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Review

A review of the 2005 Kashmir earthquake-induced landslides; from a remote sensing prospective

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ABSTRACT

The 8th October 2005 Kashmir earthquake, in northern Pakistan has triggered thousands of landslides, which was the second major factor in the destruction of the build-up environment, after earthquake-induced ground shaking. Subsequent to the earthquake, several researchers from home and abroad applied a variety of remote sensing techniques, supported with field observations, to develop inventories of the earthquake-triggered landslides, analyzed their spatial distribution and subsequently developed landslide-susceptibility maps. Earthquake causative fault rupture, geology, anthropogenic activities and remote sensing derived topographic attributes were observed to have major influence on the spatial distribution of landslides. These were subsequently used to develop a landslide susceptibility map, thereby demarcating the areas prone to landsliding. Temporal studies monitoring the earthquake-induced landslides shows that the earthquake-induced landslides are stabilized, contrary to earlier belief, directly after the earthquake. The biggest landslide induced dam, as a result of the massive Hattian Bala landslide, is still posing a threat to the surrounding communities. It is observed that remote sensing data is effectively and efficiently used to assess the landslides triggered by the Kashmir earthquake, however, there is still a need of more research to understand the mechanism of intensity and distribution of landslides; and their continuous monitoring using remote sensing data at a regional scale. This paper, provides an overview of remote sensing and GIS applications, for the Kashmir-earthquake triggered landslides, derived outputs and discusses the lessons learnt, advantages, limitations and recommendations for future research.

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1. Introduction

The Kashmir earthquake (8th October 2005) was the most devastating natural hazard, in the history of Pakistan, killing about 90,000 people, leaving millions homeless, and causing economic loss of about 5 billion US$ (ADB and WB, 2005). One of the distinct characteristics of the Kashmir earthquake, were the widespread slope failures, mostly along the Neelum, Jhelum and Kunhar valleys (Fig. 1). The Kashmir earthquake-induced landslides were spread throughout the affected area of >7500 km^2 (Owen et al., 2008) and resulted in ~1000 direct fatalities and many more indirectly (Kamp et al., 2008).

1.1. Earthquake induced landslides

Earthquakes are recognized as one of the major triggers for landslides. Earthquakes in a rough terrain can produce hundreds to thousands of landslides in a short time that can have devastating impacts on human lives and economy. Earthquake-induced ground shaking, causes short duration disturbances in the balance of forces, in a slope that eventually leads to slope failure. Intensity and spatial distribution of earthquake-induced landslides is influenced by the earthquake magnitude, causative fault characteristics, site specific amplification of seismic shaking and variation in physical, meteorological, topographical and anthropogenic factors (Gorum et al., 2013; Jibson et al., 2004; Meunier et al., 2008, 2013; Parkash, 2013; Sato et al., 2007; Sepulveda et al., 2005; Tatard and Grasso, 2013). Amplification of earthquake-induced ground shaking attributed to topography, soil and impedance contrast also trigger landslides (Bozzano et al., 2008; Harp and Jibson, 2002). Physical factors comprised of underlying geology, which determine the magnitude and material of landsliding, and topographic attributes like elevation, slope, curvature, drainage and aspect of terrain, control the frequency and spatial distribution of landsliding (Gorum et al., 2011; Kamp et al., 2008; Korup, 2010). Meteorological factors comprised of climate, magnitude and intensity of rainfall control the temporal occurrences of landslides. Anthropogenic factors include deforestation, excessive grazing and toe-excavation of slopes for roads, houses, mining or construction material. Evaluating the impact of these seismic, physical,

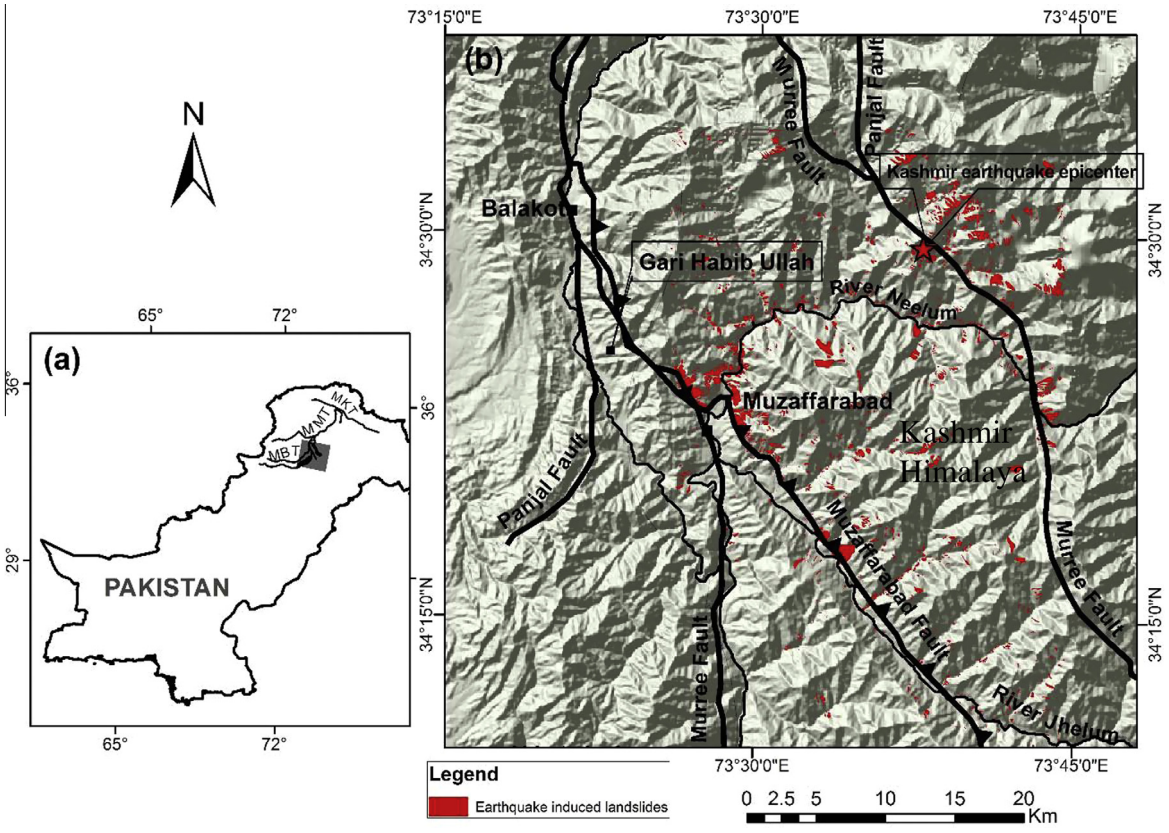

Fig. 1. Simplified tectonic map of the study area (northern Pakistan). NNW trending fold is defined as the Hazara-Kashmir Syntaxis, which refolds the major thrusts including the Panjal Thrust (PT) and the Main Boundary Thrust (MBT). Muzaffarabad Thrust, the causative fault of the Kashmir earthquake cuts across the core of the syntaxis and joins with the PT-MBT at the western margin of the syntaxis (after Searle and Khan, 1996; Hussain et al., 2009). The Kashmir earthquake induced landslide inventory is after Basharat et al. (2014).