

SOCIAL SCIENCES

Wealth and land-cover change govern landslide fatalities on world's mountains

Seçkin Fidan^{1,2*}, Tolga Görüm², Abdullah Akbaş³, Bikem Ekberzade², Ugur Ozturk^{4,5}

Despite the common perception, most fatal landslides occur in human-transformed environments. Even on steep terrain, anthropogenic disturbances may fundamentally modulate landslides. Most of our knowledge regarding landslide-human interaction is restricted to local models or regional heuristic assessments based on empirical evidence. In this study, we used land-use–land-cover change as a metric to explain human pressure as a preconditioning factor for fatal landslide occurrences to provide a global overview. We addressed countries' income levels, populations, exposure, and a dataset of ≈ 60 years of land-use–land-cover changes with mountainous landmasses to compare landslides and fatalities across 46 countries. Our statistical analyses show that land-use–land-cover changes have a substantially greater influence on the density of fatal landslides and landslide fatalities than physical factors such as topography and precipitation, especially in lower-income countries. We observed a marginal landslide impact when the land-use–land-cover change was low, regardless of the income class. Our results emphasize that effective land-use–land-cover planning is critical to decreasing landslide fatalities, especially in low- and lower-middle-income countries.

INTRODUCTION

Among the most destructive hazards, landslides typically kill more than 4500 people (2004 to 2019) (1) and cause US\$20 billion in damage annually (<2014) (2). In 2024, for instance, 766 fatal landslides claimed 4933 lives, indicating an unprecedented year of fatal landslide occurrences, as the count has been under 500 since 2004 (3). These substantial counts of fatal landslides are distributed unevenly among nations. We aim to answer why landslides are deadlier in certain regions than others with comparable potential concerning topographic relief and climate. Beyond national wealth, climate, population density, and hazard awareness, we propose that increasing human pressure on fragile mountainscapes, depicted as land-use–land-cover change (LULCC), is a key aspect modulating landslide fatalities (4–7).

Besides being exposed, human alterations to the land surface may also alter landslide occurrences (8). Approximately 60% of the mountainous areas are under intense human pressure (9). The number of people exposed to natural hazards in mountain areas doubled between 1975 and 2015 (10, 11), quicker than the average population rise (12). Clear-cutting and the transition of forests to pasture and cropland alter hillslope hydrology, decreasing slope stability (13–15). Activities linked to mining infrastructures and road constructions disrupt the natural continuity of hillsides, destabilizing hillslopes (16–18). As a result, although the mean annual population exposed to landslides is expected to rise by about 90%, mean annual fatalities are projected to increase by 140% by 2060 (19).

We need a global understanding of how human pressure, measured as LULCC rate, influences landslides across mountain ranges. State-of-the-art research has explored the importance of increasing human pressure regionally (20, 21), such as in the Andes (4, 22), the

Apennines (6), and the Kivu Rift (23), demonstrating a considerable role of LULCC on fatal landslide events and their fatalities. A global evaluation of landslide and land-use–land-cover interactions is complicated, as terrain conditions, land management strategies, population densities, and intercountry socioeconomic conditions vary considerably among mountainous communities. Until recently, we also lacked high-resolution global datasets, such as historic (>50 years) land-use–land-cover (24) and population data (25), which would allow exploring the above-listed differences. A lack of complete global landslide database also hinders such an assessment; however, there are efforts to track landslide fatalities globally to provide a rough proxy in this regard, thanks to community efforts (1).

To address these gaps, we adopted a K1 mountain characterization (26) and focused on mountainous areas of 46 countries (Fig. 1, A to D), categorized by income level. Initially, we calculated a ≈ 60 -year-long land-use–land-cover (24) and a 45-year-long population (25) change rate and analyzed how these variables relate to landslide fatalities. We introduced a new metric, total LULCC rate (LC_{SN}), to quantify the overall change across multiple land-use–land-cover types. We also included population density, exposure, topographic relief, precipitation, and income level factors in our models. Thanks to the recent data advancements and this metric, we could build a statistical model to determine whether LULCC and population growth were associated with observed landslides and fatalities in mountainous areas.

In this study, we show that high-income (7%) and upper-middle-income (13%) countries show more stable and limited transitions in terms of LULCC. The change in mountainous areas of lower-middle-income (18%) and low-income (50%) countries is more pronounced. In addition, the increasing LULCC rate (LC_{SN}) correlates with a corresponding increase in the density of fatal landslides and the density of landslide fatalities in low- and lower-middle-income countries. For example, in some countries, such as Haiti, Sri Lanka, and El Salvador, the LULCC rate is directly associated with increased fatal landslides and the number of fatalities. However, the correlation weakens in high-income countries such as Switzerland, Japan, Italy, Austria, and South Korea despite favorable conditions for landslide occurrence considering topographic relief and climate.

¹Department of Architecture and Urban Planning, Ankara University, Ankara 06100, Türkiye. ²Eurasia Institute of Earth Sciences, Istanbul Technical University, Istanbul 34469, Türkiye. ³Department of Geography, Faculty of Arts and Science, Bursa Uludag University, Bursa 16059, Türkiye. ⁴Department of Geography and Regional Research, University of Vienna, Vienna 1010, Austria. ⁵Section of Seismic Hazard and Risk Dynamics, GFZ Helmholtz Centre for Geosciences, Potsdam, 14473, Germany. *Corresponding author. Email: seckinfidan@ankara.edu.tr