Integration of GIS with Remote Sensing and GPS for Disaster Mitigation

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ABSTRACT :

Natural disasters like flood, earthquake, cyclone, volcanic eruption and others are causing immense losses to the property and lives every year. Current status and actual loss information of natural hazards can be determined and also prediction for next probable disasters can be made using different remote sensing and mapping technologies. Global Positioning System (GPS) calculates the exact position of damage. It can also communicate with wireless sensor nodes embedded in potentially dangerous places. GPS provide precise and accurate locations and other related information like speed, track, direction and distance of target object to emergency responders.

Remote Sensing facilitates to map damages without having physical contact with target area. Now with the addition of more remote sensing satellites and other advancements, early warning system is used very efficiently. Remote sensing is being used both at local and global scale. High Resolution Satellite Imagery (HRSI), airborne remote sensing and space-borne remote sensing is playing vital role in disaster management.

Early on Geographic Information System (GIS) was used to collect, arrange, and map the spatial information but now it has capability to analyze spatial data. This analytical ability of GIS is the main cause of its adaption by different emergency services providers like police and ambulance service.

Full potential of these so called 3S technologies cannot be used in alone. Integration of GPS and other remote sensing techniques with GIS has pointed new horizons in modeling of earth science activities. Many remote sensing cases including Asian Ocean Tsunami in 2004, Mount Mangart landslides and Pakistan-India earthquake in 2005 are described in this paper.

KEYWORDS:
Disaster Mitigation, GPS, GIS, Remote sensing

1. INTRODUCTION

Natural Disasters are severe events caused by natural environmental factors which cause great damages to lives and properties. These disasters include floods, volcanoes, earthquakes, landslides and cyclones etc. Different approaches like field observations, photogrammetry, GIS and remote sensing are being used for mapping, modeling and predicting these hazards [13].

Disaster mapping is done for two purposes [1]; one is to estimate the loss of already occurred event and other is to predict the next probable event. A large percentage of natural disasters are related to Geomorphology. So remote sensing technologies like GPS, Satellite sensing, radar technology and other image processing techniques integrated with GIS help Geomorphologists to map, analyze and predict these disastrous events [1,13].

Global positioning system assists to map and model the damaged areas like coasts, mountains and glaciers etc. after calculating the accurate position of target, GPS can find other dimensions like speed, distance from destination, direction and track etc. This helps in predicting the disasters like land sliding, coastal inundation and volcanic eruption. GPS also communicate with fixed WSN nodes to keep emergency responders aware of hazards. GPS data is received by GPS receivers on earth, which are time synchronized with satellites for accurate measurement [2]. More than 1200 electronic control point are employed in Japan for monitoring of ground motions to predict earthquakes [1]. GPS provides 24 hour monitoring in all weather conditions.

Remote sensing technology helps to analyze natural disasters without having physical contact with those environments. Big advantage of remote sensing technology is that it provides high resolution spatial imagery of environment [1] using high resolution imagery tools like IKONOS, OrbView and QuickBird. These imagery techniques integrated with GIS database used to compare before and after event images so that actual losses could be estimated. Disadvantages of remote sensing are about its poor mapping in bad light conditions and in cloudy weather. In such conditions, imagery of remote sensing satellite became almost invisible.

GIS plays very important role in mapping of Earth science activities. It is often used with different remote sensing techniques. GIS has ability to not only map data but also analyze it [17]. Due to this analytic ability for generation of simple and easily understandable maps, GIS has great attraction for emergency responders and also it is easily accessible for even non-technical persons [12]. With the day by day advancements in mapping and modeling techniques, GIS mapping has dimmed the difference between reality and virtual reality [27].

Full potential of 3S technologies cannot be utilized when these are implemented alone for environmental monitoring [7]. Integration of RS, GIS and GPS not only diversified the environmental monitoring techniques but also provided with new horizons in this field (e.g. emergency response).

Few of remote sensing cases are described in this paper in which these 3S technologies played an important role in combination with each other. Post disaster loss estimation and measurement of intensity at particular area helps recovery managers to mitigate those damages. Some methods were used to predict next probable disasters and their intensity [19].

Events described in this paper are Asian Ocean Tsunami of 2004, Kashmir-Pakistan Earthquake of October 2005, Mount Mangart landslides, Niigata chu-etsu Japan earthquake of October 2004 and a huge flood of Regione Peemonte northern Italy in 1994.

2. ROLE OF GPS FOR DISASTER MANAGEMENT

Global Positioning System playing very important role in environmental sciences or earth sciences for four decades. Earlier on 24 GPS satellites were launched in six different orbits by Department of Defense. But in 1980s these satellites were allowed for civilian use also. Each orbit has four satellites orbiting the Earth about two cycles a day and remains in its particular orbit, 20200 Kilometers above the Earth [9, 10]. Three dimensional position of target point on ground can be found by minimum of three GPS satellites [2]. These GPS satellites equipped with atomic clock in them, which helps to synchronize these satellites with each other.

Electronic Control Points (ECP) or GPS receivers (see figure 1) receive signals of satellite on ground [2]. Position of receiver on Earth can be determined by the time difference of signals of different satellite reaching at target point. After intersecting each satellite signal it is determined that how far GPS satellite is from target. Simultaneous and synchronized communication between satellite with GPS receiver is possible through high precision quartz clock existed in GPS receiver on Earth [2].

GPS satellites are synchronized enough that these satellites have the time difference of some microseconds. Although that was not a big difference in the past decades but in these days, with the advancements of remote sensing techniques and for accurate and precise results, this time difference can be reduce to few nanoseconds [9].

Like other remote sensing technologies, GPS performs his role in disaster mitigation by accurate, flexible and precise positioning of target. GPS could be vital among other remote sensing technologies for earthquake measurements as it provides millimeter level accurate measures about seismic activities. These seismic activities cause Ground deformation and displacements, which can be very accurately and precisely measured by GPS based remote sensing. GPS helps to estimate earthquake disaster losses through accurate assessment of distribution of earthquake ground motions [6].

An earthquake monitoring system was discovered in university of Tokyo. Triangulation method was implemented for monitoring the change ratio of triangular area in geocentric coordinate system. That earthquake monitoring system was implemented and pre-event signals were found (see figure 2) before some earthquakes [1].

Fixed GPS stations are also very practicable for assessment of natural hazards like land sliding and earthquakes. This type of station are fixed in the area where monitoring is required i.e. fix on glaciers to find velocity, track distance and direction of glaciers to prevent landslide. Fixed GPS stations provide 24 hour monitoring of the target [1].

2.1 GPS AND GIS INTEGRATION

GIS is very often used in integration with remote sensing technologies. GPS integration with GIS is being used very efficiently in mapping and modeling in Earth sciences. Damaged area where direct contact of monitoring system looks impossible, GPS is used for mapping of that area in integration with GIS because it has the capability to integrate image data into field data [2]. GIS needs very accurate data for better representation of geospatial data. GPS' ability to very accurate positioning helps to improve its functioning by improving the quality of GIS spatial data.

Figure 1 GPS receiver for monitoring of seismic activities [24]

3. REMOTE SENSING FOR MONITORING NATURAL HAZARDS

Remote sensing is data acquisition of remote locations through various techniques, where physical contact is very difficult or impossible. These techniques involve high resolution imagery through satellites, airborne remote sensing through scanners and Arial photography [7]. Remote sensing technologies are often used with Geographic information system (GIS) because users have to map remotely sensed data into visual representation. This system is being widely used for early warning system [12].

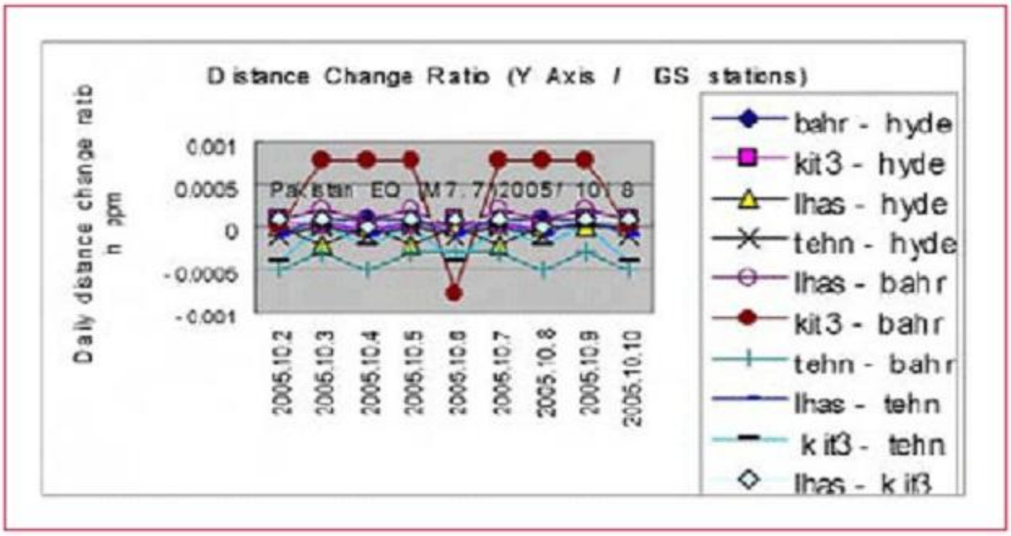

Figure 2 pre-event signals of Pakistan earthquake received at GPS receiver, employed by Geographic Survey Institute (GSI) in Japan [28]

Among all three remote sensing techniques (microwave, optical, infrared), microwave remote sensing is being widely use because of its range and penetration power. Normally it is not affected by clouds and other bad lighting conditions. It can detect very small deformation and vibration caused by some natural disasters like volcanic eruption, land sliding and Earthquakes. This remote sensing technique is used by Synthetic Aperture Radar (SAR) and Interferometric Synthetic Aperture Radar (InSAR), for 3D mapping of damages caused by natural disasters [12]. Other two types of satellite remote sensing are optical remote sensing and infrared remote sensing. Optical remote sensing is highly affected by daylight conditions and clouds. In such conditions optical remote sensing became almost invisible. But infrared remote sensors have capability to communicate even in bad atmospheric conditions [12, 1].

Remote monitoring of disasters whether before or after the occurrence of event is done at both scales; global and local. At global scale, tools used for satellite remote sensing for monitoring of E1 Nino and E1 Nina are MODIS and AVHRR. Typhonic activities can be monitor by meteorological satellites (e.g. GSM and GOES). Method applied for monitoring rain fall intensity at global scale is Tropical Rainfall Measurement Mission (TRMM).

At local scale, different satellite and airborne systems are employed for particular target event. Many tools of satellite remote sensing systems from space agencies and other commercial imaging sources like IKONOS, QuickBird and OrbView are being extensively used for their high resolution imaging capacity [1, 6].

In Airborne remote sensing, scanner is mounted in an aircraft. Difference between Arial photography and airborne remote sensing is image quality of land. Airborne remote sensing provides higher precision (20-30cm accuracy in elevation from the altitude of 1500 meters) than Arial photography [1, 3]. Airborne laser scanner or Lidar (Light Detection and Ranging) has the capability to display contour lines very clearly and its colored representations of slops and geomorphology can be used practicably for risk monitoring of land sliding. Lidar is also very useful for the mapping of coastal areas having flood potential [1].

Space-borne remote sensing can be divided into two types, meteorology and Earth Resources Satellites (ERS) remote sensing [3]. Hyperspectral imagery offers the measurements about earth structure like ground deformation, its composition, gases (CO_2, SO_2), its topography and modeling which is better suited to predict volcanic activities [6].

3.1 REAL TIME APPLICATIONS OF REMOTE SENSING FOR DISASTER MITIGATION

An Earthquake of magnitude 9.0 triggered a great Asian Ocean Tsunami which induced great damages of lives as well as resources. Victims of that Tsunami were more than 230000. SPOT 5 images were taken before and after the affected areas for comparison to assess the damages. Ground truth data was acquired through precise and clear images of IKONOS and QuickBird [14].

On 24th October 2004, a huge Earthquake strike against Niigata Chu-etsu Japan causing immense landslides in that area. Due to these landslides, physical approach to those places was difficult. To overcome that trouble, IKONOS images were used very effectively in link with Arial photography for the assessment of damages. Another earthquake on 8th October 2005 strikes the northern areas of Pakistan. This 7.6M earthquake caused 3 million people homeless. To find big faults and other losses details, QuickBird and IKONOS images (see figure 3) were used [1].

Figure 3 IKONOS imagery of Balakot after Pakistan-Kashmir earth quake of 7.6M [25]

On November 2000, due to heavy rains, a landslide occurred at Mount Mangart in north-western Slovenia. After continues heavy rains, these initially caused landslides changed into the debris flow which flowed away valued ground resources with it. Post disaster mapping of the damaged area and for finding the measures of slopes, elevations and terrain orientations a digital elevation model InSAR DEM 25 was used very effectively. Before the use of this digital elevation model, ERS and RADARSAT images were used to find humidity in that mountainous area. For land use mapping, LANDSAT and SPOT images were utilized in combination [15].

4. GIS ROLE IN DISASTER MITIGATION

With the rapid growth of digital spatial data, it is very important to have an efficient database. Geographic Information Systems (GIS) are satisfying this need very effectively [2]. GIS is used for mapping of environmental activities. It provides visual and easily understandable representations to find the relationship between the cause of any change occur in environment and its effect in that environment [21]. GIS is very often used in combination with other remote sensing techniques. It provides easy enough mapping of spatial data that even non-technical user can understand this mapping [12]. GIS not only provides the mapping and modeling of geospatial data but its use is going beyond due to its analytical capacity [17]. Due to this capability it is allowing emergency responders with decision making support. Main reason of adopting this GIS and GPS based integrated system by ambulance services, police, rescue and fire brigade system is also its emergency dispatch service [17].

Coastal area mapping for flood prediction, mountainous area mapping for volcanic activities and land sliding with image processing techniques [16] and also earthquake monitoring are some of applications of GIS in disaster mitigation.

4.1 Real Time applications of GIS for Disaster Mitigation

In developing countries of Asia, river flood give rise to great havoc due to Monsoon rains every year. Economy of most of those countries depends upon agriculture. These river floods ruin their agriculture every year. GIS help local authorities to develop efficient strategies against floods and also it has potential to estimate the probable damages due to river floods. Because of low cost and easy data acquisition, GIS are attracting those developing countries [18].

During the study about the great Tsunami of Asian Ocean in 2004, a method was discovered using the high resolution imagery techniques along with GIS. This method was used to quickly estimate the total damages caused by Tsunami disaster. According to that method, number of population exposed to the Tsunami was tried to discover. Method was called Potential Tsunami Exposure (PTE) which is strongly recommended by researchers to estimate the severity of next possible Tsunami disaster [19].

A GIS based system was used with SAR images and topography for mapping of affected areas of huge destructive flood in Regione Peemonte northern Italy in 1994. When loss estimation map was compared with the original map of local authorities, it shows 96% accuracy [20].

4.2 INTEGRATION WITH GPS AND REMOTE SENSING

GIS in integration with remote sensing and GPS is helping geomorphologists and emergency responders to collect, analyze, map and model the data about land activities specially within natural and manmade disasters context [13]. Both of these techniques are used for thematic mapping of natural disasters by integrating elevation data to predict the potential of probable disaster [8] and to estimate the post event loss.

Accurate mapping of water resources on ground is possible through GIS and remote sensing. This integrated system provides the distribution of water resources on Earth and save their state. Whenever any change occur in this distribution, this system alerts the emergency responders to take preventive measures of flood [21].
Figure 4 shows the GIS mapping of horizontal shift due to the recent earthquake of magnitude 8.9 in Japan.

4.2.1 GIS MAPS IN FUTURE

Organizations like Microsoft, Google and other such organizations have introduced the new patterns in modeling techniques. Also due to the addition of new satellites in remote sensing system, GIS maps or not only maps but intelligent three dimensional images [27]. Manmade and natural disasters can be efficiently predicted using such maps. Rescue service providers can find great help, when they would know where to go first for rescue measuring the intensity of hazard.

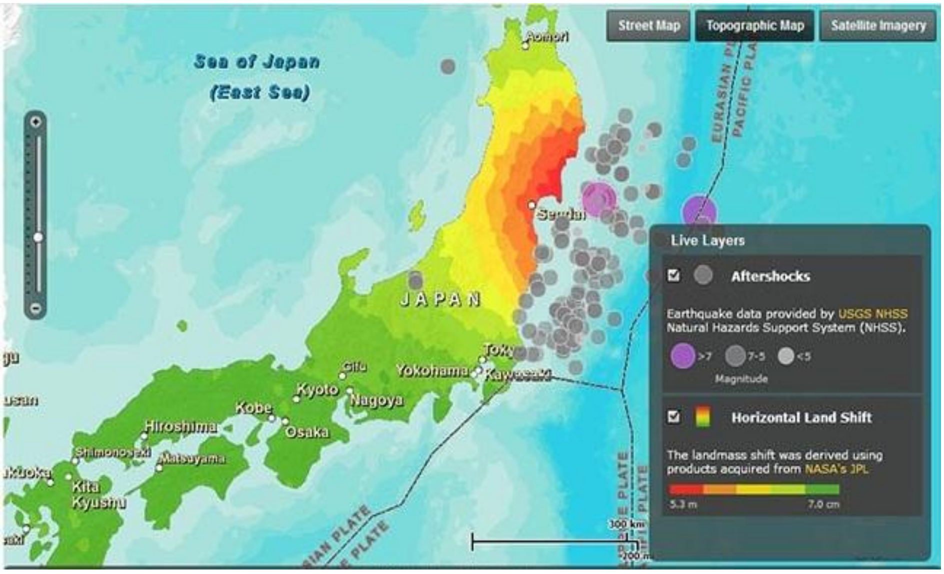

Figure 4 GIS map of horizontal shift due to Japan earthquake

5. CONCLUSIONS

- GPS is providing very efficient monitoring of damaged areas where physical contact is impossible or very difficult. Combining with GIS, it helps to quickly respond for natural disasters.

- GPS communicates with fixed wireless nodes in potentially unsafe area for advance warning system.
- Remote Sensing is spatial data acquisition through satellite, airborne and space-borne systems and Arial photography. Remote sensing is being done at both local and global scales using three techniques (microwave, optical, infrared). At global scale, for typhoons monitoring, GSM and GOES being used. For measurement of rain fall intensity, method applied is TRMM. At local scale, high resolution satellite imagery is used.
- Air-borne and space-borne remote sensing induced very widely in disasters management due to their very high precision. Lidar is playing important role as it maps shorelines and create digital elevation models very accurately, precisely and flexibly.
- Post disaster loss estimation of Asian Ocean tsunami was made through the comparison of before and after SPOT 5 images. Loss estimation of Pakistan earthquake and Niigata chu-etsu Japan earthquake was drawn using high precision satellite images (IKONOS). In case of Mount Mangart landslides, digital elevation model INSAR DEM 25 was used and for humidity measurements ERS and RADARSAT imagery was employed.
- GIS often used in combination with GPS and other remote sensing technologies for mapping of damaged areas. Due to its analytic ability, it is greatly adopted by emergency responders and rescue services providers.

GIS attracts developing countries of Asia, facing the huge losses due to Monsoon rains. Cause of attraction is its low cost and easy data acquisition. In Asian Ocean Tsunami of 2004, a Potential Tsunami Exposure (PTE) method was used to estimate the total loss and to predict the next probable disaster. A GIS based system was used in combination with SAR imagery for the mapping of huge destructive flood of Regione Peemonte northern Italy in 1994 with very high precision.

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