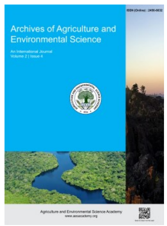
Archives of Agriculture and Environmental Science 8(3): 302-309 (2023)
https://doi.org/10.26832/24566632.2023.080305

e-ISSN: 2456-6632

This content is available online at AESA

Archives of Agriculture and Environmental Science

Journal homepage: journals.aesacademy.org/index.php/aaes



ORIGINAL RESEARCH ARTICLE

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Assessment of slope-cut landslides along Pokhara-Baglung Highway, Nepal

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ARTICLE HISTORY

Received: 03 July 2023
Revised received: 12 August 2023
Accepted: 28 August 2023

Keywords

Environmental effects
Plasticity Index
Road extension
Sieve analysis

ABSTRACT

The study addresses the ramifications of development initiatives in delicate mountainous terrains, unveiling significant economic constraints and multifaceted environmental challenges. It focuses on investigating substantial landslides triggered by excavations along a specified stretch of Nepal's Pokhara-Baglung Highway. This research holds significance for policymakers engaged in devising highway development strategies that mitigate future landslides, minimizing both costs and the toll on life and assets. The investigation encompassed on-site cataloging of landslides, lab test of sampled soils and a structured questionnaire distributed among local residents. This comprehensive approach facilitated a thorough assessment of landslide occurrences and their consequential effects. The identified landslides exhibited a consistent rotational pattern, characterized by abundant quartzite and phyllite rock formations. The predominant soil composition consisted of fine-to-medium sands, exhibiting a Plasticity Index (PI) range of 0.5 to 3, indicating marginal plasticity. Significantly, a substantial portion (70%) of the populace reported tangible impacts from landslides, with about 32% of affected individuals confirming an average agricultural productivity loss of 4330 kg/km^2. Statistical analysis using the Chi-square test indicated a uniform impact across various demographic categories, including gender, education, proximity to the affected site, and social caste. Although fluctuations in the region, the observed temporal precipitation consistency over decades suggests as an accelerating rather than primary causative factor for landslides. Thus, principal causes of slope failures predominantly link to inadequately managed bedrock excavations and suboptimal road drainage systems underscoring the necessity for systematic inquiries into soil stability post-slope incisions. These measures are pivotal in guiding the construction and expansion of road networks within Nepal's Himalayan region.

Citation of this article: Dhungana, S., & Maharjan, M. (2023). Assessment of slope-cut landslides along Pokhara-Baglung Highway, Nepal. *Archives of Agriculture and Environmental Science*, 8(3), 302-309, https://dx.doi.org/10.26832/24566632.2023.080305

INTRODUCTION

A landslide event, characterized by the sudden movement of land and water, results from a complex interplay of factors including terrain composition, topographical configuration, precipitation intensity, and anthropogenic interventions that disrupt the inherent stability of slopes (Santini *et al*., 2009). These geomorphic processes wield significant influence on terrestrial landscapes worldwide, sculpting mountains and contributing sedimentation to river networks (Mondini *et al*., 2021). The phenomenon entails the downward displacement of rocks, debris, or soil along inclines due to the omnipresent force of gravity (Cruden and Varnes, 1996; Hungr *et al*., 2014). With variable estimates, the global average of over 4,300 annual fatalities underscores the considerable human toll brought about by landslides (Froude and Petley, 2018).

Nepal, recognized as a geographically predisposed region to frequent natural calamities (Dilley *et al*., 2005), experiences an exacerbation of these hazards due to human interventions. The intricate mountainous topography, delicate geological formations, loose soil covers, copious monsoonal precipitation, seismic activities, and heightened susceptibility of mountainous terrain collectively contribute to the recurrent incidence of landslides (Upreti and Dhital, 1996). Within the Nepalese Himalayas, these events span a spectrum from extensive failures encompassing entire mountainous expanses to localized slope collapses and rock dislodgements (Hasegawa *et al*., 2009). Notably, the monsoon period amplifies the threat of landslides along road networks, attributed to intensified uphill slope gradients and the deposition of excavated materials downhill, which are prone to mobilization during heavy rainfall (Sidle *et al*., 2006). Conspicuously, road construction endeavors play a pivotal role in heightening the susceptibility to landslides, particularly through practices such as undercutting (Sidle *et al*., 2006). In developing nations, regions adjacent to highways are particularly susceptible due to suboptimal engineering designs (Sidle *et al*., 2006; Sidle and Ochiai, 2006). The instability of slopes materializes when external forces, such as excavation or water intrusion, disrupt the original stress equilibrium of the soil or diminish its resistance against shearing forces (Deoja *et al*., 1991).

In Nepal, informal road construction has been correlated with five primary modes of potentially perilous mass movements: debris flows, deep-seated landslides stemming from inadequate road drainage, shallow failures due to over-steepened road cuts, shallow landslides induced by oversteepening, and deeper-seated collapses triggered by oversteepening near road cuts, including bedrock instability (McAdoo *et al*., 2018). However, comprehensive investigations into the influence of geology and geomorphology on the distribution of large-scale landslides and their subsequent repercussions remain scarce in Nepal. As such, this study endeavors to evaluate landslide occurrences along the Pokhara-Baglung Highway, Nepal. The outcomes of this research are poised to provide valuable insights for policymakers, aiding in the formulation of development strategies along the highway that prioritize designs mitigating future landslide events. This, in turn, serves to curtail the loss of life and property, enhance transportation safety, and minimize the expenses associated with highway maintenance.

MATERIALS AND METHODS

Study area

Pokhara-Baglung highway is a 72 km long highway west of Pokhara, which lies in the Lesser Himalayan Zone of Nepal between Main Central Thrust (MCT) and Main Boundary Thrust (MBT) (Figure 1). Geomorphologically, the study area lies in the midlands, where mostly schist, phyllite, gneiss, quartzite, granite, and limestone are abundant (Dahal, 2006; Hasegawa *et al*., 2009). The study area lies from Suikhet, Kaski to Kushma, Parbat (approx. 30km), with elevation ranges from 850 m to more than 1260 m above sea level. The selection of this particular area was due to past to recent landslide events, easy accessibility, high precipitation, and road extension. The monthly precipitation on these area ranges from 600 mm to 1500 mm (DHM, 2021). As recent as 2015, the road extension program on the highway is creating disturbances in the region's mountains. Hence, because of both natural and anthropogenic factors, these areas are highly susceptible to landslides.

Data collection

Geomorphological data collection

The topographic map of sheet no. 2883-15B (Kushma, 1:25000 scale), 2283-12C (Naudada, 1:25000), 2883-12D (Lamachaur, 1:25000), and 2883-11D (Patichour, 1:25000 scale), published by the Survey Department, Government of Nepal were used for the study. Geological mapping (Soller, 2004) of the study area was done through geological traversing along Pokhara-Baglung highway from Suikhet, Kaski to Kushma, Parbat. An inventory form for landslide mapping was prepared beforehand comprising various important aspects of landslide mapping. Landslide inventory mapping was done with the measurement of its dimensions (Westen, 2016). The landslides' location was noted by using GPS. Lithological characteristics of rocks were studied with geological hammer by striking and testing it with either physical touch or through Hydrochloric Acid (HCl) (Budhathoki, 2019). The data regarding the altitude of bedding or foliation plane were measured using the geological compass, Also, geological structures; fault and fold, rock types, attitude of bedding or foliation, direction and inclination of slopes, land use pattern, were carefully transferred to the topographic map. The information of landslide regarding dimension, types of material involved, seepage conditions, direction and inclination of slopes were also noted. Lumle and Kushma meteorological stations were present nearby the landslide study areas alongside Pokhara-Baglung Highway, Nepal. The monthly precipitation data from 2011 to 2020 from these stations were obtained from Department of Hydrology and Meteorology (DHM, 2021), Kathmandu, Nepal.

Laboratory analysis of soil

Different soil samples were collected from the slip surface part of landslides for further laboratory analysis on Shree Galeshwor Secondary School's Civil Engineering Lab, Beni-09, Myagdi, Nepal. Sieving and hydrometer analysis was carried out to designate the grain size of soils in the study area (Hossain *et al*., 2021).

Socio-economic data collection

The local nearby people from the landslide areas were questionnaire regarding the past and the present environmental effects felt from the landslides. The survey was conducted with 40 random people (10 people/landslide area) living around one km radius from all the four landslides. This was conducted to understand the cascading effects caused by landslide on human and environment.

Data analysis

The logarithmic scale is used for the sieve size on the graph. The percentage retained in each sieve is calculated using the equation (García-Gaines and Frankenstein, 2015).

$$\% \text{ Retained} = \frac{\text{Wsieve}}{\text{Wtotal}} \times 100\% \quad (1)$$

where W_{Sieve} is the mass of aggregate in the sieve and W_{total} is the total mass of the aggregate. The cumulative percent passing of the aggregate is found by subtracting the percent retained from 100% (Bureau, 2015).

$$\text{Cumulative Passing} = 100\ \%\text{-}\%\ \text{Cumulative retained} \quad (2)$$

Calculations of Plasticity Limit (PL) and Liquid Limit (LL) are done simultaneously (Bureau, 2015).

$$\text{Moisture Content} = \frac{\text{Water of weight}}{\text{Water of Oven-dried soil}} \times 100 \quad (3)$$

For PL, the two moisture contents were averaged to obtain the limit. Re-testing was required if the test results varied significantly to ensure the correct plastic limit. For LL, a flow-curve graph was plotted on a semi-logarithmic graph with moisture contents on the x-axis and the number of blows on the y-axis. The flow curve was a straight line drawn as close as possible through the three or more plotted points Calculation of PI was done through difference between the LL and PL (Bureau, 2015).

$$\text{PI=LL-PL} \quad (4)$$

Estimated volume of debris from the landslide areas were calculated by multiplying the height, The precipitation data was processed through MS Excel and linear regression analysis was conducted to calculate the change in annual sum of precipitation.

$$y = a + bx \quad (5)$$

where, y=time, x=precipitation, a and b are constants

Statistical analysis

Pearson Chi-squared test was conducted between people responding being affected by the landslide with various factors like gender, education, distance from the landslide and caste. Chi-square test for affected people with different factors like were done through R-studio. The data collected from social survey were analyzed by making bar-diagrams and pie-charts through MS Excel.

RESULTS AND DISCUSSION

Characteristics of landslides

The landslides under investigation are designated by the local appellations of the nearby local name of the place or the nearby river as Ghattekhola, Dhawa, Modikhola, and Paradi (Figure 2). These occurrences are evenly spread along the highway and exhibit a variety of geological and geomorphological attributes. To encompass the entirety of the landslide areas, a distance of 7.5 km is demarcated around each station, while an additional 4.5 km radius is delineated to depict the highly influenced zone of the recording station (Figure 2). Although these landslides are encompassed within a 10 km radius, they exhibit distinct morphological and formational disparities. The majority of these landslides' manifest rotational movement, with one exception displaying complex motion. Geological compositions vary across different landslides, including the Kunchha formation and Nayagaun formation in Kaski, Nepal, and the Naudanda Quartzite formation in Parbat, Nepal. The gradient of the hill slopes for these landslides predominantly ranges from 40° to 60°, with the rock composition primarily comprising quartzite, sometimes intermingled with phyllite. These landslides have experienced substantial soil loss (Table 1). Hasegawa *et al.* (2009) observed that geological formations rich in phyllite, schist, and gneiss exhibit instability. Phyllite is prevalent in about half of the study area, while quartzite is present across all sites. Research conducted on the Araniko Highway by Nepal *et al.* (2019) highlights that hill-slopes with inclinations between 50° and 60° are most vulnerable to landslides. In contrast, findings by Pandey (2017) propose that slope failure due to steep relief isn't a primary factor, and regions with gentler slopes (≤ 30°) experience larger landslides. This implies that excavation during construction, irrespective of initial slope, can trigger landslides. Notably, our study reveals slope cuts ranging from 60° to 80°, which could be a major factor in slope failure (Table 2). Landslide occurrence is also influenced by aspect, with most events in the study area transpiring on northern/north-western slopes, consistent with studies by Pandey (2017), Rolpa landslides, and Mugling-Naranghat (Devkota *et al.*, 2013).

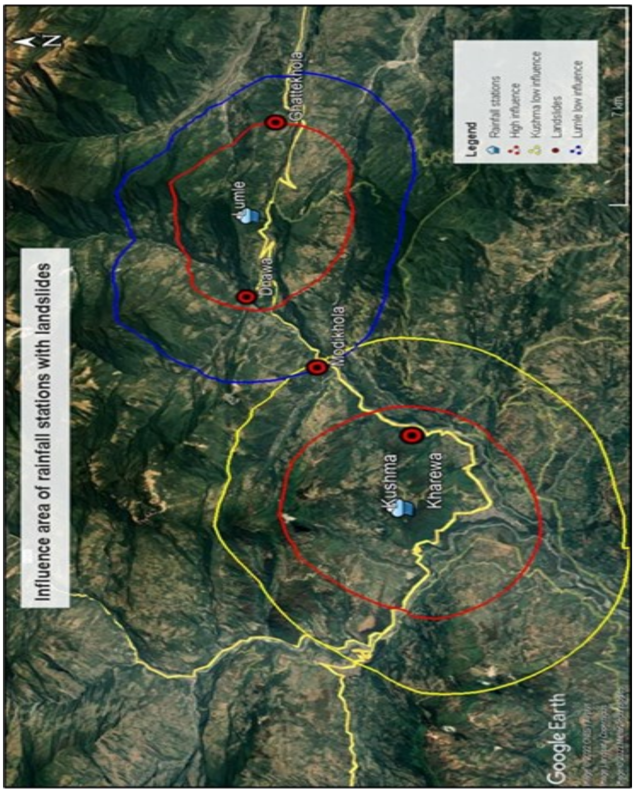

Figure 2. *GEP image showing the rainfall stations and landslide area.*

The investigation outcomes reveal that the prevalent soil types in the study zones are medium-fine sand, exhibiting slight plasticity as well as non-plasticity (Table 2). The results further indicate that the liquid limit (LL) spans between 15% and 21%, averaging at 17.79%, while the plastic limit (PL) ranges from 15% to 17.5%, with an average of 16.2% (Table 2). The plasticity index (PI) extends from 0.5% to 3%, with an average value of 1.56% (Table 2). Sieve analysis of soils derived from the study sites portrays a composition of fine sand, medium sands, and soil particles within the silts-clay size range (Figure 4). Bhat and Wakai (2018) investigated soil samples from major Nepalese highways and noted a plasticity index (PI) range of 4.2-18.48%, indicating medium to low plasticity clays with significant silt content. However, this contrasts with our laboratory tests, which indicate a PI range of 0.5-5%, suggesting slightly lower plasticity with medium to low sand content (Table 3).

Analyzing the trend of annual rainfall in Lumle and Kushma during the past decade (2011-2020) (Figure 3), it's evident that there has been a marginal increase in annual precipitation. Lumle witnessed its peak annual precipitation in 2020 with 6153 mm, while the lowest levels were recorded in 2012 and 2015 at 4688 mm. The average annual precipitation for Lumle over the entire decade was 5250 mm. Conversely, Kushma experienced a significantly lower average annual rainfall of 2426.89 mm. This underscores the considerable variation in rainfall between these two stations. Historical research demonstrates that rainfall-triggered landslides are prominent in mountainous regions (Hungr, 2003). Despite efforts to establish rainfall-induced landslide thresholds in the Himalayas (Khanal and Watanabe, 2005), site-specific variations render such approaches insufficient (Dahal *et al.*, 2006). In Nepal, over 80% of rainfall occurs during the monsoon, coinciding with all landslide events (Dahal *et al.*, 2006). While rainfall is a key trigger, human activities modifying topography and inadequate conservation measures amplify its impact, as highlighted by Pandey (2017). In our study, although stations recorded consistently high rainfall throughout the year (Figure 3), it's not the sole cause for landslides, given the long-term persistence. Thus, while rainfall is a triggering factor, other contributing elements must also be considered.

Table 1. Landslides and their salient features.

	Landslides			
Name	**Ghattekhola**	**Dhawa**	**Modikhola**	**Paradi**
Type	Rotational (Varnes,1978)	Rotational (Varnes,1978)	Rotational (Varnes,1978)	Complex movement (Varnes, 1978)
Location	28°17.221'N, 83°51.673'E	28°18.123'N, 83° 46.66'E	28°16.434'N, 83°44.471'E	28°14.311'N, 83°42.626'E
Geological formation	Kunchha formation (Dhital, 2015)	Nayagaun formation (Dhital, 2015)	Naudanda Quartzite (Dhital, 2015)	Naudanda Quartzite (Dhital, 2015)
Length(l)	45m	30-40m	30-45m	60-80m
Width(w)	55111	145m	30m	110m
Depth(d)	5-10m	20-60m	2-5m	7-10m
Dip/Dip direction	35/210	25/24	24/310	77/290
Strike	120°	335°	30°	26°
Hill Slope	60°	41°	45°	52°
Cut slope	82°	61-73°	75-85°	60-65°
Aspect	Northern	Northern	North-Western	Western
Rock types	Phyllite-quartzite	Phyllite with intercalated quartzite	White Quartzite	White Quartzite

Table 2. Characteristics of sample soils from studied landslides.

Landslides	Ghattekhola	Dhawa	Modikhola	Paradi
Soil types	Medium-fine sand	Fine sand	Medium-fine sand	Medium-fine sand
PL	17.5	15.3	16.4	15.7
LL	20.57	15.81	18.02	16.75
PI	3.08	0.52	1.62	1.06
Soil behavior	Slightly plastic	Non plastic	Slightly plastic	Non plastic

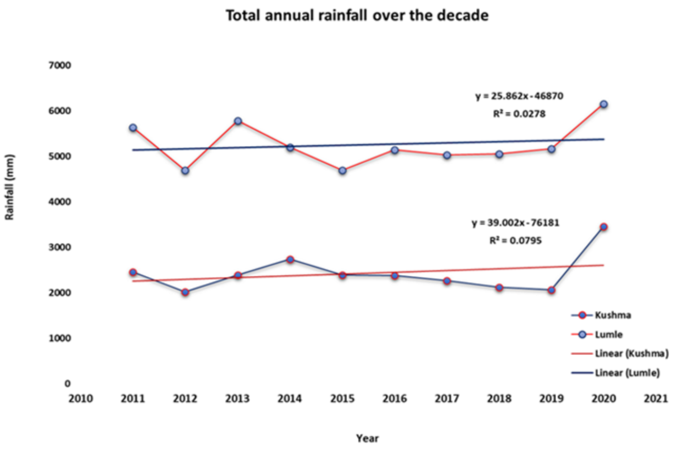

Figure 3. *Line graph showing the total annual rainfall recorded on Lumle station (upper) and Kushma station (lower) (source: DHM, 2020).*

Socio-economic impact of landslide

In the context of the conducted survey involving 40 respondents, it was ascertained that 62% of the participants were male, while the remaining 38% were female. Age distribution revealed that a significant proportion, constituting 60%, belonged to the 41–60-year age bracket, whereas a minor proportion, amounting to 8%, fell within the above 61-year age range. The majority of respondents (60%) identified themselves as belonging to the Brahmin and Chhetri communities, while Dalits and indigenous individuals accounted for 30% and 10%, respectively. In terms of literacy, 92% of respondents were found to be literate, leaving a mere 8% categorized as illiterate. Occupationally, 44% of respondents identified agriculture as their primary means of livelihood, 17% mentioned business, and 40% indicated office jobs, tourism, and services. With regard to landholdings, 53% of respondents held land within the range of 500-2500 m^2, whereas 17% possessed less than 500 m^2.

A notable 70% of the respondents acknowledged direct impacts from landslides (Figure 5A), affecting various sectors such as agriculture, water, air, forest, and household. Notably, all respondents (10) from the Ghattekhola site reported experiencing the multifaceted effects of landslides (Figure 5B), while only 4 respondents from the Modikhola site reported similar experiences. To understand the cascading repercussions of landslides, multiple sectors encompassing agriculture, household, forest, and water sources were taken into account. Predominantly, respondents recognized the effects on agriculture and housing (Figure 5C), with a substantial 32% experiencing impacts in these two sectors exclusively.

Among the total respondent pool, 15 individuals acknowledged the impact of landslides on agriculture, primarily associated with productivity loss, including land loss. The mean change in agricultural yield across the four landslide sites was determined to be 4330 kg/km^2 (57%) (Table 4). Of the 15 respondents acknowledging landslide effects, 12 provided estimates of production losses. Two respondents were unable to quantify their losses, while one indicated that the destruction of an irrigation system hindered land cultivation, subsequently affecting overall agricultural output. Given that landslides tend to modify hill slope topography, hydrological connectivity, and subsurface water storage dynamics (Mirus *et al.*, 2017) our findings highlighted the loss of surface and subsurface water sources, likely contributing to diminished agricultural productivity (Table 4).

Table 3. General description of respondents in the study site condition.

Category	Sub-category	Number	Percentage
	Male	25	62
Gender	Female	15	38
	20-40	12	30
Age (years)	41-60	25	62
	61 above	3	8
	Dalit	12	30
Ethnicity	Indigenous	4	10
	Other	24	60
	Illiterate	3	8
Education	Literate	37	92
	Farming	17	43
Occupation	Business	7	17
	Other	16	40
	<500 m^2	12	30
Landholdings	500-2500 m^2	21	53
	>2500 m^2	7	17

Table 4. Change in Agricultural Yeild Before and After Landslide (kg/km^2).

Before	After	Mean Change
7480.31	5905.51	1574.80
5314.96	3543.31	1771.65
7086.61	0.00	7086.61
12401.57	0.00	12401.57
5314.96	2755.91	2559.06
3543.31	1771.65	1771.65
7086.61	3543.31	3543.31
13779.53	7480.31	6299.21
5905.51	2952.76	2952.76
27559.06	23622.05	3937.01
8858.27	0.00	8858.27
3149.61	984.25	1574.80
1968.50	1968.50	1968.50
	Average	4330.71

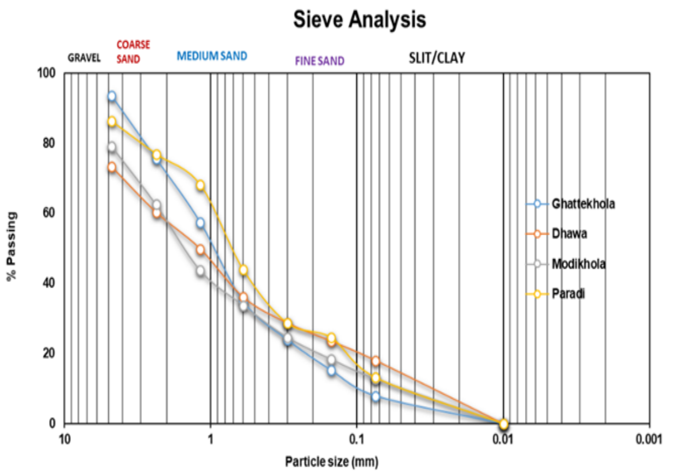

Figure 4. *Grain size distribution analysis of soil samples.*

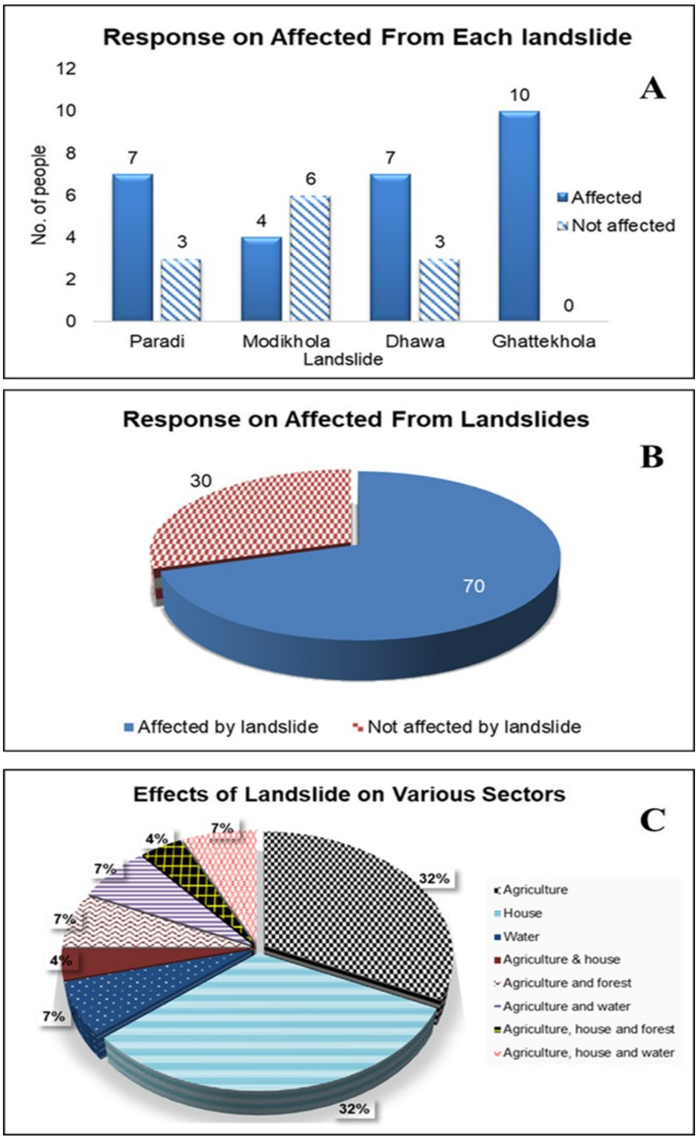

Figure 5. *Graphs showing affected people from landslide.*

Following agriculture, human settlements encountered substantial landslide effects, with 13 respondents reporting impacts on households. Temporary displacement was experienced by eight households, and one household relocated permanently. Water quality degradation was another prominent outcome, as water turned turbid during the monsoon due to landslides. While human casualties were absent, two instances of domestic animal fatalities were recorded due to landslides. Water quality and availability were profoundly affected, with both water sources and irrigation systems being destroyed. Respondents also lamented the loss of traditional springs due to landslides. The implications of the studied landslides were far-reaching, severely impacting agriculture, forests, water, air, settlements, and domestic animals. A previous study suggested a 20% agricultural yield loss (Mertens *et al.*, 2016); however, our findings indicate a substantial 57% loss (Table 4). The ecological impact was also significant, as landslides altered soil, vegetation, and site characteristics (Geertsema and Pojar, 2007), leading to deforestation and soil displacement (Geertsema *et al.*, 2009), leaving previously productive land barren, either muddy or parched, contingent on the season and precipitation. Recent incidents of landslides have introduced a heightened pollution challenge, spanning air, water, and land. Among respondents, eight highlighted debris accumulation as a considerable issue, starkly visible in the study sites. Land deformation due to landslides significantly impacted trees and vegetation, resulting in the destruction of various species such as *Macaranga Denticulate*, *Schima Wallichii*, and *Alnus Nepalensis*. Furthermore, substantial debris accumulation led to pollution of air, water, and land quality (see Annex).

Table 5. Chi Square Test of effect of landslide with various factors.

Pearson Chi-Square test with Yates' continuity correction		
	Gender	
Affected	**Male**	**Female**
Yes	16	12
No	9	3
X-squared = 0.50794, d.f. = 1, p-value = 0.476		
	Education	
Affected	**Formal**	**Informal**
Yes	15	13
No	4	8
X-squared = 0.68743, d.f. = 1, p-value = 0407		
	Distance	
Affected	**Less than 500m**	**More than 500m**
Yes	23	5
No	11	1
X-squared = 0.084034, d.f. =1, p-value = 0.7719		
	Caste	
Affected	**Dalits/ Indigenous**	**Brahmins Chhetri**
Yes	11	17
No	5	7
X-squared = 2.7391e-31, d.f. = 1, p-value = 1		

The application of Chi-square tests revealed no statistically significant disparities in the proportion of affected individuals concerning factors such as gender, education, distance, and caste, based on the acquired data (Table 5). This differs from findings in a study on Indonesian landslides, which found women to be more vulnerable due to caregiving roles and resource limitations (Sari *et al.*, 2017). In our study area, a mix of diverse castes with similar infrastructure and resource access contributed to the disparity. Additionally, the survey focused on respondents residing within a one-kilometer radius of landslide-prone areas, suggesting that developmental endeavors could be directed towards regions with fewer settlements within this proximity.

Road induced landslide

The establishment of road infrastructure within Nepal's mountainous terrain has been confronted by intricate complexities stemming from factors such as elevated gradients, substantial soil profiles, frail rock masses, and pronounced monsoon precipitation (Dahal *et al.*, 2006). McAdoo *et al.* (2018) posit that inadequately constructed roads during the monsoon season are prone to yielding twice the number of landslides when compared to regions devoid of roadways. This establishes a pronounced spatial association between roads and landslide occurrences, a correlation substantiated by empirical observations and antecedent investigations (Froude and Petley, 2018).

In Nepal, the incidence of relatively modest to moderate landslides along roadside inclines is spurred by an average daily precipitation of 200-240 mm, often witnessed on the east, south, or west-facing slopes at lower elevations (Pandey, 2017). The construction of highways within the topographically intricate mountain regions considerably heightens the susceptibility to landslides (Hayati *et al.*, 2012). The alteration of land use scenarios has underscored a discernible correlation between forest cover and slope stability, with landslide incidences predominantly concentrated within areas characterized by a lack of vegetation (66.6%), in contrast to pastures (15.8%) and forests (14.7%) (Reichenbach *et al.*, 2014). Notably, the expansion of the road network in the study area resulted in the clearing of forested or pasture lands, leading to the destabilization of previously stable terrain in favor of more vulnerable, barren soils.

Field observations directly indicate that multiple factors including topography, rock compositions, pre-existing fractures or faults in geological formations, soil attributes and thicknesses, vegetative coverage, and land utilization patterns exert a degree of influence over landslide occurrences. However, none of these factors singularly emerge as a definitive causative element, as their respective thresholds do not align with findings from analogous investigations encompassing similar facets. Consequently, the genesis of landslides along the Pokhara-Baglung highway can be attributed to suboptimal road drainage or a confluence of deep and shallow failures induced by excessively steepened road cuts, even involving bedrock formations (McAdoo *et al.*, 2018). This contention is corroborated by the deficient road drainage systems and over-escalated slope cuts observed within the study area. The juxtaposition of these factors with the transformation of forested regions into exposed soils, coupled with intensified precipitation, jointly accentuates landslide propensity and soil instability.

Conclusion

In summary, the landslides induced by slope cuts encompass a range of contributing factors. The geological composition of the area, characterized by stable rock formations such as Quartzite and relatively less landslide-prone slit-sandy soils exhibiting a Plasticity Index (PI) within the range of 0.5 to 3.075 with slight plasticity, played a significant role in landslide occurrences. Variations in rainfall distribution were evident between the proximate meteorological stations, Lumle and Kushma, with recorded annual average rainfall over the past decade measuring 5250 mm and 2427 mm respectively. The impact of these landslides was particularly pronounced in the domains of agriculture and households. The displacement of substantial tracts of land, comprising forests, soils, and agricultural areas, resulted from the documented landslides. This phenomenon engendered adverse effects on soil productivity and agricultural output, substantiated by an average agricultural production loss of 4330 kg /km^2 attributed to landslides. Moreover, the dwindling of water sources further impeded agricultural activities. Remarkably, the Chi-square analysis underscored the absence of significant discrepancies among the impacted population concerning variables like education, caste, distance from the site, and gender. This homogeneity suggests that the landslide's effects were uniformly distributed across all demographic categories. Hence, the observed landslides were, to a considerable extent, consequences of insufficiently researched slope incisions and inadequate road drainage systems. The cascading ramifications of these landslides extend across various sectors, significantly affecting human lives and livelihoods. Thus, as expansion projects for highways are envisaged, meticulous research and effective roadside management must be considerations, particularly when undertaking construction activities within mountainous terrains.

ACKNOWLEDGEMENT

We would like to acknowledge Ministry of Forest, Environment and Soil Conservation (MoFESC) of Gandaki Province for providing financial support to accomplish this study. We are thankful to Ashok Baral, Roshan Adhikari, Bishal Adhikari, Er. Sushil Dhungana and Pooja Basnet for their untiring help and encouragement. Also, we are grateful to all reviewers, editors, and well-wishers for their valuable comments and suggestions during the finalization of the paper.

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