A Technical Survey of Various Methodologies for Landslide Susceptibility Mapping and Hazard Analysis

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Abstract— **The effect of landslide and its consequences always impact negatively on the inhabitants of a certain region or zone. The overall damage of socio- economic structure and loss of human lives always a matter of concern. Numerous approaches of landslide susceptibility mapping, hazard analysis have been developed and in most cases remote sensing, Geographical Information System (GIS) remains the core of the developed model. In this paper a detailed technical review of various satellite images and based on those inputs, developed methodologies have been discussed to draw and monitor general synopsis of the developed landslide susceptibility mapping and hazard analysis techniques and systems. Discussion on Various satellite image dataset of SPOT-5, MODIS, Quickbird, IKONOS, ALOS AVNIR, TerraSAR-X and use of software such as E-GEOs, GAMMA package, Geomatica, ERDAS Imagine etc. working on those datasets also been recognized. The importance of Image processing techniques such as Brovey Transform method, Smoothing filter-based modulation, Image Fusion, on such datasets have been illustrated. Change monitoring methodologies of a geographical region based on normalized vegetation index (NDVI) also been analyzed.**

Keywords- Landslide, GIS, SAR, TerraSAR, DInSAR, Interferogram, Remote sensing, LiDAR, Time series analysis, High Resolution images, QUICKBIRD, Image mosaic, NDVI, ERDAS, Analytic Hierarchy Process, Image Fusion

I. INTRODUCTION

Landslide is a disastrous natural incident which involves down slope mass movement of soil, rock, and glacier driven by gravitational force. Structural anatomy of a landslip has several features like scarp, toe, crown, bedrock, slip plane, rubble etc. Landslide refers to various types of mass movements such as debris flow, earth flow, mudflow, sturzstrom, and slump. Debris flow is a kind of mass movement of mud and rock under the influence of rainfall and melting of snow. Geological influences like slope instability, earthquake, erosion may cause landslides. Natural causes of landslip could be intense rainfall, snowfall, soil erosion, volcanic eruption, change in ground water level etc. Human activities also influence the occurrence of landslides such as deforestation due to industrial growth, use of vibratory machineries, pollution and mining. As a result of this natural calamity, economic situation becomes imbalanced. Economic rehabilitation in the landslide affected area costs a lot undoubtedly. Landslide also damages various infrastructures like buildings, skyscrapers, airports, metro tracks, in short, leading to the destruction of a city. It causes severe damage to communication systems. Loss of life cannot be treated in terms of monetary loss but something more than that. Geological anatomy gets affected greatly due to landslide phenomenon. Rivers change their flow direction causing waterlogged areas, thick sediments somewhere. Mountainous areas become either flat somewhere or unstable, dangerous and increasingly high steeps in other regions.

Towards the prevention of landslides to occur, various steps can be followed like prevention of deforestation, retaining walls, planting vegetation, prevention of soil erosion etc. In order to minimize this devastating after-effect of landslides, several detection procedures are in use to detect landslides prior to its occurrence. The most popular landslide detection is conducted by means of geotechnical measurements using field surveys. This geotechnical procedure involves experiment of various geological factors like soil moisture, rainfall, location of rivers, mountains, underground water etc. It is very costly in terms of both man power and economy because many geologists and geoscientists are needed for the experimentations and observations. Another variant of detection procedure makes use of some kind of sensor networks in some susceptible areas. Various real time monitoring systems use sensors to detect various parameters which greatly influence the probable occurrence of landslide. These sensor based networks are very helpful as it can be exposed to the area for always and can warn people before the occurrence of landslide. These are also economically cheap, instantaneous in nature and save man power. Another most challenging landslide detection procedure is performed using remote sensing techniques by means of aerial image processing. This is the most challenging task as it is solely dependent on satellite image processing excluding other geological factors from that particular field. Various semi automatic systems have been designed using this remote sensing technique to detect several landslide phenomena.

Various approaches have been followed towards the landslide detection phenomena using remote sensing. One of them is the landslide susceptibility mapping using remote sensing technique and data prior to landslide. This technique maps and indicates the most vulnerable areas or landslide-prone areas in the corresponding map. Another approach is based on the hazard analysis of post-landslide area which differentiates the greatly affected zones from that of minors.

Change detection is the key to the hazard analysis and risk management. Post-landslide monitoring via remote sensing is done in order to extract several features from a particular landslide so that these features could be used as a training dataset to train and classify various landslides in the near future. There are many automatic and semi-automatic landslide detection systems which not only use remote sensing procedures and imagery data only but also some other parameters and data for efficient and accurate results. Several algorithmic approaches like soft computing, probabilistic and statistical approach and geological approach have been used till today.

II. METHODOLOGY

In respect with input data patterns and analysis techniques the whole survey is segmented among two major parts,

1. Type of input data.

2. Techniques or methodologies applied on that data.

This is important because there remain various types of satellite images to work with and not all techniques or methods are applicable to each type of images.

1. Input Dataset:

TerraSAR data in present days, it is the latest trend to apply the technology, for detection and Monitoring of landslide prone areas, on the input images by the satellite TerraSAR-X in X-band. TerraSAR-X is a germen earth observation high-resolution RADAR satellite which delivers unique, novel quality SAR image data with a resolution up to 1m. This kind of data provides extremely geometric accuracy as well as radiometric accuracy. It has different imaging modes like SpoiLight, StripMap, and ScanSAR. TerraSAR data has many applications like on detecting surface movement, change detection, environmental application etc.

1.1 Method

So far we've got mainly two approaches of detecting the landslide prone areas on the basis of the TerraSAR-X images, PSI analysis and DInSAR time series analysis. The first approach is discussed in the paper of [1] by Mr. Silvia Bianchini and her fellow members, where the landslide prone area is recognized by means of ground movement using different parameters like PS (persistent scatter) Annual Mean Velocities, Deformation Time Series. Here the PSI (Persistent scatter interferometry) analysis is done on the input SAR data. The inputs are processed by E-GEOs by means of PSP approach (PSP-IFSAR analysis). .. Interferogram quality is strongly affected by temporal decorelation and atmospheric disturbances. Reliable deformation measurements can be obtained in a multi-image frame work on a small subset of image pixels, corresponding to stable areas. These points are called permanent Scatterers .Within the PS velocity a threshold range is fixed for classifying PS rates and for distinguishing moving areas from the not moving ones where the moving ones is considered as the landslide prone area. Now in the paper of [2] Fasil Beyene discussed about the second approach. It is told that rainfall induced soil moisture, pore-water pressure as the main reason for the occurrence of landslides. Here time series DInSAR techniques are used to estimate the surface deformation. DInSAR data is used to extract ground deformation when an insufficient number of SAR images are available over an area of interest. The two principle results of DInSAR analysis are:-Interferograms and Deformation map. Here the concept of Deformation map is discussed. .The main focus of this project is slope instability analysis over time and to observe the deformation phenomena in relation to the seasonal rainfall. A deformation maps highlights areas of ground affected by displacement on a continuous scale. A qualitative estimate of displacement can be calculated by unwrapping the fringers of an Interferograms. . 40 TSX / TDX images of the area of interest were taken during the whole year allowing 11 and 22 days of intervals in the months of rainy and dry season's respectively.392 Interferograms were generated using the GAMMA software package. To remove topographic phase from Interferograms the Shuttle Radar Topographic Mission (SRTM) with 3arc-resolution digital elevation model (DEM) and then the minimum cost flow algorithm (MCF) is used to unwrap the Interferograms. From the unwrapped Interferograms, displacement maps in the line of sight (LOS) direction are generated to conduct time series analysis. Finally the coherent pixels which fall in the site of landslide are systematically selected from coherent map in order to see the trend of deformation in profile curve.

2. Input Dataset

High Resolution Image High resolution means to have the capability of producing an image characterized by film details that is there are more pixels per square inch than the lower resolutions. As a consequence more detailed and sharp images can be got. There are various types of High Resolution images for example, Quickbird, Spot, GEOEYE-I, Rapid EYE etc.

2.1 Method

Remote Sensing: Remote sensing techniques provide observations of physical environment from instruments mounted on aircrafts or satellites. The instruments are not in direct contact with the objects under investigation. Remote sensing are of two types, Passive remote sensing which is based on detecting available electro-magnetic energy from natural sources like sunlight. Examples of passive sensors are film photography, infrared, radiometers; charged couple device etc. Active remote sensing depends on an artificial light source, like RADAR to illuminate the source. Examples of active remote sensors are: RADAR and LiDAR. Collection of data on dangerous and in accessible areas is possible by Remote Sensing. The software application by which the Remotely Sensed data are processed is known as Remote Sensing Application. Examples of some of the applications are Geomatica, ERDAS Imagine, ENVI, GRASS GIS and Google Earth etc. Some of the applications will be discussed in this paper.

3. Input Dataset

Single and Stereo satellite image.

3.1 Method

In the paper [3] the analysis for detailed landslide hazard using remote sensing techniques, has discussed on the input data like single and stereo satellite images from IKONOS Very High Resolution (VHR) Centre by Mr. Janet Nichol. IKONOS is the satellite by which large volumes of tonally balanced, map accurate, mosaicked imagery for a wide variety of applications are collected and delivered. For detailed landslide interpretation using single image, four image fusion techniques are used (IHS method, Brovey Transform method, Smoothing filter-based modulation (SFIM) method, and Pan sharpening (PCI Geomatica) method). Image Fusion is a technique by which a single highly refined informative image can be formed by combining the information of interest from two or more images of a scene with the help of certain algorithm. Image fusion is performed in three processing levels- pixels, feature and decision level. At pixel level merging of the measured parameters is done whereas at feature level extraction of objects recognized in various data sources are achieved and finally at the decision level where individually info extraction process of the input images are done. Image Fusion technology forms a rapidly developing area of research in remote sensing. The other applications of remote sensing are in medical diagnosis and navigation, digital cameras, computers etc. The visual and statistical analyses are investigated on the fused images. Generation of the DEM and the display of the IKONOS stereo model are achieved using Image Station digital photogrammetric, and ERDAS Imagine software. A DEM is a digital model or three dimensional representation of a terrain's surface, commonly for a planet (ex earth), moon or asteroid created from terrain elevation data. DEM can be represented by two ways, RADAR or primary way and Vector based Triangular irregular Network (TIN) which is a secondary way. DEM can be acquired through techniques such as Photogrammetry, LiDAR, and If SAR land surveying etc. Stereo model is a 3- D model. In stereoscopy the two given 2-D images are combined to form a 3-D image. The creation of a 3-D image and viewing it that is the real depth sensation using both of our eyes is enabled by this technique. Simplest method of viewing stereoscopic image is to look cross eyed at the image. Stereoscopy is different from displaying images in three full dimensions. ERDAS imagine is Remote Sensing application software which processed the remotely sensed data. To eliminate some positional bias and small rotations, GCPs from existing maps are used to calculate modified co-efficient of the model.

Technology used

Remote Sensing and InSAR technology.

In the paper of [4] mainly two types of technologies-Remote Sensing and InSAR are discussed in monitoring environmental disasters of mining cities in China by Yang Fan. The experiment has been carried out in several steps. Remote Sensing Monitoring in Land Dynamic Use Here, technologies of processing GIS spatial data is used by Landsat TM data and the movement information of land is extracted by processing and analysis software from the RS image(multi-spectral and multi temporal images). Interrelated software of GIS system (MAPGIS, SUPERMAP, ENVI, ER-DAS, etc.) is used to have images correct, register, inlay, multi-source data fusion, acquire change information, analyze and contrast to the former survey data of land change and then the fieldwork is instructed through the global positioning system to make data validation and verification and finally the work of land-use dynamic monitoring is completed. Vegetation Monitoring, the vegetation information is extracted from the hyper-spectral image as it has much higher spectral resolution than the previously used Landsat TM data and SPOT data. Monitoring of Harmful Gases, Presence of harmful gases can be detected by change in color, texture and dynamic signs in the input images such as dark color in infrared images. The other signs like decreases in tree canopy density and abnormal individual vegetation can also be analyzed for monitoring of harmful gases. Multi-Spectral imaging instruments are used to detect the changes in the polluted crop growth to the normal crop growth as well as the changes of vegetation on the ground due to groundwater pollution. Water Remote Sensing mining cities, Water pollution of mining cities is determined by calculating the gray values of the TM images. If the gray value of TM image data closely co-relates with the water pollution parameters, then the water is considered to be polluted. InSAR monitoring Used in Slope Deformation, InSAR stands for Interferometric Synthetic Aperture Radar. InSAR technology is used to generate maps of surface deformation or digital elevation using differences in the phase of the waves returning to the satellite or aircraft and geophysical monitoring of natural hazards can also be done by this technology. In this paper InSAR technology is used to get space surface deformation information. Technology of satellite Radar interference is used in open-pit slope observation.

Technology used

Remote Sensing and Spatial Analysis.

4. Input Dataset

SPOT-5 imagery, QUICKBIRD imagery, IKONOS and ALOS AVNIR-2 imagery, a wide, 60 km x 60 km area is covered by SPOT imagery and a full range of resolutions from 2.5 to 20 m for application on regional or local scales (1:000,000 to 1:10,000) is offered. A single SPOT image covers 3,600 km2. An IKONOS image efficiently collects and delivers large volumes of tonally balanced, map accurate, mosaicked imagery for a wide variety of applications. QUICKBIRD imagery provides 60 centimeter panchromatic and 2.44 meter multispectral imagery on a global basis. ALOS AVNIR-2 imagery provides 80 x 80 km complete coverage of the landslide affected area.

4.1 Method

In the paper of [5] different types of data inputs are taken before and after landslide, and then compared and analyzed by K.E. Joyce. SPOT-5 imagery is obtained before and after the landslide, QUICKBIRD and IKONOS images are acquired before and after the landslide respectively whereas the ALOS AVNIR-2 imagery is acquired a year after the landslide to evaluate the re-vegetation on the landslides. All the data are radiometrically calibrated to at-sensor radiance and a dark pixel subtraction is applied for atmospheric co-reaction in the absence of more comprehensive atmospheric measurements. In the whole procedure needs of different inputs are different. For example ALOS AVNIR-2 data is required for additional geometric processing to remove the sensor line staggering effect. The data were orthorectified using the supplies rational polynomial co-efficient (RPC) files, and a 10m digital elevation model (DEM) of the region. The QUICKBIRD data are subsequently co-registered, resample and subset to the same spatial dimensions as the IKONOS data, producing an image of approximately 10x10 km. Both the images are pan sharpened using the Gram-Schmidt method and all images are processed using ENVI/IDL software. After completion of different image processing techniques the spectral angle mapper (SAM) classifier is selected to provide the most accurate landslide map of the region using the SPOT-5 and ALOS AVNIR-2 data. Both pan sharpened QUICKBIRD and IKONOS images are viewed in Arc Map and landslides visible in the IKONOS image were manually digitized. All landslides are attributed with information on the basis of their age (new or old).A area is not considered as area of landslide if there is any doubt.

4.2 Use of NDVI

The normalized vegetation index (NDVI) is used to determine a threshold of values and mask water bodies from the QUICKBIRD imagery. Using a series of ISODATA unsupervised classifications, multispectral QUICKBIRD imagery is classified into three broad categories: woody vegetation, non-woody vegetation and non-vegetated. Summery statistics are calculated on the number and size of landslides, in addition to their relationship with land cover type, elevation, slope (DEM derived) and geology. The maximum slope for each landslide is derived from a 10m cell size DEM, which is lower in resolution of the imagery used for digitizing the landslides (pansharpened to 1m).

5. Input Dataset

ALOS/PALSAR dataset.

5.1 Method

In the paper [6], a way to model landslide propagation, specifically mud flow propagation has explained by the author Tomohito Asaka. Interest here lies on the propagation of a mud front on the ground surface depending on several constraints. Here, SAR interferograms are generated twice, a set prior to landslide and another set after the event. Then, geometric modification map could be drawn using the differential interferograms. Two main steps are involved here,

Interferometry Analysis, JAXA/SIGMA-SAR software is used to process PALSAR L1.0 data and DEM is created from ALOS/PALSAR dat.RGB Color Composite Image Using DEMs, The change detection is done on the pre and post images of landslides by assigning a primary color channel (red, green and blue)to pre and post DEM data. Landslide area can be detected by assigning SRTM-3 as red color and InSAR DEM data as both green and blue colors.

In the paper [7], NDVI subtractive method and band combination symbol coding method has followed by the author Lili Tang and her team for the purpose of pixel level change detection of an area affected by typhoon called “morakot” .Comparing images acquired before and after “morakot”. Preprocessing of the images include various operations. Images of pre and post landslide are both preprocessed, including image mosaicing, histogram matching, accurate registration, cutting and mask operation.Difference image is generated after the application of NDVI subtractive method and better result can be obtained by adjusting the change threshold repeatedly. Last step involves separation of different types and direction of changes and analyzed each types of changes quantitatively.

Technology Used

Assessing Image Processing(remote sensing)

6. Input Dataset

SPOT-5 satellite imagery.

6.1 Methodology

In the paper of [8] two input data(SPOT-5 imagery) one is before landslide and other is after landslide are collected and analyzed is done by K.E. Joyce for mapping landslide. Different methodologies are applied on the before landslide image and the after landslide image.Radio metrically correction along with an additional empirical line correction is performed on the before multispectral SPOT-5 image to spectrally calibrate it with the after multispectral data.For mapping landslide a number of data enhancements and information extraction routines are used including supervised classification (parallelepiped, minimum distance to means, spectralangle mapper(SAM)), single band image thresholding (Normalized Difference Vegetation Index(NDVI), Principal Component Analysis(PCA)), multi-temporal image differencing, and manual digitizing (color infrared and panchromatic).An area of interest (AOI) is determined where a variety of landslide sizes are present .Field survey is conducted in the AOI to manually map each individual landslide for comparison with the image classifications and use for accuracy assessment.

6.2 Method

Remote sensing Technique, Digital Landslide Technique High Resolution Remote sensing image (ETM+ data, ASTER 2 phases of aero photo and QUICKBIRD image), geographical control data including relief map and 178 GPS control points. in the paper of [9] mainly two types of technology-remote sensing and Digital landslide technique is discussed by the author Yang Ri-hong.Image Processing Technology, Image processing software of PCI and ENVI is used to process the remotely sensed data. The image is processed including geomatic precision correction, DEM registration, color matching and image mosaic etc.After Image Processing, The digital orthophoto map is formed which is vivid, transitional nature, highness harmonious contrast and reflect actual object. Method Of Interpretation, based on relief map and landslide the technique of digital landslide, 3D information system software(ERDAS and ARCGIS) is used to set up 3D diorama which can dynamic browse the surface of slope and the deposit of landslide from different altitude or angle. The characteristic of landslide is interpreted by the combination of 2D and 3D display window, and the result becomes much more credibility and higher precision. The main micro-geomorphologic features on surface of the slope and landslide features(displaced material, borderline, main scrap, verge scrap and slide step etc.) are extracted. Soma characteristics dots which can show their location before and after the landslide can be found from the aero photo and QUICKBIRD imagery. Its slip length can be determined by the connected length of the dots.

In the paper of [10] A. Stumpf has discussed mainly about three technologies, Active Learning, Spatial Sampling, Object Oriented Image Analysis.Image Segmentation And Feature Extraction, Image segmentation is performed on post landslide image with equal weights of the panchromatic and multispectral bands using the e-cognition’s multi-resolution segmentation with a scale of factor of 20.For each of the resulting objects 106 features (e.g. intensity values, band ratios, texture, shape, neighborhood relationships, topographic location) are calculated and the class(landslide, non-landslide) is assigned considering the overlap(majority vote) with the reference inventory.Active learning Approach, Query-by-Committee QBC strategy where the next sample is chosen to maximum disagreement of the ensemble, is followed by the Active Learning approach. A RF with 500 fully grown trees are adopted as a base classifier and the vote entropy is used as a measure of the classification uncertainty. Based on the notation of uncertainty, three approaches differing mainly in their query function are tested.Each time the region is queried with the highest standard deviation of the entropy thereby encouraging the presence of uncertain and diverse samples within the batch. Out of the m regions (m>1) with highest entropy, one with highest diversity is chosen. To compare diversity with the previous one Euclidian distance is computed.Final sampling region is chosen out of m candidates according to the maximum standard deviation of the Euclidian distance to favor both diversity within the batch and distinctiveness from the already known training set.The three approaches are compared in terms of accuracy gains (F-measure) per iterations and algorithm runtime average over 10 random seeded runs.

7. Input Dataset

GIS data and maps.

7.1 Method

In the paper [11], adaptive neuro-fuzzy inference system coded in MATLAB is used by the author J.Choi and his team for classification and decision making. GIS software tools (ARCGIS) are used for the manipulation of various GIS data and maps. Various maps like topographic, soil, forest and lineament maps were produced using GIS from raw data. The set of these maps constitute a spatial database. Several landslides related factors like slope, soil texture, wood type, lithology, and density of lineament were extracted from these maps generated by GIS software. The landslide susceptibility map is made using landslide susceptibility index (LSI) value for interpretation. The index is classified by equal areas and grouped into five classes for visual interpretation. Susceptibility to landslide is greater with the higher probability. Ultimately landslide susceptible area map and the factors are given as input to the ANFIS to output an extended landslide susceptibility mapping. ANFIS proved to be 84.96% accurate in identifying susceptible zone.

8. Input Dataset

MODIS data, SRTM data, data from Geological Atlas of China, data from The Institute of Soil Science, data from Chinese Academy of Science.

8.1 Method

In the paper [12], author and his team followed AHP (Analytic Hierarchy Process) algorithm for the multiple criteria decision making to produce an output map of vulnerability assessment map with the help of GIS using various inputs from various sources. This vulnerability assessment map included five levels of vulnerability named slight, mild, moderate, high and highest indicated using five different colors. The landslide factors evaluated from various databases are mainly of two types called quasi static variables and dynamic variables. The Quasi static factors are slope, fault zone, river, lithology, soil type and the dynamic factor is NDVI. The values of these factors are used in AHP for the decision making.

III. CONCLUSION

In this survey, the main objective was to identify which satellite images are generally used along with which methodologies. The progress on geographical or geological change detection based on images is also identified to help researchers to go beyond those known barriers.

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