Post Disaster Reconnaissance Studies of Landslides in India: Current Practices and Opportunities

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ABSTRACT

Recently, India has witnessed several extreme rainfall events that caused moderate to severe landslides. However, extreme landslide events and their impacts can be mitigated by implementing effective preventive measures and policies derived from well-documented reports. Systematic and efficient post-disaster reconnaissance practices coupled with imagery-based technologies are essential for collecting perishable data and detailed geo-disasters documentation. A review of the current practices that are being implemented globally for acquiring spatial-temporal information using advanced technologies is presented. To this end, research articles, reconnaissance, and social media reports of a few notable extreme landslide events, namely 2013 Uttarakhand India, 2015 Kfarnabrakh Lebanon, 2018 Hokkaido Japan Eastern, were summarized. The best practices for future landslide reconnaissance studies in India, including the benefits of methodically acquiring and archiving photographic imagery using mobile devices and cloud apps, are presented.

INTRODUCTION

An extreme event is defined based on two terms: occurrence and impact. Disaster studies are based on the hazard's impact, which explains the "extremeness" of the natural hazard (event) in terms of loss of life, destruction of property, loss of financial resources, personal injury, or illness, among many other factors. From another perspective, an event that opens up the new dimensions of learning and provides unique or particular opportunities to unravel scientific mysteries and prepare for future events can also be called "extreme events." Geotechnical disasters such as landslides, earthquakes, and climate change catalyzed events that satisfy the above criteria are termed extreme events. In India, excluding the permafrost regions in North India, about 0.42 million km^2 areas (12.6%) are landslide-prone. The Himalaya Mountain Range is the most seismically active segment of the Indian subcontinent, and landslides are common in the geo-dynamically sensitive belt. "Landslide hazard" is defined as the probability of occurrence of a damaging landslide event in a given area and a given time period (Varnes,1984). One of the significant challenges in managing landslide disasters in India, as identified by the Ministry of Home Affairs India, is the lack of systematic data. The data generated so far by researchers and practitioners are scattered and unconnected, making it challenging to manipulate, understand, and analyze the landslides.

Every disaster comes with certain learning opportunities because they can serve as laboratories for understanding the physical and social factors governing them. Much of the data generated by landslides are perishable (crucial and essential), and therefore, it must be collected within a few hours, days, or weeks of the event. In the recent past, significant developments and innovations are seen in imagery-based technologies, crowdsourcing apps, and instrumentation technologies that can generate significantly useful data for turning landslide disaster into knowledge (Rathje et al. 2006, Keaton et al. 2014 and Sarkar et al. 2017). Portable devices such as mobile phones and drones can be invaluable in disaster management and recording or collecting perishable data after an event. Thus methodical employment of these technologies for post-disaster reconnaissance of landslides can result in the preparation of well-documented reports for several purposes such as preparedness, mitigation, and management. Rapid deployment of first responders with portable technologies along with planned and organized scientific community visits are critical for post-disaster reconnaissance. In this context, the paper presents a review of imagery-based techniques and geo-characterization methods that have served as significant data sources for documentation and enhancing of geotechnical analysis of landslides. The current post-disaster reconnaissance practices worldwide and the associated achievements in systematic documentation leveraging the new ecosystem of advanced technologies are summarized below.

CURRENT PRACTICES FOR ACQUIRING SPATIAL-TEMPORAL INFORMATION AND POST- RECONNAISSANCE OF LANDSLIDES

In the literature review process, we followed a methodical approach to select papers related to "landslides," "post-reconnaissance," and "advanced tools." Initially, we searched in Google Scholar, ResearchGate, and Google with the three keywords and obtained 7,240 results. Afterward, we have primarily looked into published papers, social media news, resourceful websites that include reconnaissance reports of four notable extreme landslide events, namely Uttarakhand India Landslide (2013), Kfarnabrakh Lebanon Landslide (2015), Hokkaido Japan earthquake (2018), and Monsoon disaster in Kerala, India (2018)—intending to compare the reconnaissance approaches adopted in the different situations and to identify the best practices for data management and data archiving for the Indian scenario. Further, the articles that focused on imagery-based technologies and field surveys to document landslide events were targeted. This step led to a total of 50 different relevant articles. The summary of these papers is presented in the following sections.

IMAGERY BASED AND FIELD STUDIES IN LANDSLIDES

Imagery-based technologies such as satellites, LiDAR (light detection and ranging), UAVs (Unmanned Aerial Vehicles), and mobile /cloud apps are powerful tools for acquiring spatial-temporal information as discussed in Frost et al. 2018. The documented data of landslides is used for qualitative and quantitative analysis of geomorphological changes, the structural deformation of land areas, directional changes, frequency-area statistics of the mapped landslides, identification of damages, drainage patterns, debris flow, localized and large deformations, development of Digital Elevation Model (DEM) models of a specific location and collapsed buildings (Kosta et al. 2020; Babee et al. 2020). Yu et al. 2018 reviewed several papers related to imagery-based technologies and other data sources for disaster management and presented article distribution by technologies/data sources. Figure 1 illustrates a modified and updated version of the number of articles distribution by imagery-based and field investigation technologies. The additional papers relevant to the paper's context were reviewed to envision the usage of different imagery-based techniques such as satellites, ground-based LiDAR, UAVs, various mobile /cloud apps, social media, and field investigations in the landslide documentation, and only their references are included in the paper. It is evident from Figure 1 among imagery-based techniques during the 2014-2016 and 2018-2020 periods; the emphasis is placed on satellite-derived remote sensing methods because of the ready availability. It provides a near-real-time understanding of parameters such as lithology, structural geology, drainage morphometric information, hydrogeological conditions, relative relief, land use, and land cover. This macroscopic information can be used for understanding the broad view of the factors responsible for landslide failures and their impacts. On the other hand, for a more comprehensive understanding of the landslide damages, several researchers have focused on aerial photography/scanning methods such as UAVs (during 2015 and 2017-2020), airborne LIDAR, or ground-based LiDAR (during 2017-2020), which are capable of providing mesoscopic information such as construction of 3-D elevation/surface models for detection and identification of localized deformations, estimation of area and volume of involved mass, type of crack formations, slope profile delineation and lateral displacements. Airborne LiDAR mapping technology proved useful in documenting landslide inventories in the City of Zagreb (Gazibara et al. 2019). Fig. 1 also suggests that for a more detailed understanding of ground truth, many researchers have focused on field studies (during 2018-19) that include a combination of geophysical and geotechnical studies such as cone penetration tests, electrical resistivity tomography (ERT), drilling, and laboratory tests. A comprehensive analysis of their results can be used for understanding the geological structure and geotechnical parameters of the landslide. This microscopic information can be used to investigate the landslide stability through experimental (model) and numerical studies (Pasierb et al. 2019).

The other data sources, namely social media and mobile apps /GPS that provide disaster relevant information extraction, geolocation pattern/text/image analysis, visual documentation for qualitative assessment of damage, and dissemination of information (Dobhal et al. 2013) served as the most popular data for landslide documentation as shown in Fig.1. This platform usage has increased every year and peaked in 2015 and 2020 due to rapid developments in cellular technology/mobile technology. The innovative use of smartphones to record landslide damages resulting from the 2015, Kfarnabrakh landslide allow engineers to collect systematically and analyze observations carefully in a consistent manner.

Literature suggests that advanced imagery-based technologies, social media, and field investigations have become reliable data sources to document landslides at different scales and resolutions.

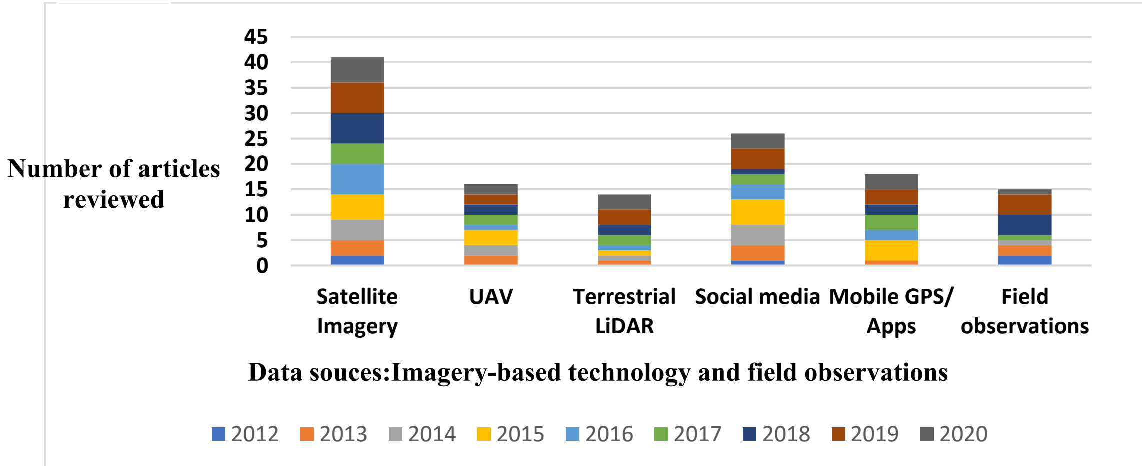

Figure-1 distribution of the number of articles by imagery-based technology and field observations data source for geo-disaster documentation, 2012–2020 (updated and modified from Yu et al. 2018).

NOTABLE EXTREME EVENTS RECONNAISSANCE DOCUMENTATION

2013 Uttarakhand Floods and Landslides

The 2013 Uttarakhand, India floods represent one of the most devastating natural disasters in history in terms of human impact, with an estimated 580 deaths and millions rendered homeless. The major landslides were observed in Pithoragarh, Bageshwar, Rudraprayag, Chamoli, and Uttarkashi. (Source: Disaster Mitigation and Management Centre (DMMC) and The Statesman dated 17.9.2013). This event was captured and documented through remote sensing satellite imagery-based methods (e.g., Cartosat/Resourcesat) by the Indian Space Research Organization (ISRO). Initial results of the Uttarakhand disaster were subsequently hosted in the National Remote Sensing Centre (NRSC) web portal (www.bhuvan.nrsc.gov.in). Other modes of documentation of these events were done by the Geological Survey of India (GSI)- the nodal agency for landslides studies in India. Typically they carry out field visits to document the impact and causative factors of landslide damages based on visual inspection and technical expert advice. This document is an inventory of 42 geo-parametric attributes of landslide incidences such as location, latitude, movement rate, depth, volume, and many more. A few researchers (Dobhal et al. 2013, Ray et al. 2016) have also visited the sites and documented them through onsite pictures, field tests, surveying data (GPS, total station). A detailed landslide inventory of this event was prepared using the integrated datasets of satellite imagery-based data and historical records (Marth et al. 2014).

Several researchers have used this available information to understand the different aspects of the event such as geomorphological changes, to compare and identify failure locations, and plausible causes of the landslide events (Dobhal et al. 2013), to map geomorphological characteristics (as shown in Figure2), monitor the catchment of glacier-fed rivers, and to identify potential river blockade areas, avalanches landslides, as well as lake formation and volume estimation by preparing digital elevation models at varying resolution (Ray et al. 2016). This study was able to assist with what went wrong due to determining which hazard turned into an extreme event, i.e., improper documentation, dissemination of event information was missing, inattentiveness of people at vulnerable locations, lack of eyewitnesses, mindless and unscientific constructions. Hence, the authors understood the localized failures, but detailed investigation, using advanced reconnaissance tools/technologies such as geotechnical characterization and quick field experiments was missing. With the inclusion of mobile data/ cloud apps for monitoring in addition to this imagery-based data; this event could have been well documented.

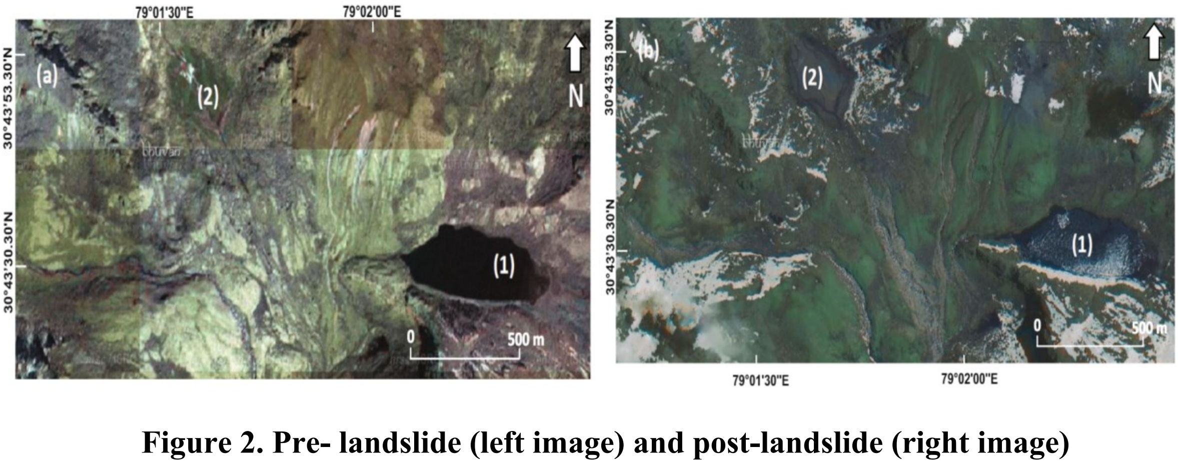

Figure 2. Pre- landslide (left image) and post-landslide (right image) satellite images for Kedarnath disaster (Ray et al 2016).

2015 Kfarnabrakh Landslide

On 30 November 2015, the mountain town of Kfarnabrakh, Lebanon experienced a significant landslide at one of the town's rock cliffs. This event was documented by Mohtar et al. 2016 on the basis of field observations, interpretation of satellite imagery-based data integrated with historical data, aerial photography (UAVs), and mobile data videos that effectively helped to observe the changes in water supply before the event, cracks, surface water runoff, and damage assessment. The video captured by local residents using mobile phones was also used as essential information to observe the displacement of the rock mass and its failure mechanism, as shown in Fig.3. The author claimed that the methodical approach of documentation would help in future preparedness. It can be used to provide adequate information for assessing the causative factors, localized failures, and future risks.

Figure 3. Snapshot from a video of landslide showing a lateral displacement of the rock mass with a gap created between it and the stable ground, Kfarnabrakh landslide (Mohtar et al. 2016).

2018 Kerala Landslides

During August 2018 in Kerala, India, the incidence of incessant rain happened which led to an unprecedented number of landslides in three districts: Idukki, Wayanad, and Thrissur, which caused a death toll of about 500 people, while 1.25 million people were displaced, and around 20,000 houses seriously damaged (Source: Kerala floods assessment report by Sphere India). The documentation of this event was primarily based on field observations (Kanungo et al. 2020) and geotechnical in-situ tests (Oommen et al. 2018), satellite-based imagery, and Google Earth mapping technology (Hao et al. 2020) to construct a landslide inventory.

Oommen et al. 2018 used satellite images to identify and verify the size and locations of landslide failures. For the analysis of localized deformations, 3D scanners were deployed, and post-processing of the scanned photos was done to develop 3D models, as shown in Figure4. The field observations and investigations were also carried out to determine geotechnical properties, slope profile delineation, and fragile areas. The detailed macro to micro information of the event helped assess the different damages and their distribution effectively.

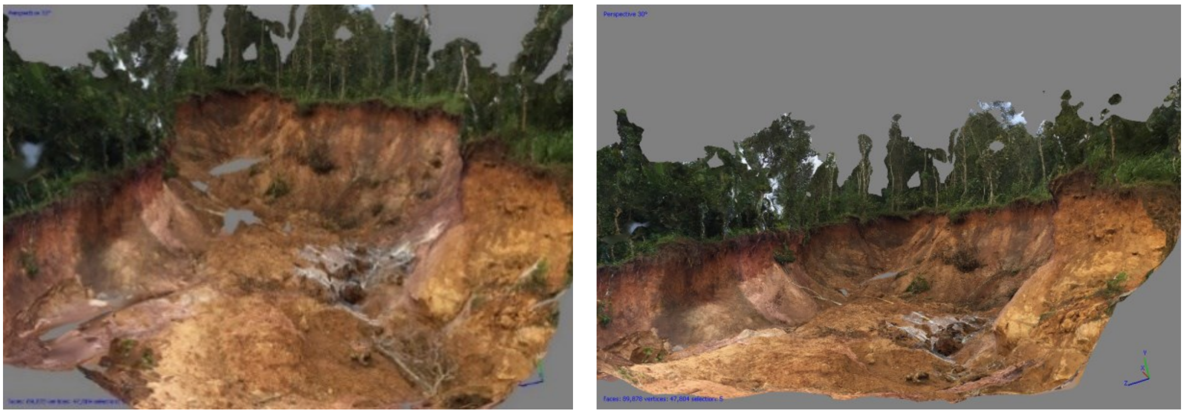

Figure 4. Three-dimensional reconstruction of Kattappana Landslide using Photoscan. (a) left side isometric projection, (b) right side isometric projection. (after Oommen et al. 2018).

2018 Hokkaido Eastern Earthquake Induced Landslides

The Hokkaido Eastern Iburi, Japan earthquake that occurred on 6 September 2018, with moment magnitude,M_w, 6.6 triggered several landslides and crippled multiple industries and public facilities in the region. Kayen et al. 2019 conducted a reconnaissance survey from 27 September to 3 October 2018 and combined traditional reconnaissance activities of on-ground mapping of field conditions with advanced imaging and damage detection routines enabled by state-of-the-art geomatics technology. Structure from Motion (SfM), which is one of the innovative geomatics technologies was used to develop the UAV-SfM model of the study area (over approximately 10^2 km), as shown in Figure 5, to determine the localized damages. The field observations and investigations were carried out to determine the geotechnical parameters for characterization, slope stability analysis, and document geomorphic evidence of pre-existing failures. The vehicles used for the field visits were equipped with smartphones, digital cameras, maps, computers, and GPS units to record tracklogs and site locations. Further, this information was merged into a common database to generate dynamic digital maps using Google Earth to preserve displacement and damage data. The authors demonstrated the importance of this documented information for a detailed understanding of geotechnical failures and their impacts. Also, they emphasized the usefulness of this well-documented data for future preparedness.

Figure 5. UAV-SfM model of the Yoshino landslide complex (after Kayen et al. 2019).

OPPORTUNITIES AND BEST PRACTICES FOR SMART RESILIENCE IN INDIA

In India, on 5 February 2014, GSI launched the macro-scale (1:50,000) National Landslide Susceptibility Mapping (NLSM) program intending to cover the 0.42 million sq. km landslide-prone areas of the country. Lately, GSI focused on upgrading this landslide mapping from macro (1:50,000) to meso (1:10,000) for higher resolution information. The primary sources of data involved in the preparation of macroscale and mesoscale maps are geologic maps, satellite imagery, historical records, and toposheets. These maps primarily focus on geological aspects of landslides and barely consider other disciplines such as geotechnical engineering, engineering geology, and earth science. To address this issue, GSI initiated one more project focusing on the development of site-specific landslide mapping based on microscale (1:2,000) information that relies on published literature/reports, high-resolution remote sensing, geographic information system (GIS), drone-based technologies, detailed field visits, and investigations. This emphasizes the importance of reconnaissance studies of landslides through advanced technologies for generating high-resolution data. Geotechnical Extreme Events Reconnaissance (GEER) actively coordinates with geo-researchers worldwide to form effective reconnaissance teams and work effectively with organizations of different disciplines to capture perishable and other vital data from a disaster event. GEER reports demonstrate best practices and methodical documentation of an event by vertical integration of macro, meso, and micro information (2018 Kerala floods, 2015 Kfarnabrakh Landslide and 2018 Hokkaido Eastern Iburi Earthquake Induced Landslides) and its usefulness in damage assessments resulting from landslides, future preparedness, and early warning systems. GSI can adopt similar approaches to generate very high-resolution data for detailed failure analysis and document the same to preserve it for future studies.

In India, practice and approaches for collecting perishable data after an event are not fully established yet. Typically, post-reconnaissance studies by nodal agencies or geo-researchers are carried out only after the subsidence of landslide activity. This time delay leads to the possibility of loss of perishable data. The most reliable and possible way to record this data is by integrating portable devices such as smart mobile phones (capable of providing high-resolution images or stereo images, 360 pictures, videos, and static pictures) to the first responders, which can help in automatic geotagging of image/video (Mohtar et al. 2016) with GPS coordinates and bearing/direction (Information Technology & Services (2018) Filio app, https://www.filio.io/(accessed 20-10-2020)). The number of smartphone users in India has increased from 220 million in 2014 to 697 million in 2020 (Asher, V.,2020). Smartphone users in India 2015-2025, <statista.com> (accessed 29-10-2020). Thus, fast, efficient, user-friendly, and multi-platform compatible software/apps are urgently needed to generate a plethora of microscale data. Exploiting crowdsourcing techniques and archiving videos and images of an event posted on social media by locals may significantly help post-reconnaissance documentation of perishable data. The integration of such practices can help in effective documentation of extreme landslide event

Adopting such practices (imagery-based data coupled with field investigations) leads to systematic and efficient post-disaster reconnaissance documentation. It can serve as a guidebook for the response, and relief mechanism through proper mapping, formulation of mountain zone regulations/policies, and stabilization and mitigation of problematic landslides in India. As emphasized in National Landslide Risk Management Strategy (NLRMs 2019) document prepared by National Disaster Management Authority, Ministry of Home Affairs, Government of India.

CONCLUSIONS

The importance of imagery-based data obtained from remote sensing techniques at three different scales (macro, meso, and micro) of infor mation from post-reconnaissance studies of landslide events is significantly recognized worldwide among all geo-researchers. The demand for site-specific mapping and a clear understanding of landslides has increased globally. Therefore, more emphasis is placed on meso and micro-scale imagery-based data generated from UAVs, ground-based LiDAR, social media and field data. However,in India, most of the post-reconnassiance reports are developed based on satellite, onsite non geo-coded imagery data, and preliminary data obtained from field visits. Based on the review of extreme events documentation and its usefulness, it is understood that the best practices of post reconnaissance studies such as done by the GEER Association for some of the events such as the Kerala 2018 floods and Hokkaido Eastern Iburi Earthquake. This indicates that the best practice should include the collaboration of different disciplines and timely collection of the perishable and non-perishable data and imagery-based data coupled with field investigations. Also, deployment of first responders with portable gadgets such as mobile phones with appropriate apps and drones can be crucial in disaster management and collecting perishable data of the event that could help in data management and data archiving. In this context, India has more potential in crowdsourcing as there is rapid increase in the number of cellular users since 2014. Post disaster reconnaisaance studies have historically often included collection of data set with little knowledge of underlying metadata.

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