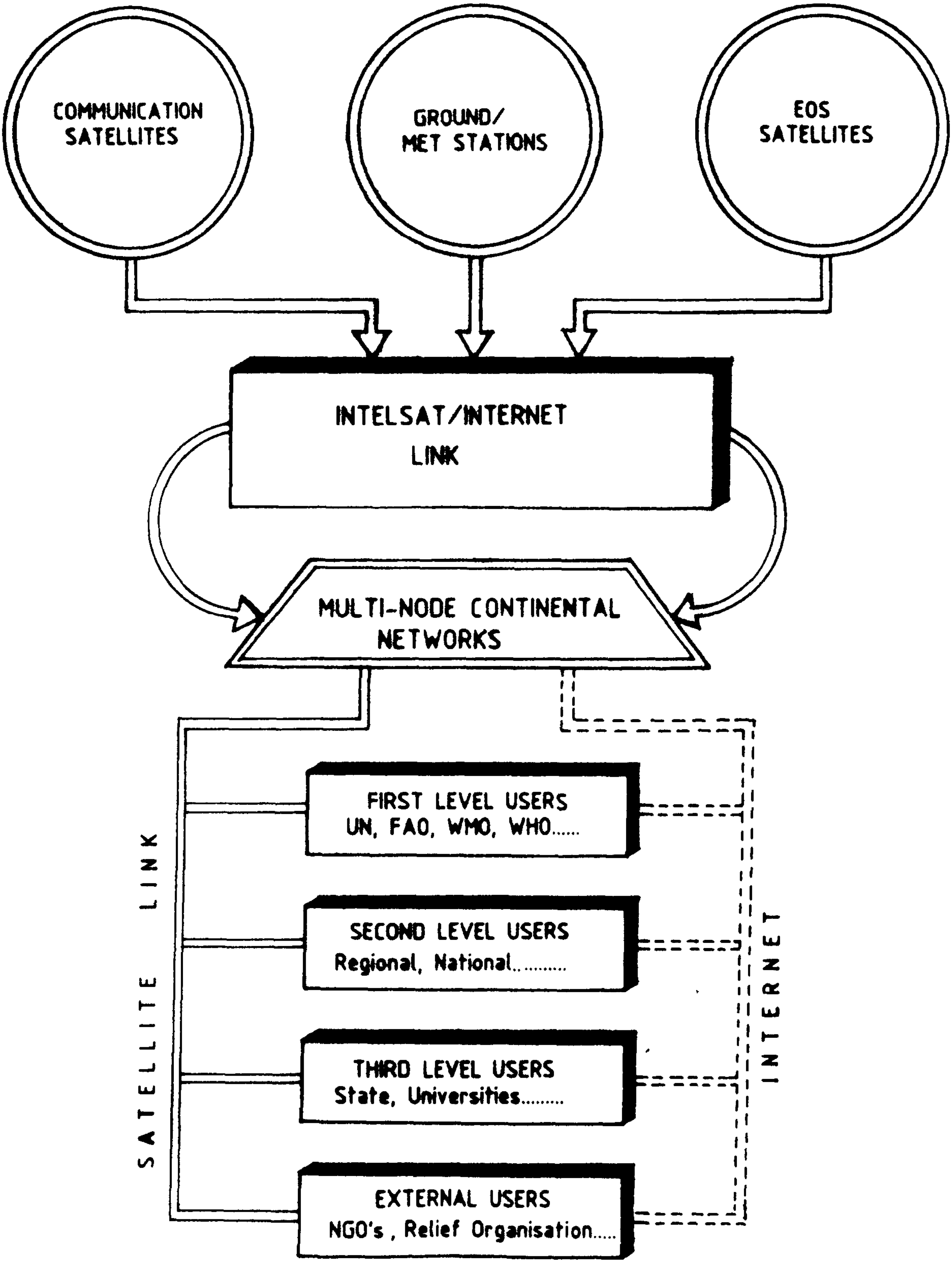


Fig. 15 : Linking communication and EOS satellites for disaster management