Int. J. Econ. Environ. Geol. Vol. 10 (4) 30-34, 2019

Journal home page: www.econ-environ-geol.org

Open Access

ISSN: 2223-957X

Landslide Hazard Risk Assessment and Landuse Planning of Mayoon, Hunza, Gilgit-Baltistan, Pakistan

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Received: *07 October, 2019* ***Accepted:*** *23 December, 2019*

Abstract: Gilgit-Baltistan, Pakistan is highly vulnerable and hazard-prone area according to National Disaster Managerment Authority, based on frequency of avalanches, landslides, glacier lake outburst floods, rockfall and flash floods. These hazards have been quite frequent since 2010, potentially due to changing climatic conditions and unique tectonic setting resulting in massive destruction, economic loss and human migration. In this study, geospatial techniques (GIS/RS) were used to identify landslide hazard with elements at risk. The resultant maps will be used for better planning and resilience of local communities. Landslide area has been marked based on field observations (GPS data). Risk category is ranked high, medium and low based on field observations, geological setting and historical landslide data. There are six offshoots of MKT crossing parallel to each other along KKH from Chalt to Ahmadabad. Chalt fault is crossing nearby the Mayoon landslide, which may affect the entire valley. This study identifies landslide as a major hazard in the area.

Keywords: Climate change, landslide, GIS/RS, risk, main karakoram thrust.

Introduction

Pakistan is located in one of the most active tectonic regions of the world and includes the western part of the Himalayan plate boundary between Indian and Eurasian plates. The plate boundary involves some of the world's most spectacular mountain ranges, including Karakoram, Hindu Kush and Himalayas in the north. The country especially northern areas have experienced many landslides and earthquakes in the past and are prone to such geological hazards because of the active plate tectonics (Varnes, 1958).

Gilgit-Baltistan has been categorized by National Disaster Managerment Authority, as the most vulnerable area for avalanches, landslides and flash floods. In this study as geospatial tool (GIS/RS) was used to map existing hazard, risk and vulnerability map of Mayoon village, Hunza. The study is aimed to reduce risk through proper land use planning and build/suggest resilient house designs for local communities. Hazards will be identified, ranked and risks based on primary data collected from field and secondary geological and historical data obtained for hazard-risk assessment.

According to seismic micro-zonation of (Pakistan Building Code (2007), the study area falls under seismic zone-3 with Main Karakoram Thrust posing seismic hazard. Heavy rains with thunder lightning are the primary cause of landslide, where the mountain edges are steep, which triggers the activity. According to risk classification, 100% of the village comes under high risk category. Although socio-economic conditions are good but unwise land use without implementing building codes, is common.

Landslides are a natural phenomenon involving the movement of earth materials (soil/rock) on different scales varying from small insignificant rock falls to massive displacement of materials producing catastrophic effects (Varnes, 1958). Slope movements occur in the following ways i) by detachment of rock as rockfalls ii) by shear failure on existing large-scale geological surfaces and iii) by gradual adjustments on microscopic scale or creep.

The Mayoon landslide is in the Hunza district, located at a distance of 65 kilometers from main Gilgit town (40 km aerial distance north of Gilgit) between longitudes 74°24.7' to 74°25.9' and latitudes 36°14.3' and 36°14.75' (Fig. 1). The area comprises of 120 houses, five shops, two schools and one Jamat khana. The study area falls in Karakorum block, which comprises of low to medium grade metamorphism, from west to east. The metamorphic grade is gradually increased due to continuous movement of Indian plate drifted island arc to northward, which may cause collision zone between Eurasian plate with Kohistan island arc, known as Main Karakorum Thrust (Gaetani, 2016). There are six offshoots of MKT crossing parallel to each other along Karakoram highway from Chalt to Ahmadabad (Fig. 2). Chalt fault is crossing near the Mayoon landslide, which may affect the entire valley. Due to proximity of major tectonic features, the rocks are highly foliated, folded and fractured

(Thiebes, 2012). Local faults are common with minor displacements. Past strong motions have shaken the highly fractured rocks and caused opening of joints. The study site generally comprises of slate, phylite and schist with lenses of underlying ultramafic rocks. The rocks at places are intensely folded and fractured that are behaving as soil (Hungr et al., 2014). The face of the earth is continuously shifting, influenced by the process called plate tectonics (Khan et al., 2009).

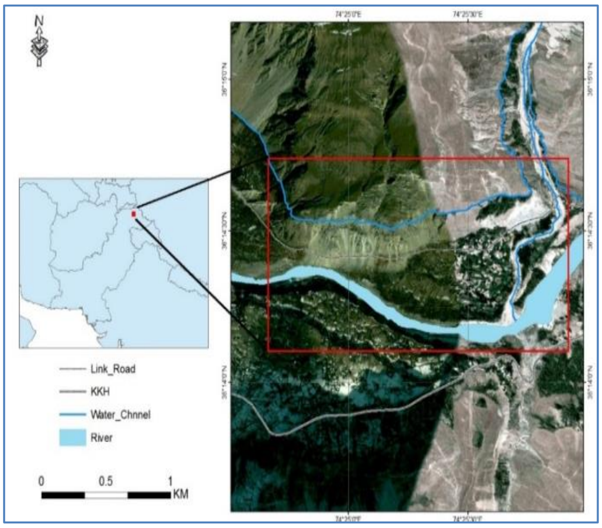

Fig. 1. Map of Mayoon village, Hunza (Gilgit-Baltistan).

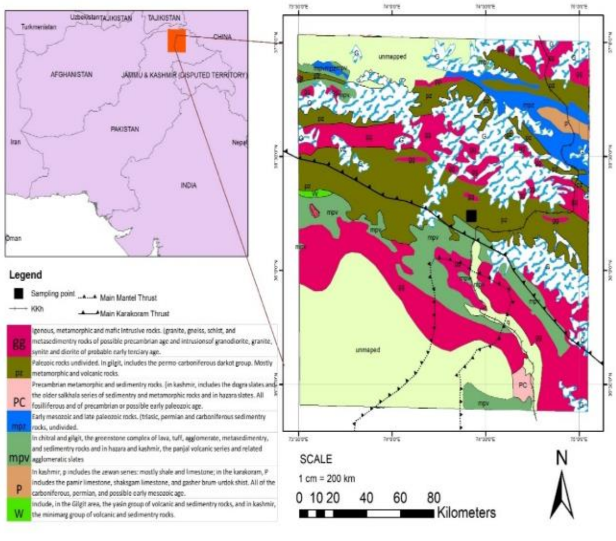

Fig. 2 Geological map of Mayoon village, Hunza, Gilgit-Baltistan (Khan et al. 1964).

Materials and Methods

Community-based hazard vulnerability risk assessment (HVRA) conducted to acquire indigenous knowledge about hazards and disaster history and their frequency through questionnaires and key informant interviews. Two significant risk categorization data layers will be incorporated into GIS to produce maps for the following layers: a) Hazard layers were covering landslides, flash floods, seismic zones, fault lines, avalanches and erosion etc. b) Typical layers were covering infrastructure, settlements, rivers and drainage etc. (WWF-P, 2011).

Hazard and risk assessment process consists of 3 stages, such as offsite preliminary assessment. Before onsite assessments using satellite images, base maps for a specific location/village were developed. Some primary data i.e. size of the village, altitude, access roads and general topography were marked on the base map. The demarcation of activity and living zones were developed (Hungr et al., 2014). The onsite assessment which included geo-hazard assessment, participatory risk assessment (PRA), data consolidation and analysis. After geo-hazard assessment and PRA, all the data were compiled and consolidated in geo-database for preparing GIS maps (Blackburn and McClure, 2009).

Following are critical steps for assessing a potential landslide, which observes cracks and overburden/rock outcrop by measuring its dimensions (length and width) with range finder/measuring tape and orientation by compass. Similarly, cracks are observed, if present or developing on the infrastructures. Its width was measured and directions were marked by compass and presence of water springs and other water sources at the head or the toe of the landslide were also observed. The erosion was recorded along the toe of the landslide with measurement of the slope angle and direction as well as geology (rock structure and geomorphology) of the study area. However, the historical data of past events (frequency) and damages (magnitude) from the community were also collected through interviews and by demarcating hazard zones, or mark different classes on the base map through range finder, GPS and Compass.

Field surveys were conducted to collect the Global Positioning System (GPS) based sampling points for mapping the different hydro-meteorological related hazard classes. Furthermore, geological data will be collected simultaneously for identification of hazard-prone areas in the study area. Some of the selected coordinates were also used to assess the overall accuracy of the output maps (Malet et al., 2002). To develop hazard risk maps, landsat satellite images were used to delineate each active landslide area to quantify the risk factor analysis. Initially, all satellite images were processed to apply on all the datasets before the assessment of landslide boundary. Available literature about the past trends of impacts and frequency of natural disasters were reviewed. Climatic data were acquired from Pakistan Meteorological Department and geo-coded to develop a weighted layer. Besides, layers of historic and current disasters with spatial extent, intensity and frequency were also developed (Focus, 2010).

Results and Discussion

According to hazard vulnerability and risk assessment tools, there are 120 houses with an average of 8 persons in each home. About 90% of them are living permanently in the village and 90% of people are above the poverty line. Whereas, 100% children are regularly attending the school and 100% of people have excellent sanitation facilities. People of Mayoon village are working in diversified fields like agriculture/livestock, labor, small-scale businesses and other services. About 10% of people are independent of primary sources of livelihood, 5% have life insurance coverage and no one has medical and asset insurance coverage. In the village, there is emergency response kit available for post-disaster, but there is no heavy machinery to clear out road and rubbles. The food insecurity was experienced in the past making village inaccessible to motor vehicles in spring of 2012. The closest medical facilities are at about one hour distance from the village and administrative centers. There are 80-90% of structurally vulnerable households. Focus humanitarian assistance conducted awareness seminars and community was informed about evacuation routes and mock drills were carried out to reduce the risk. Extensometers and automatic weather stations were installed along the cracks and in the village respectively for early warning systems.

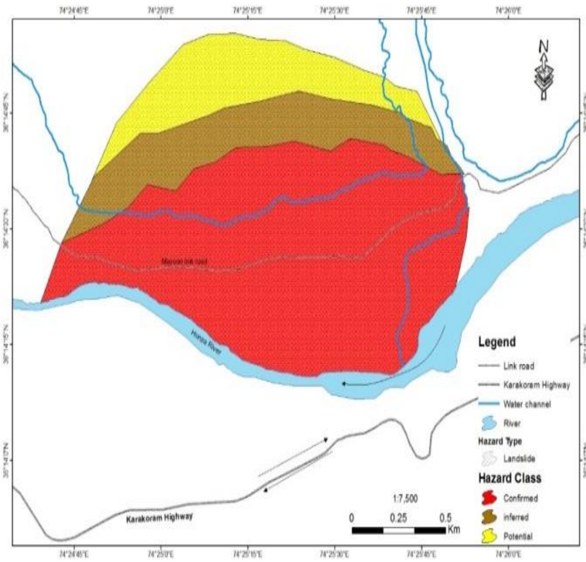

Fig. *3*. Hazard map of Mayoon landslide (Hunza valley) with different levels of hazard.

For disaster preparedness adequate (community emergency response team (CERT) volunteers were trained or refreshed, whereas Village Disaster Management Plan (VDMP) was also developed in the village during last three years. On-field observation the Mayoon landslide is confirmed hazard because there are visible open cracks, tilted trees and cracks alongwith seepage in the structure. The type of slide is deep-seated, rotational slide on the top and translational slide in the bottom and erosion due to river on the western side of the slope. During fieldwork, it was observed that the rocks above the water channel are very fragile and highly brecciated due to overburden of slope. At the top of the slope, there is a rotational landslide on a glacial, fluvial deposits while below the water channel, the slide is rotational because there is no movement at the eastern side of the slope. On the western side, the movement is visible in which water channel is moved about 20 to 60 feet downward and trees are tilted due to movement in the slope. On the main scarf, several cracks are parallel to each other in a sequence. The ratio of the visible cracks is between 2 to 14 feet. The primary crack is about 4.27 meters wide and 40 to 50 meters in length. These cracks are formed due to movement of the block, which may cause the instability in the naturally occurring slope. On the center top of the slope, there is Nallah in which the seepage is visible. During intense rainfall, the water directly seeps into the cracks which may cause the instability of the slope. The angle of the slope is about 60 to 80º. GPS points were taken along the cracks for plotting on the risk map in ArcGIS.

Mayoon faced many landslides in the past years. According to the villagers, the first landslide occurred in 1976, which destroyed 100 canals of land, agricultural land and forestry land of the area. Rockfall occurred due to collapse of scarf in 2010, which demaged agricultural, forestry and settlements in the area. Failure of scarf occurred on eastern end in 2011, damaging link road, irrigation channels, cattle sheds, water tanks and orchards. In 2012 minor landslide at western side damaged two main irrigation channels (water supply to Hussainabad village), link road, crop land and social forestry (plantation and crop). Eastern side of the village faces rockfall in raining season and especially in winter.

Mayoon village covers relatively a small area of 600 m^2, but it poses significant threat for the Mayoon village in the valley due to movement of overlying material. Landslide area covers about 1874.33 km^2. Hazard is classified into three types based on field observations, confirmed, inferred and potential. The red color indicates confirmed, brown indicates inferred and yellow indicates potential. It is a rotational landslide on the top of the slope, while translational on the bottom of the slope and active landslide affecting people, their houses and livestock. Heavy rainfall and snow in winters can trigger a large portion of landslide. The area is characterized by steep slope, rock falls and tension cracks. It lies in an active fault zone and there is a possibility of triggering landslide as a result of seismic activity. The rocks are very fragile, overlain by non-plastic silty sand. The valley is irrigated by a water channel, where a part of the channel is open and in rest water is supplied by PVC pipes. The water seeps down the soft sediments and rocks, where the channel is open and as a result, there is a noticeable soil movement and rockfall. The area below the PVC pipes is relatively stable. All the settlements and facilities are at high risk according to hazard. Risk is divided into three classes, high, moderate and low (Fig. 4).

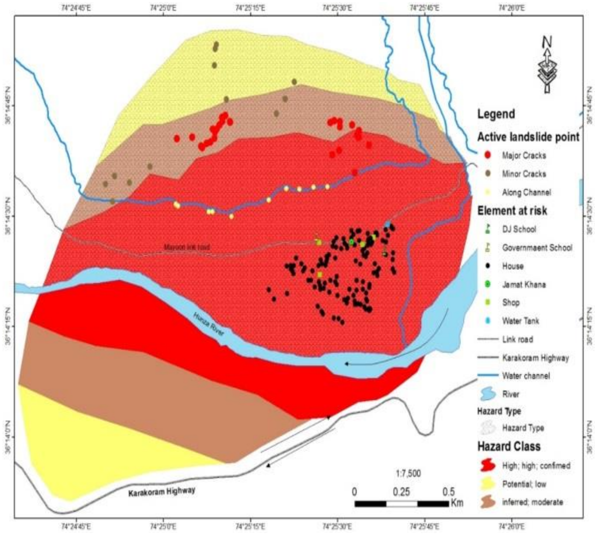

Fig. 4 Risk map with hazard classes (element at risk) of the Mayoon landslide, Hunza valley.

In the red shade, the black dots indicate the houses, while green and yellow flags indicate school, yellow square and blue color indicates shops and water tank respectively. In brown shade, the red dots are significant cracks. On the main scarf, brown dots in the brown and yellow zone show minor cracks.

The entire valley is in the high risk, but some areas are highlighted and mentioned in the inferred and moderate risk and about 80% area was covered during the field work (Fig. 5). Cracks on the main scarf are widened and new cracks are formed at the top of the main scarf, which are parallel to each other. The width of cracks on the main scarf ranges between 2-14 feets. If land sliding is triggered in case of ground shaking or intense rainfall, the entire village is in high risk as well as the opposite side of the village is also on high risk in some areas, which are close to the bank. It is recommended that no new infrastructure is built at that location.

Focus Humanitarian Assistance had done a detailed investigation on Mayoon landslide in 2015 by

Fig. 5 Field snap short of study area (A. Indicating direction of scarp, B. Measurement of major scarp, C. Indicating scarp extant and D. Measurement of minor scarp E. Village snapshot near from extensive meter).

conducting topographic and geophysical surveys and geotechnical investigations. The topographic survey using total station provided useful results for generating surface terrain model and calculating slopes in the area. However, for high-resolution survey (<5m contour interval) encompassing the whole landslide area, a detailed geotechnical, geophysical and topographical site study was carried out, followed by analysis of available data by Focus Humanitarian Assistance. At Mayoon landslide area, the bedrock layer was identified at depth of 4-9m on two profiles, while it was not clear on most of profiles. The cracks observed on the ground surface extend up to 6m depth, but no cracks have been observed in the bedrock in all GPR sections.

Conclusion

It is concluded that the Mayoon village is at high risk which will be affecting entire valley in terms of both up and downstream. The results of this analysis (hazard risk assessment) should therefore be considered and incorporated into future landuse planning and timely evacuation of the living population of mayoon into safer areas. Similar studies should also be carried out in different parts and villages of Hunza valley.

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