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GIS-based Earthquake Disaster Management A case study for Solapur city (Maharashtra, India)

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***Abstract*—** This paper aims to demonstrate a Geographic Information System (GIS)-based study on development of City Disaster Management System for earthquake for Solapur city (India).An approach has been designed to explore the scope for the combination of Disaster Management and GIS. The disaster-prone areas have been identified and their positions are marked using ArcView 9.1. GIS has been exploited to obtain the spatial information for the effective disaster management for earthquake-affected areas. ArcView 9.1 has been used as a tool for storing all types of relevant data for analysis and decision making. The various thematic maps include road network map, drinking water sources map, land use map, population density map, ward boundaries and location of slums. The paper proposes development of a GIS-based early response system, and an emergency preparedness plan for the Solapur city and also analysis of the impact of earthquake disasters in the region and its relationship to infrastructure development with a view to identifying how local governing bodies could be helped in addressing these issues. The proposed GIS-based flood mitigation and management program would improve the current practices of disaster management process. If implemented properly, it would result in proper and quick decisions for the rescue and safetyof the general public, which in turn would help in minimizing loss of life and property.

Index Terms— Geographical Information Systems (GIS), Disasters, Earthquakes, India

INTRODUCTION

A disaster is defined as an event (happening with or without warning) causing serious disruption to the functioning of a community or a society, means of causing or threatening death, injury or disease, damage to property, economic or environmental losses which exceed the ability of the affected community or society to cope using its own resources (DKKV, 2002). Owing to increase in the amount of research going into disasters and their management and mitigation, almost all the definitions have more or less been talking about human sensitivity towards natural or man-made or environmental hazards. Disasters are classified into three types: natural, man-made, and hybrid disasters and they are mix of both physical factors (such as intense rainfall over a short period) and other social and economic factors (such as poverty, population growth, etc.). Disasters have different characteristics and impact; however, disasters have a common element, which is their severity. People are described as vulnerable to disasters depending on the extent to which they are likely to be damaged or life disrupted by the impact of a disaster hazard. Vulnerability to a disaster usually follows a progression arising from such factors as poverty, a lack of infrastructure, and a fragile environment. Vulnerability to disasters is also closely linked to the history,that shaped the circumstances in which people find themselves. India has witnessed several major disasters due to earthquakes in the last two decades such as Killari(Latur) earthquake of September1993, Bhuj earthquake of Jan.26, 2001, Sumatra earthquake of December 26, 2004, Kashmir earthquake of October 8,2005. Most of the causalities were due to collapse of the buildings and or due to lack of rescue, insufficient data for risk prediction, inadequate knowledge to counterattack during emergency phase of disaster management and relief to the victims under the collapsed buildings. Earthquakes do not kill people but poorly designed or constructed buildings do.

On an average 4,888 people are killed and 59 million get affected annually from various types of disasters (International Federation of Red Cross and Red Crescent Societies,1994). The recent document of Swiss Re reports that in 1999 alone, natural and man-made disasters killed more than 1,05,000 people and resulted in US$100billion economic loss. The ability to react to these disasters, whether by government or individual is not tested very often, and many times when it is, chaos usually reins for a short period until authorities can fully mobilise and take affirmative action. The importance of uncertainty in natural hazard risk management has received recent attention (Goodchild, 1991; Rejeski, 1993). Figure1 presents both the manmade and the natural disaster victims during period 1970-2007. The observation is that there is continuous growth of man-made disasters due to human activities. The impact of natural catastrophes on societies has increased considerably over the last two decades, driven by climate change, population growth and expanded economic activity. While average insured catastrophe losses between 1970 and 1989 were USD8.3 billion per annum, these losses went up to USD32 billion per annum between 1990 and 2007.

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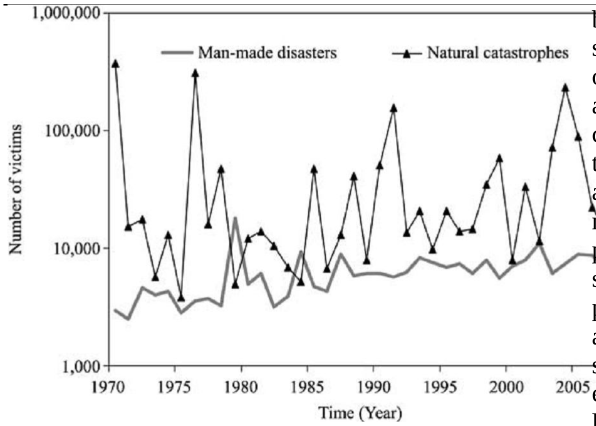

Figure 1: Numbers of victims 1970-2007

Figure 2 gives an indication of World Risk Index (WRI) of vulnerability natural disasters of the geographical distribution of a number of major hazards, such as earthquakes, volcanoes, tropical storms and cyclones. As can be seen from this figure earthquake and volcanoes, for example, are concentrated mainly on the earth's plate boundaries (Cees Van Westen 2000). Earthquakes result in the largest amount of losses. Of the total losses it accounts for 35%, ahead of floods (30%), windstorms (28%) and others (7%). Earthquake is also the main cause in terms of the number of fatalities (47%), followed by windstorms (45%), floods (7%), and others (1%) (Munich, 1999)

Figure 2: WRI of Vulnerability Natural Disasters

There are a number of factors responsible for this, which can be subdivided into the several factors leading to a larger risk and factors leading to a higher occurrence of hazardous events. The increased risk is due to the rapid increase of the world population, which has doubled in size from 3 billion in the 1960s to 6 billion in 2000. Depending on the expected growth rates, world population is estimated to be between 7 and 10 billion by the year 2050.There seems to be an inverse relationship between the level of development and loss of human lives in the case of a disaster. About 95 percent of the disaster related casualties occur in developing countries, where more than 4.200 million people live. Economic losses attributable to natural hazards in developing countries may represent as much as 10% of their gross national product. In industrialized countries, where warning - systems are more sophisticated, it is more feasible to predict the occurrence of certain natural phenomena, and to carry out massive evacuation. The Indian subcontinent is prone to all types of natural disasters, e.g. earthquake, flood, drought, cyclone, tsunami, landslides, avalanche, forest fires, etc. According to World Bank estimate, reported direct losses are on the order of $ 30 billion over the past 35 years. In 2005 alone, disasters in India caused direct losses approaching Rs 87.5 Billions. The decade 1990-2000 was designated the *International Decade for Natural Disaster Reduction* (IDNDR) by the general assembly of the United Nations. However, after the end of the IDNDR, we must conclude that the efforts for reducing the effects for disaster reduction during the last decade have not been sufficient, and have to be enhanced in the next decade.

Earthquake disaster

Earthquakes refer to shaking of earth. There is continuous activity going on below the surface of the earth. There are several large plates (size of continents) below the surface of the earth, which move (at a very slow speed). As a part of this movement, sometimes, they collide against each other. And, after the collision, they might still continue to push each other. As they continually keep pushing each other, there is a pressure building up across these plates below the surface and then, at a certain time, one of the plates might slide over another. This causes an earthquake. Some earthquakes might be caused by activity above the surface. For example in a mountainous region, there might be a heavy landslide. Due to a huge mass of land falling, at the point of the fall, there could be a minor shaking of earth, due the impact of fall. However, usually, such earthquakes are not very major. India's increasing population and extensive unscientific constructions mushrooming all over, including multistoried luxury apartments, huge factory buildings, gigantic malls, supermarkets as well as warehouses and masonry buildings keep - India at high risk. During the last 15 years, the country has experienced 10 major earthquakes that have resulted in over 20,000 deaths. As per the current seismic zone map of the country (IS 1893: 2002), over 59 per cent of India’s land area is under threat of moderate to severe seismic hazard-;

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that means it is prone to shaking of MSK Intensity VII and above
(BMTPC,2006). In fact, the entire Himalayan belt is considered prone to great earthquakes of magnitude exceeding 8.0-; and in a relatively short span of about 50 years, four such earthquakes have occurred: 1897 Shillong (M8.7); 1905 Kangra (M8.0); 1934 Bihar-Nepal (M8.3); and 1950 Assam-Tibet (M8.6). At one time regions of the country away from the Himalayas and other inter-plate boundaries were considered to be relatively safe from damaging earthquakes. However, in the recent past, even these areas have experienced devastating earthquakes, albeit of lower magnitude than the Himalayan earthquakes.

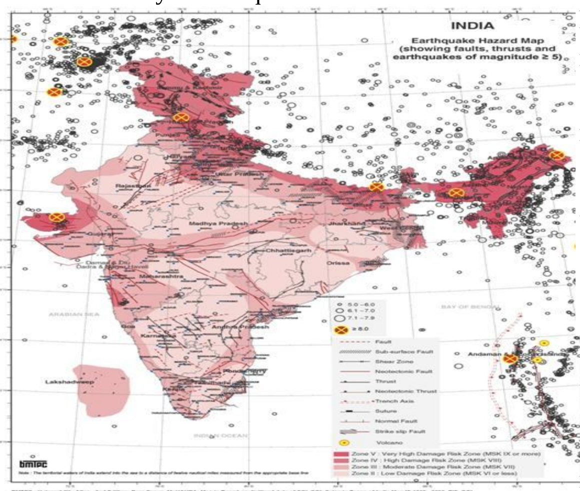

Figure 3: Earthquake Hazard Map

The Koyna earthquake in 1967 led to revision of the seismic zoning map, resulting in deletion of the non-seismic zone from the map. The areas surrounding Koyna were also re-designated to Seismic Zone IV, indicating high hazard. The occurrence of the Killari earthquake in 1993 resulted in further revision of the seismic zoning map as shown in Figure 3 in which the low hazard zone or Seismic Zone I was merged with Seismic Zone II, and some parts of Deccan and Peninsular India were brought under Seismic Zone III consisting of areas designated as moderate hazard zone areas. Recent research suggests that as understanding of the seismic hazard of these regions increases, more areas assigned as low hazard may be re-designated to higher level of seismic hazard, or vice-versa.

The North-Eastern part of the country continues to experience moderate to large earthquakes at frequent intervals including the two great earthquakes mentioned above. On an average, the region experiences an earthquake with a magnitude greater than 6.0 every year.The increase in earthquake risk is due to a spurt in developmental activities driven by urbanization, economic development and the globalization of India's economy. The increase in use of high-technology equipment and tools in manufacturing and service industries has also made them susceptible to disruption due to relatively moderate ground shaking. As a result, loss of human life is not the only determinant of earthquake risk any more. Severe economic losses leading to the collapse of the local or regional economy after an earthquake may have long-term adverse consequences for the entire country. This effect would be further magnified if an earthquake affects a mega-city, such as Delhi or Mumbai.

II. DISASTER MANAGEMENT

The Red Cross and Red Crescent societies defines Disaster Management as the organization and management of resources and responsibilities for dealing with all humanitarian aspects of emergencies, in particular preparedness, response and recovery in order to lessen the impact of disasters.

A. Disaster Management Cycle

The Figure 4 shows, Disaster management activities can be grouped into five phases that are related by time and function to all types of emergencies and disasters. These phases are also related to each other, and each involves different types of skills.

Development

The activities those are necessary to analyze and document the possibility of an emergency or disaster and the potential consequences or impacts on life, property, and the environment. This includes assessing the hazards, risks, mitigation, preparedness, response, and recovery needs.

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Figure 4: Disaster Management Cycle

Mitigation

The activities those are necessary to eliminate or reduce the probability of a disaster. It also includes long-term activities designed to reduce the effects of unavoidable disaster.

Preparedness

The activities those are necessary to the extent that mitigation measures have not, or cannot, prevent disasters. In the preparedness phase, governments, organizations, and individuals develop plans to save lives and minimize disaster. Preparedness measures also seek to enhance disaster response operations.

Response

The activities those are necessary to follow during an emergency or disaster. These activities are designed to provide emergency assistance for victims .They also seek to stabilize the situation and reduce the probability of secondary damage and to speed recovery operations.

Recovery

The activities those are necessary to return all systems to normal or better. It may be observed that advancement in information technology in the form of GIS, remote sensing can help on a great extent in planning and implementation of hazards reduction measures.

B. GIS: a Tool for Disaster Management

Geographic Information System (GIS) is a tool that can assist earthquake disaster managers in identifying earthquake prone areas in their community. By overlaying or intersecting different geographical layers, earthquake prone areas can be identified and targeted for mitigation or strict earthquake disaster management practices after all of the information has been collected and organized in a GIS database. Figure 5 shows that GIS has become an integrated, well developed and successful tool in disaster management. GIS allows the combination of different kinds of data using models and the different kinds of spatial data, with non-spatial data, attribute data and use them as useful information in the various stages of disaster management.GIS is a computer-based system capable of assembling, storing, manipulating, and displaying geographically referenced information. GIS technology supports spatial data handling and analysis efficiently and can be used to create an integrated geo-database on biological, meteorological, hydrological, socio-economic indicators for their subsequent use in modeling the simple/complex disaster related indices to reflect the vulnerability of an area to the disaster.

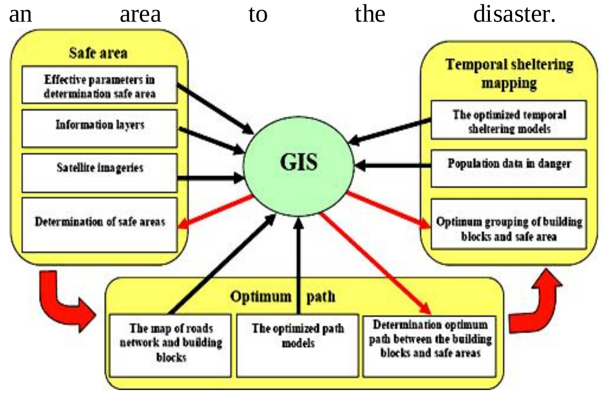

Figure 5: Role of GIS in Disaster Management

Remote sensing from satellites provides another important source of data, often used in GIS, e.g. observational data on stream flow, climate, water quality, and groundwater levels, together with remote sensing/GIS data and weather/climate grids. Advances in information technology such as fibre optics technology for river monitoring provide additional sources of data. Maniruzzaman et al. (2001) described the preliminary development of a prototype Response Estimation System for Cyclones under Emergency (RESCUE), a GIS-based aid intended for disaster management personnel involved with cyclone response in Bangladesh. The GIS can also help identify risk areas and plan long-term measures for disaster management. Disaster planning, response, mitigation, and recovery all become more efficient through the use of GIS (Suresh et al., 2005).

The above discussion gave the comprehensive idea that GIS-based systems can be used as an integrated administrative and decision support system to respond to the immediate humanitarian and disaster relief operation during and after the event. In view of considering these developments happening in disaster management, an attempt has been made to develop GIS-based framework for earthquake disaster for a study area of Solapur city (India).

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III. GIS-BASED CONCEPTUAL FRAMEWORK FOR SOLAPUR CITY

The disaster management is a multi-disciplinary endeavor, requiring many types of data with spatial and temporal attributes that should be available to district and city administrators in the right format for decision-making. The volume of information needed for natural disasters far exceeds the capacity to deal with them manually and thus there is a need for a GIS-based information system. Figure 6, shows the proposed organogram for Solapur city and district. According to District Disaster Management Authority (DDMA), Ministry of Home Affairs,

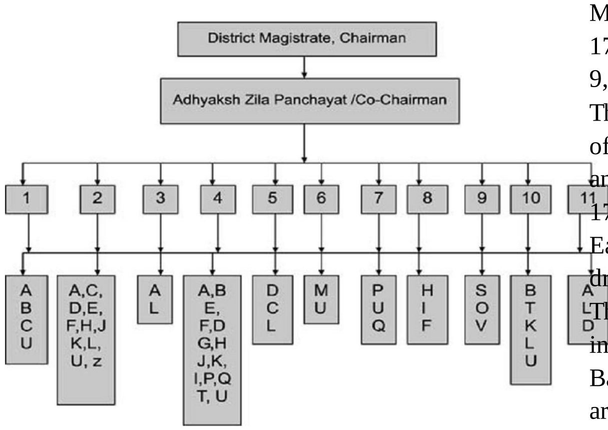

Figure 6: Organogram of DDMA

Government of India, disaster management authority is governed by a chairman (District Magistrate) and nominated officers and the co-chairman is elected member of urban local body i.e. mayor of municipal corporation The whole disaster management plan is proposed to run through 11 committees. These committees are supported by 26 city and district level departments which are represented by A-Z alphabets.

Details for organogram notations:

(1) Law and order committee,(2) Rescue committee.
(3) Traffic control committee,(4) Advisory committee.
(5) Fire control committee, (6) Communication committee.
(7) Health and welfare committee.
(8) Water supply committee; (9) Transportation arrangement committee.
(10) Awareness, education committee.
(11) Emergency Operation Centre (EOC).

Supporting departments:

A) Police, B) Intelligence; C) Army; D) Fire brigade;
E) Public Works Department (PWD); F) Irrigation;
G) District Disaster Management Division;
H) Solapur Municipal Corporation
I) City Development Authority J) Water Board K) Media;
L) Non Governmental Organisations (NGOs);
M) Telecommunication; N) Electricity Supply;
O) Railways; P) Medical department;
Q) District Industries; R) Petrol/Gas departments;
S) Transport department, T) Institutions;
U) City Administration; V) Road Transport Officer (RTO);
W) Agriculture Department; X) Veterinary Department;
Y) Education Department; and
Z) Civil Supply Department

IV. CASE STUDY OF SOLAPUR CITY

The present study area is Solapur city of Maharashtra state (India) which has its current area is 178.57 sq.km area, accommodating a population of 9,51,118 persons as per the Census record of 2011. The Solapur district situated on the south-east fringe of the Maharashtra State lies entirely in the Bhima and Sina Basins. Geographically it is located between 17.10^{o} to 18.32^{o} North Latitudes and 74.42^{o} to 76.15^{o} East Longitudes. Almost whole of the district is drained either by Bhima River or by its tributaries. There is no important hill system in the district. Only in the North of Barshi Tehsil several spurs of Balaghat range pass south for a few kilometres. There are also scattered hills in Karmala, Madha and Malshiras Tehsil. The district has in general flat or undulating terrain. The low table-land and small separate hills in Karmala and Madha Tehsils act as watershed between the Bhima and Sina rivers.The Divisional Commissioner's office for Solapur district is therefore located at Pune headquarters. The Solapur district is divided into 11 Tehsils (administrative units) and three sub-divisions (CRISIL,2013)

V. METHODOLOGY

The map of Solapur city is prepared using Arc GIS 9.1. The disaster management efforts, namely, prevention, reduction, mitigation, relief and rehabilitation require precise maps with spatial data and non-spatial data. The various stages involved in the preparation of a comprehensive disaster management strategy for study area include the following:

- .development of an integrated geo-database consisting of various thematic maps, demographic data, socio-economic data and infrastructural facilities at village level under GIS environment;
- the utilities like education facilities, medical facilities, road connectivity, cinema hall, news paper, telephone and telegraph facilities, irrigated and un irrigated area facilities, electricity, etc. and

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other information from Census 2001 available for the district are represented spatially using GIS;

- the Survey of India (SOI) maps are suitably supplemented for information relating to specific and individual disasters as well as for planning of developmental programmes; and
- the various thematic maps prepared include road network map, water supply network map, fire control office map, urban sprawl map, drainage map and land use map of different of the study area.

VI. Development of GIS-based Maps for Disaster Management

Various maps were generated for the analysis in the GIS platform. Some of these maps are indicates closeness of houses and congested transportation network in Solapur city

Figure 7 shows the road network of villages that are more vulnerable and are not been connected by main road as well as metal road. Those villages that are not having transport connectivity can be identified, and there is no chance to escape quickly because of difficulty in transport mobility. With the help of above information, one can provide rescue first to those areas not connected through metal road and after that

provide transportation to metal road connected areas of city.

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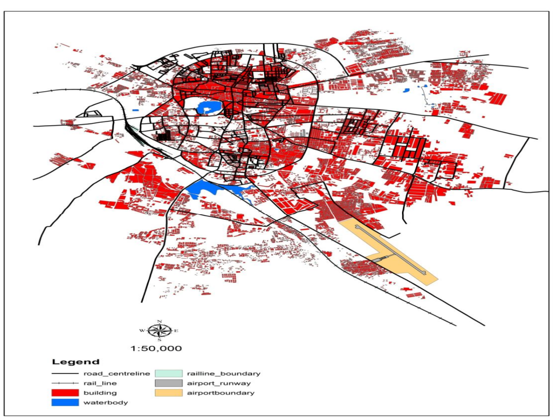

Figure 7: Road Network of the Solapur City

Following are some of the examples of the locations which are problematic in terms of the closeness of the houses, poor road network. Following Figure 8 and Figure 9 illustrate such example. It's quite clear the GIS based analysis can aid greatly in identifying such areas. These are the part of the mitigation IRS ID PAN data of Solapur city and surrounds overlaid with multiple GIS layers useful for the seismic probable prediction model to be applied for suitable mitigation plan.

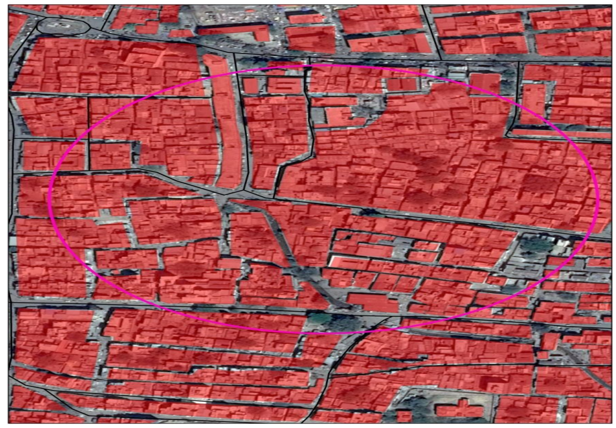

Figure 8: GIS layer showing the Housing Pattern and Road Network

The layers dropped over areas under,

1) Square figure with red boundary indicates the closeness of houses.

2) Thick gray line strip indicates the transportation network in the study area.

3) Thick red colour circle indicates the boundary line of the study area.

The Solapur Disaster Management Action Plan (SD-MAP) is prepared for its operationalisation with help of Solapur Disaster Management Cell (SDMC). This plan provides for institutional arrangements, roles and responsibilities of the various agencies, interlinks in disaster management and the scope of their activities.

The *purpose* of this plan is to evolve a system to;

- Assess the status of existing resources and facilities available with the various departments and agencies involved in disaster management in the Solapur;
- Assess their adequacies in dealing with a disaster;
- Identify the requirements for institutional strengthening, technological support, up gradation of information systems and data management for improving the quality of administrative response to disasters at the ward/peth level.
- Make the SD-MAP an effective response mechanism as well as a policy and planning tools

- Rescue operation centers have been suggested at four corners of the main city at comparatively

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elevated grounds with more safety foundation conditions

- The SW rescue center may be attached to Ashwini hospital and research center with ability to import the rescue support from Pune and Hydrabad and also from the air landing ground located in the south-west of Solapur city.
- From the above mitigation plan, it is seen that the maximum rescue centers are near the transportation system from where help of the people can get.

VII. Conclusions

Since Solapur city lies in seismic zone III, There is a need to study the various aspects like topographic failure and slope stability, pre and post seismic changes, the vulnerable areas, with respect to Solapur city. In many parts of Solapur city, soil creep was ignored by foundation engineers. The results is seismic ground failure, mainly due to wave amplification and liquefaction. Unfortunately, the recent temporal pre and post disaster data of nearby area was not available for study. Some pre and post event image data from various other places have been studied to co relate the observed mode of destruction with that of the probable destruction in Solapur city, in case the major event happens. The study of changed pixels on the rasters of post events found to speak about the change in IRS 1 D LISS III and PAN data of Indian Remote Sensing satellites. This type of correlation analysis is really the inevitable step, as the same is very useful in designing the predictive model and hence the mitigation plan. Thus, RS and GIS is the effective, efficient tool for fast and accurate spatial data management to construct the predictive management and mitigation plan for unexpected seismic disaster but with high resolution data. There is a need of the improvement in Indian satellites and sensors for getting better data quality so as to detect and map the micro level vulnerability.

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