Extended Abstract DOI:https://doi.org/10.64862/ajeg.2025.2sp.100.238 Open Access

Compositional Analysis of Reactivated Landslide Soil from Kodari, Sindhupalchok District, Nepal

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Received: July 25, 2025, Accepted: October 31, 2025

Abstract: The tectonically active and climatically dynamic Himalayas are prone to landslide reactivation. The soil compositional ratio of the Kodari reactivated landslide is examined utilizing compositional statistical analysis. Altogether 40 soil samples were collected from the total landslide area. General sieve analysis yielded gravel, sand, and fines. Grain-size distribution and compositional analyses show a sand–gravel matrix with few fines, whereas centered log-ratio (clr) transformation shows fines as the most important variable and hydrologically sensitive component. The dominant sand-gravel composition affects infiltration and underground percolation. The low-plastic coarse-grained soil deformed because of the 2015 Gorkha earthquake and frequent aftershocks and began to move in the monsoon. This compositional method provides a mechanical explanation for Himalayan slope failures and helps with hazard assessment and slope management.

Keywords: ***Paleolandslide, Nepal Himalaya, Compositional analysis, Kodari introduction.***

Introduction

Reactivated landslides denote formerly inactive landslides that have restarted movement after a phase of dormancy (Bhandari and Dhakal, 2020). When external and internal factors change the slope stability conditions, they can revive landslides that have been inactive for years or decades. Steep terrain, active tectonics, and monsoon precipitation in the Himalayas combine to make the slope unstable. The 7.8 Mw Gorkha earthquake in 2015 triggered around 20,000 landslides, predominantly in central Nepal, particularly in the Sindhupalchok District (Roback et al., 2018). The earthquakes and monsoon storms primarily affect the slope condition, whether the slope is bedrock or an old landslide deposit. Soil composition significantly contributes to the initiation and reactivation of landslides, influenced by different external sources. This study examines the factors of soil composition that contribute to the reactivation of paleo-landslides as a result of seismic and hydrologic effects.

Research area and methodology

Kodari village in Nepal is located on the main thoroughfare connecting Nepal and China, referred to as the Araniko Highway. The region is situated in the Sindhupalchok district, approximately 2.5 kilometers from the Zhangmu Border Station in the Tibetan province of China, adjacent to the Bhote Koshi River Valley. The Kodari landslide is located in the Sindhupalchok District, specifically in Kodari village in Bhotekosi Rural Municipality, approximately 102 kilometers northeast of Kathmandu.

Data collection

The soil samples were collected from 40 different locations of the landslide, from the old scar to the toe area. The remolded soil samples were collected by using local equipment and wrapped in the plastic bag. The locations of samples were selected at the reactivated area. Soil samples were obtained from ten sites at each reactivated area of landslide for compositional study. Sieve analysis was performed to determine the percentages of fine (clay and silt), sand, and gravel in the soil. The particle size distribution of soil was analyzed in accordance with the ASTM D422 standard. The mass of the fine sand and gravel was obtained based on the percentage passed through the standard sieve.

Analysis and results

A comprehensive examination of grain size distribution has been conducted using compositional statistics (Bhandari and Dhakal, 2020). A variation array of the mean log-ratio between the data centroid and the variance of the same log-ratio was compiled for additional information. The variance of the identical log-ratio provides a quantification of the dispersion of values relative to the centroid. The centered log-ratio (clr) transformation was ultimately derived. Likewise, the centered log-ratio (clr) variance for each component was calculated to assess each grain size fraction following the centered log-ratio transformation.

The soil samples are predominantly sand (mean = 65.39%), with moderate gravel content (mean = 28.10%) and low fines (mean = 6.45%). The result shows that the soils are well-graded, with sand as the dominant fraction, suggesting favorable drainage potential. The CLR variance analysis indicates that fines (CLR variance = 0.039) show slightly higher variability compared to sand (0.0341) and gravel (0.0324) (Table 1). The higher variability in fines, despite their low proportion, suggests that small changes in fine content may significantly influence hydrological responses, such as infiltration and pore pressure buildup. In contrast, the sand-to-gravel ratio remains relatively stable, reflecting a coarse soil skeleton with generally good drainage. The mean log-ratio variance (0.0974) confirms the overall balance among soil fractions, with fines acting as the most sensitive component influencing slope stability.

Table 1, Variation array of the soil components.

	Variance ln (Xi/Xj)				
Xi\Xj	Fine %	Sand %	Gravel %	clr variance	
Fine%		0.0977	0.0925	0.0309	
Sand %	2.3431		0.1020	0.0341	
Gravel %	1.4800	-0.8631		0.0324	
	Mean ln (Xi/Xj)			0.0974	Total Variance

The ternary predictive region demonstrates that the soil matrix is strongly dominated by sand with a subordinate proportion of gravel and consistently low fines (Figure1).

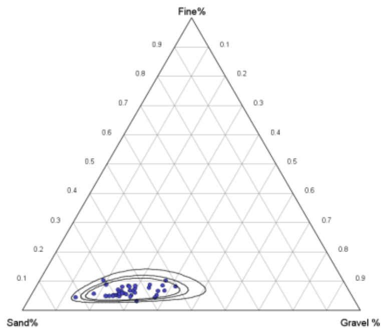

Figure 1, The predictive region of the soil components.

The ternary diagram shows that the central confidence region is narrowly constrained along the sand–gravel axis, with consistently low fine content (Figure 2). The tight clustering of samples and the compact confidence ellipse indicate low compositional variability and a predominantly coarse-grained soil texture.

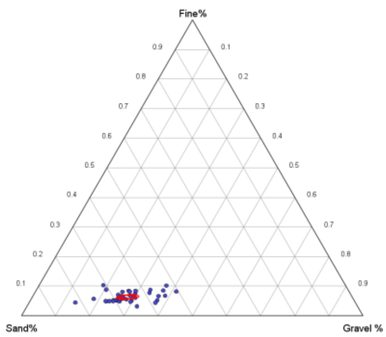

Figure 2, Central confident region of the soil components.

In Figure 3, the axes ilr.1 and ilr.2 represent the first two isometric log ratio (ilr) coordinates, which contain the principal dimensions of variance in the soil composition data. The gravel and fine percentages both contribute, but in opposite directions, implying a trade-off relationship. The sand vector points to the right, indicating that samples oriented in that way have a larger concentration of sand. The gravel vector points to the left, opposite the sand vector.

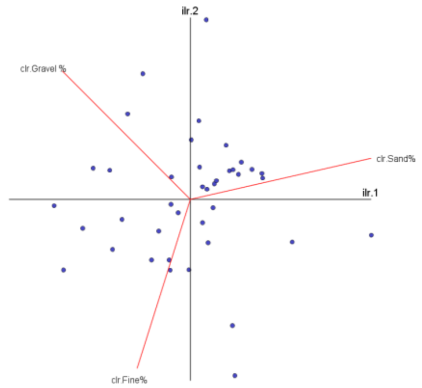

Figure 3, Isometric and central log ratio biplot of the soil components.

Conclusion

The Kodari landslide, a reactivation of a paleo-landslide deposit in Sindhupalchok, Nepal, exemplifies the compound influence of tectonic and climatic drivers on slope instability in the central Himalaya. Grain-size distribution reveals a sandy–gravelly soil matrix with limited fines that favor shallow, rainfall- and earthquake-induced failures. The higher value of sand-gravel central log ratio indicates the percolating role of soil. The low fine between the higher coarse compositions shows the condition of rainwater infiltration. The frequent seismic activities and continuous rainfall in the monsoon period caused the deformation and movement of sand gravel reach paleo-landslide deposit. For the Kodari corridor, integrated monitoring and mitigation strategies are essential to safeguard communities and infrastructure along this critical Nepal–China border route.

References

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