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ORIGINAL PAPER

Cost assessment of losses due to recent reactivation of Kaliasaur landslide on National Highway 58 in Garhwal Himalaya

Indervir S. Negi · Kishor Kumar · Anil Kathait · P. S. Prasad

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Abstract National Highway (NH) 58 is one of the important and the major lifelines, which connects Uttarakhand state with rest of the country and linked with its socioeconomic progress. Uttarakhand, being one of the major tourist and pilgrimage hubs of the country, highways are preferred to be consistently maintained and trafficable. However, due to frequent landslide occurrences, particularly during monsoon months (July to September), the highway is poorly maintained. There are hundreds of landslides along the NH 58 starting from Rishikesh (the foot of the Garhwal Himalaya) to Badrinath, the holy shrine of India covering a distance of 320 km. Many landslides are historic, 4–5 decades old and recurring every year during monsoon. Kaliasaur landslide (147 km), Pakhi landslide (250 km), Tangni landslide (254 km), Patalganga landslide (256 km), and Lambagarh landslide (302 km) are a few among the critical ones. Kaliasaur landslide that is one of the most critical landslides recurring for over 9 decades at 147 km on National Highway 58 (from Haridwar) has been selected for the study. It has reportedly occurred first time in 1920 and since then recurring at regular intervals, causing huge socioeconomic losses involving both direct and indirect costs. Previous records of any attempt to estimate the direct (rehabilitation cost, cost on prevention and control) or indirect cost (expenses due to detouring, cost of productive time loss, loss of tourism, and loss in business) have not been found. As a result, the accurate economical impact of landslide on society is very roughly estimated. Even if the estimates of indirect losses are roughly estimated, added with some direct losses will provide the basis for developing the right strategies for proper mitigation and management of landslides. In this paper, an effort is made, first time, to examine the effects of Kaliasaur landslide on socioeconomics of the region. Since the direct losses on property damaged could not be estimated due to lack of recorded documentation, this study mainly focuses on the indirect losses on detouring during the damage/blockage of the highway and some significant direct losses such as restoration work, loss of lives, and damage of vehicles.

Keywords Socioeconomic impact · Unit cost estimation method · Indirect landslide losses

I. S. Negi (✉) · K. Kumar · A. Kathait · P. S. Prasad
Geotechnical Engineering Division, Central Road Research Institute, Mathura Road, New Delhi 110025, India
e-mail: inder.lvgeo@gmail.com

1 Introduction

Landslides are geological hazards that cause damage to infrastructure, loss of human life and create disturbance and other problems related to transport (Suh et al. 2011), ranging from minor trouble to social and economic catastrophe (Crozier and Glade 2005). In recent years, because of urbanization and development, increased precipitation in landslide—vulnerable areas arising from changing patterns of global climate, the frequency of landslide events and the extent of damage resulting from slope failure are expected to be increased (Keller and Blodgett 2007, in Suh et al. 2011). Generally, landslides can be triggered by a variety of external stimulus, such as intense rainfall, earthquake shaking, water level change, storm waves, or rapid stream erosion that cause a rapid increase in shear stress or decrease in shear strength of slope-forming materials (Dai et al. 2002). Among the all causative factors, rainfall is the most common triggering agent. Landslides are triggered by both high intensities and short-duration rainfall (Glade 1998) as well as prolonged rainfall (Church and Miles 1987). Landslide damages are often reported as a result of a triggering event like an earthquake or an excessive rainfall episode (Spiker and Gori 2003), which can be represented by purely economic costs (Glade 1998). The overall cost of landslides includes both direct and indirect costs. Direct costs typically include property damage and restoration cost specifically associated with the physical impacts of landslide events (Schuster 1996). Indirect cost such as those incurred through the expenses resulting from driving longer distances and increased travel times (Zêzere et al. 2007). However, an accurate accounting of these costs is often difficult and not visible to a majority of the population (Highland 2003). The indirect costs from landslides can be as large, and in some cases, significantly more than the commonly reported direct damage figures, if they were realistically determined (Schuster and Fleming 1986). Generally, damage output data become available from several months to some years after the landslide occurrence, so that the data gathering turns to a complicated and long process. Consequently, so far, the estimation of the landslides monetary losses is not systematically or comprehensively investigated. The past estimates have been, in general, very qualitative and not well documented (Highland 2006). In the region of great Himalayan mountain ranges, one of the main causes of land degradation is landslides, and it is annually recurring phenomenon along the major communication routes. The occurrence of landslides is particularly common in geodynamically sensitive belts, that is, zones and areas repeatedly rocked by earthquakes and affected by the neotectonic activities (Valdiya 1987). The long sweep of Himalaya consists 30 percent of world's landslide (MHA 2011) in which Garhwal region is an essential and well known for its rapid altitudinal variation, varied topography and climatic extremes resulting a much varied and complex physical characteristics (Kharkwal 1993). Scientific studies about Garhwal Himalaya clearly reveal that there is an average of two landslides per sq. km (MHA 2011). The National Highways, especially NH 58, have been damaged every year at several locations. Consequently, the monetary losses through the landslides have become a serious matter. Thus, it is necessary to investigate landslides in a proper manner and suggest the ways for estimating losses either direct or indirect, associated with landslides. Kaliasaur landslide is a complex slope failure problem and one of the major landslides in India, which has consistently damaged the NH 58 for last nine decades. The landslide is located at 147 km on NH 58, 18 km ahead of Srinagar town, in Rudraprayag district of Uttarakhand (Fig. 1). According to the records of Geological Survey of India, Kaliasaur landslide came into existence in the year 1920 at this location. On September 19, 1969, a major slide occurred which have completely damaged 300 m length of highway and blocked three-forth of Alaknanda River, flowing 100 m below the highway. From 1970 to 1972, the sliding rate of the landslide varied from moderate to

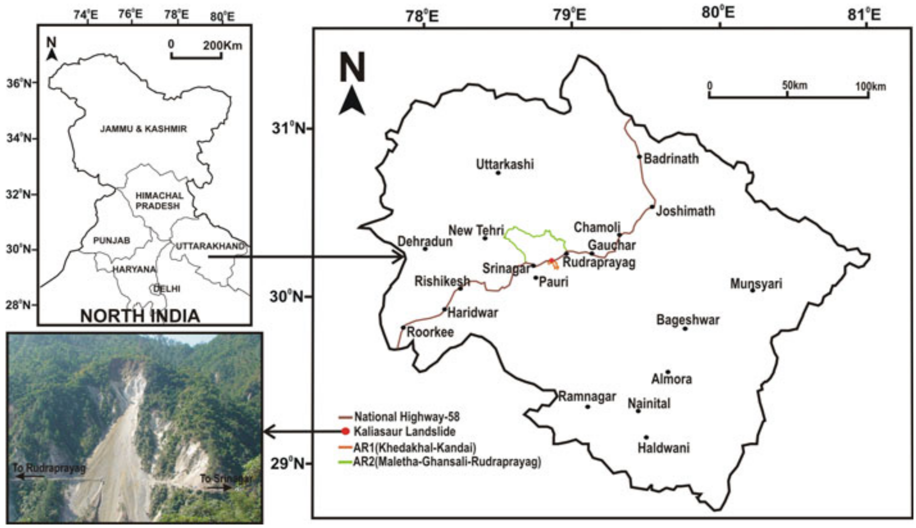

Fig. 1 Location map of Kaliasaur landslide

heavy (Sinha and Kumar 2004), which has caused disruption of traffic. Between 1974 and 1984, only minor slides have occurred except a major slide in the months of August–September 1984 (Bhandari et al. 1984). Thereafter, no major sliding took place; however, minor events kept on occurring during every rainy season. After a gap of at least 17 years, the landslide has reactivated again during September 2010 with high magnitude. Huge amount of material has slided down, which has completely covered the highway for 95 meter length. As a result, National Highway 58 was cut off for 45 days almost continuously and intermittently for 5 months. Due to this, the life of the inhabitants, the workers of Border Road Organization (BRO), and the commuters have become restless (Kumar et al. 2011a). This paper aims at highlighting the indirect and some of the direct losses associated with the slide, the hardships in reaching the destinations through other long and difficult alternative routes and estimates of the impact of landslide on socioeconomic situation of the region.

2 Study area

Kaliasaur landslide is located on the left bank of Alaknanda River about 18 km upstream of Srinagar township on NH 58 (Fig. 1). Spatially, the landslide is positioned at latitude: 30°14′30.6″ and longitude: 78°53′58.4″ stretched over an area of about 64,000 m^2. The study area belongs to Lesser Himalayan division, the rocks of which come under Rudraprayag Formation of Garhwal Group, ranging in age from Paleoproterozoic to Mesoproterozoic (Umrao et al. 2011). Lithologically, the landslide area mainly consists of metamorphic rocks namely Uttyasu Quartzite and Karanprayag Metavolcanics, which have been highly fractured due to tectonic activities in the past geological time. The prominent foliation of quartzite rocks dip toward SSW with an average azimuth of N190° and dip amount ranging from 35° to 50° and have wavy structures, that is, anticlines and synclines resulting from compressive phase of tectonic activities (Fig. 2).

The crown portion has low vegetation and existence of cracks near to periphery of the main slide. The main sliding body which has extended vertically about 265 m from crown to toe and about 140 m from road to the crown was mostly having concavo–convex slope up to 2009. The slope has transformed into mostly convex slope because of the recent landsliding in the year 2010. The main scarp has enlarged by 40 m since 1984 and 20 m in 2010 alone (Fig. 3). The lower portion just above the highway acts as zone of deposition of the debris, the slope of which earlier ranged from 35° to 45° and transformed into 40° to 50° by the sliding of highly fractured strata from crown part of the slide. The debris mainly consists of fragments of quartzite, metavolcanics, and gauge material of particles ranging from clay to boulder of 0.5 m dia. The main scarp houses both rocks: quartzite and metavolcanic. The joints in quartzite are filled with gauge material having strength ranging from 17 and 687 kpa (Sinha 1993). Due to extensive weathering and erosion from rain as well as wind, quartzite and metavolcanic rocks are in highly weathered form. Main scarp of landslide has irregular surfaces because of the numerous gullies of 0.5–1.5 m deep and 0.75–3.5 m wide sizes developed during last 2 year.

The landslide area receives maximum precipitation in July, August, and September with an average of 260 mm rainfall. However, the precipitation regime is diverse at both the inter-annual and the inter-seasonal scales. All along the highway, the vertical cut slopes are vulnerable because of moderate to highly jointed rock mass, intercalation of weaker strata, frequent minor faulting and continuous erosion and weathering of unprotected rock exposures. The planar as well as wedge failures have been observed and analyzed through kinematic analysis (Kumar et al. 2011b). A masonry retaining wall of 5 m high constructed in 2000, all through the length of the highway in the slide portion has helped in retaining the debris to some extent, but the reactivation of slide in 2010 has completely covered a stretch of 95 m of the highway (Fig. 4).

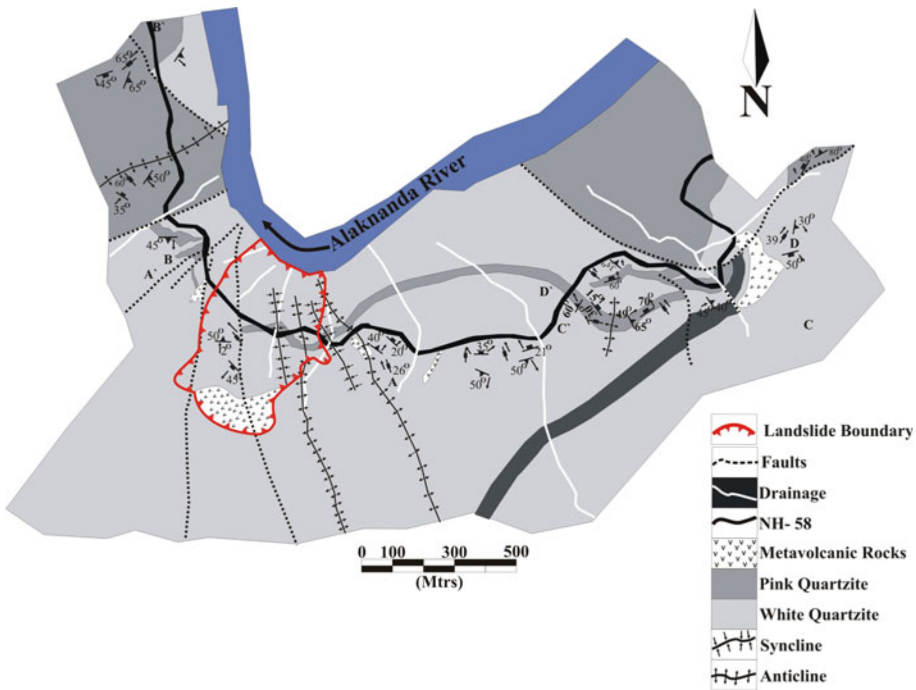

Fig. 2 Geological map of Kaliasaur landslide area

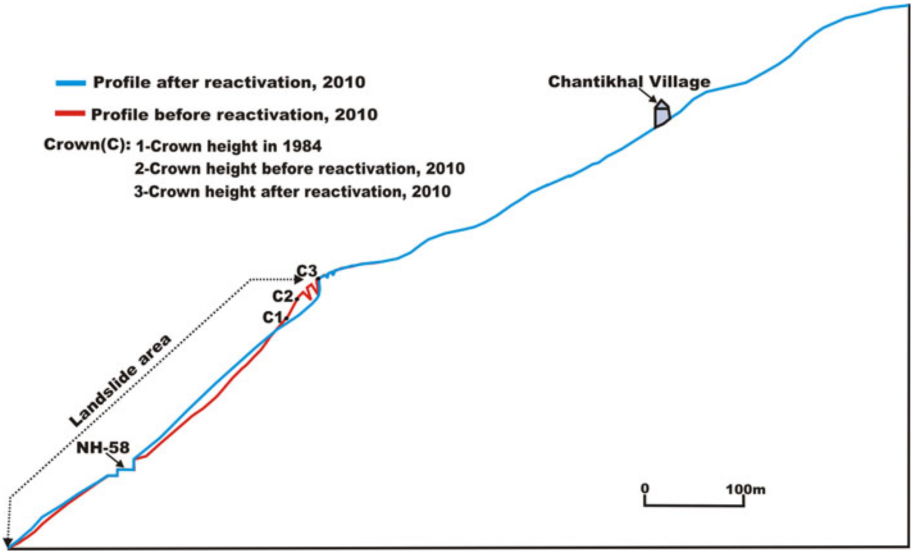

Fig. 3 Enlargement of crown of Kaliasaur Landslide since 1984

Fig. 4 Blockade of Highway due to large volume of debris generated

3 Highway closure consequences

National Highway 58 is an important and the only major lifelines of Uttarakhand, which connects the surrounding region with rest of the country and therefore linked with the socioeconomic progress of the region. Being one of the major tourist and pilgrimage hubs of the country, the highways are preferred to be always maintained without traffic disruption. However, in certain critical locations, the highways are often disrupted due to frequent landsliding. Although Kaliasaur landslide has been occurring since long, and similar events of like magnitude have been experienced earlier, no economic impact analysis was carried out. During one of the study conducted by Central Road Research Institute (CRRI) between 2006 and 2009, it was indicated that the slide was at the verge of the failure and was required to be prevented before the coming monsoon of 2010 (CRRI 2010). Due to cumulative effect of heavy rainfall during July–August, the slide has activated in the month of September 2010, and it has intensified after the rains stopped in the month of October 2010. From July to October 2010, the highway was reportedly blocked completely for 45 days and intermittently for 5 months. The chronology of the sequence of events under study area is mentioned in Table 1. As the highway remained busy most of the times because of the movement of tourists and pilgrims from all over the country, traffic disruption for such long time has created unrest among the visitors because of limited time on their schedules and excessive money for their stay and hardships, sometimes, beyond their tolerable limits. Thousands of them have travelled back to their respective places, and rest have waited for the traffic to restore (Fig. 5). Most of them who waited for a few days have followed alternate routes, namely Khedakhal-Kandai (AR_1) and Maletha-Ghansali-Rudraprayag (AR_2), 28 and 126 km long, respectively (Fig. 1). Local people who travelled for different purposes have got impacted in various ways: (a) People who travelled to earn their daily wages have lost their income, which on longer duration also impacted their families. (b) Those traveling to visit holy shrines lost their valuable time and money. (c) Many pregnant woman and several other seriously sick people needing immediate medical attention had no other option but to undergo tremendous hardship. (d) People traveling from far-flung areas of the country for visiting their families to attend the rare function/celebration etc. had to take extraordinary risk to reach the destination.

There are other serious socioeconomic consequences of the blockage of highway as the circumstances of unrest have forced few people to break the prohibitory restriction to cross the highway while taking risk to their life. This has resulted in loss of at least three lives on hitting by debris and damage of several vehicles (Fig. 6a and b).

The trading of basic amenities, fruit, vegetable, other eatables, etc. got affected, and the cost of these gone higher by multifold making unaffordable for most of the local public. This also created class inequality tension among the rich, middle class, and poor as the sky high rise cost of amenities could not be afforded by the poor people not only the local people but also the visiting tourists as well.

4 Methods for economic estimations

It is a well-considered fact that landslides are responsible for significant socioeconomic losses than is generally recognized (Khire 2004, in Kumar et al. 2010), and because of their socioeconomic implications as well as the scientific interest, these can be considered as a problem of greater relevance (L. Cascini et al. 1992, in Kumar et al. 2010). There are many appropriate approaches to evaluate the indirect landslide losses. The selection of methods that estimate the losses depends on their suitability. Some methods for estimation, as mentioned by MacLeod et al. 2005, are as follows:

- Unit cost estimation
- Empirical, probability-based risk assessments
- Survey data collection from personal accounts.

Table 1 Chronological sequences of Kaliasaur landslide reactivation

Date	Events	Remarks
July–September 2010	Heavy Rainfall over the Garhwal region averaging 504.8 mm (IMD 2011)	Broke all records and equivalent to 47 % of average rainfall of around last 5 years (Fig. 7)
July–August 2010	Minor slides continued	Highway closed repeatedly and affected the traffic intermittently
September–October 2010	Major slides occurred	Highway was completely covered by debris, around 45-day travelers force to detour, life of BRO workers became restless, thousands of tourists stranded. Three persons were killed and few vehicles have been damaged
November, 2010–February 2011	Landslide, still, in active condition but Sliding magnitude decreased	The road got blocked from time to time

Fig. 5 Vehicles trapped on both sides of NH 58 (**a**, **b**), during restoration work (**c**)

Fig. 6 **a**, **b** Damaged vehicles while crossing landslide zone

In the current study, as the landslide is on a major highway, indirect costs on detouring during the closure of highway and some direct costs like restoration work etc. are discussed. The unit cost estimation method (MacLeod et al. 2005) is used for estimating the

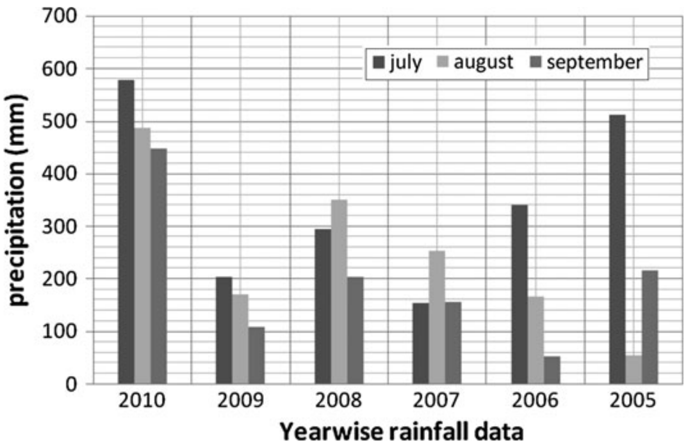

Fig. 7 Maximum rainfall in rainy season, 2010 over Kaliasaur landslide area

indirect impact of the road closure event in this case study. This method is applicable whenever a unit variable is known (e.g., days an area is affected) and the associated unit in this method, the cost (e.g., rupees lost per day) can be determined (MacLeod et al. 2005). When a road is closed for longer duration, travelers search for the alternate route and therefore mostly follow the detours. In order to use detouring through longer routes, the commuters are required to pay extra fares because of the need of extra fuel combustion and traveling time by the vehicles. In addition to that, the commuters loss the valuable productive time during detouring. The estimation of economic loss, mainly, depends on the availability of average daily traffic (ADT) data, which includes different types of vehicles such as cars, trekkers, buses, trucks, etc. Since each vehicle type has different fuel efficiency, their detour costs can be wide ranging. Hence, for the accuracy of total detour cost, detour cost of each vehicle is required to be computed.

5 Estimation of landslide costs: indirect and direct

As discussed earlier, NH 58 links the Uttarakhand state with rest of the country and is one of the most busiest highways during May to October each year. This is because, the networks of its subsidiaries are connected the four holiest shrines of India (Badrinath, Kedarnath, Gangotri, and Yamunotri called as “Char Dham”) and various other tourist places. To visit these places, millions of people travel from all over the country and world on this highway. The unit cost estimation method involves average daily traffic (ADT) data that help to estimate the number of commuters forced to detour through the alternative routes in the event of closure of the highway. On the basis of a traffic survey in that area, it was examined that a total of 1,635 vehicles of various types would have crossed the highway at this point, had the landslide not affected it (Table 2).

As shown in Fig. 8, the alternate routes used, while the highway was blocked at Kaliasaur landslide site. The alternative route AR_1 starts from Dogripant 9 km before the landslide site and meets the highway on the other end at Khakra 2 km after the landslide site covering 28 km, three times the usual distance on the highway.

Table 2 Varieties of vehicles crossed the landslide

Types of vehicles	Trekkers (i.e., local vehicles)	Tourist cars	Buses		Bikes	Trucks	
			(Mini)	(Large)		(Mini)	(Large)
Number of vehicles	630	335	125	90	260	80	115
Percentage of vehicles	38.5	20.5	7.6	5.5	15.9	4.9	7.1

Fig. 8 Alternate routes followed by stranded tourists and local commuters during blockage

This route being mostly unmetalled and temporary in nature do have rough surface with innumerable pot holes, narrow width, numerous curves, etc. Hence, the route was used mostly by the small vehicles such as cars and trekkers, etc. The large vehicles such as buses and trucks etc. had to detour through the alternate second, AR_2 (Fig. 8), which starts at Maletha around 24 km before landslide site through Ghansali to Rudraprayag meeting the highway after 19 km from site covering a distance of 126 km. The vast dissimilarities between the extents of alternate routes and NH 58 incurred huge indirect losses in many aspects like loss of productive time, extra travel fare, and additional fuel consumption. The estimation of costs resulting from these aspects allows assessing a more accurate figure of overall indirect losses. Indirect costs associated with loss of productive time are difficult to evaluate, but are very relevant as well. Firstly, we considered minimum average circulation velocities for different vehicles, that is, 20 and 35 km/h as per their performance on the routes, that is, AR_1 and AR_2, respectively. As per, the circulation time difference resulting from detour paths to the highway was calculated (Table 3). Secondly, productive hours lost

Table 3 Circulation time difference resulting from detouring to NH 58

No. of vehicles (ADT)	Alternate routes	Distance (km)	Average speed (km/h)	Mean circulation time (min)	Distance on NH 58 (km)	Average speed (km/h)	Mean circulation time (min)	Time difference
1,430	AR_1	28	20	84	9	45	12	62
205	AR_2	126	35	216	43	45	57	159

Table 4 Daily cost derived from loss of productive hours resulting from detouring

No. of vehicles (ADT)	Alternate routes	Affected people	Total hours/day	Daily time loss cost (USD)
1,430	AR_1	14,085	14,554	33,734
205	AR_2	3,380	8,957	20,760

per day were obtained, which is the product of affected people per day by the highway closure and time differences related to each detour path to the highway. Considering every affected people as labor force (Zêzere et al. 2007), it was calculated by the number of seats in different types of vehicles. Finally, an estimated income per hour of labor force equal to 2.3 USD was multiplied by the productive hours lost per day to achieve the daily cost resulting from time loss. Table 4 summarizes the daily indirect cost derived from loss of productive hours resulting from detouring through the alternate routes and number of affected people. The additional cost as a travel fare based on enquiry from local administration for chargeable vehicles, that is, buses, trekkers, tourist car, etc. varies from vehicle to vehicle because of nonexistence of a fixed fare. The difference in cost of fare as reflected in table forms an essential socioeconomic impact on tourists and local commuters (Table 5). The tourists paid exorbitant amount (i.e., 17.8 USD or 2 USD per passenger) for booking a tourist car on traveling through the alternate route AR_1. Normally, the travel fare of other vehicles like minibuses, trekkers, etc. was found more reasonable, although the journey with these vehicles was uncomfortable due to crowd inside the vehicles and unfavorable road condition. The variation of driving distance on NH 58 against alternate routes caused additional amount of fuel consumption during detouring. The cost of the extra fuel consumption was calculated by taking the fuel cost established in Uttaranchal state in October 2010 as 1.2 USD and 0.9 USD for petrol and diesel, respectively, as shown in Table 6. Total daily indirect costs resulting from detouring due to Highway closure by Kaliasaur landslide estimated as 80810 USD summarized in Table 7. Hence, the cost of indirect loss for 45 days of closure of highway in the months of September and October 2010 was estimated as 3636450 USD. Besides detouring, there are other vital direct losses, which resulted from restoring the connectivity by clearing the debris, lives lost, etc. Border Road Organization (BRO) has engaged two full time dozers for clearing the debris with certain number of laborers and BRO officers. The usage rates for dozers and man powers that have been deputed by BRO estimated as 35.3 USD per hour and 3.5 USD per day, respectively. The total usage hours for dozers and total man days on account of restoration of highway connectivity during August to February comes out to be 7,920 and 2,100, respectively. Three persons have been reported killed and two vehicles damaged, while crossing the landslide in active stage. According to the norms of assistance from calamity relief fund (CRF) (2005–2010), payment for per deceased person is 2222 USD (MHA

Table 5 Cost for extra travel fare resulting from detouring

Alternate routes	Type of vehicles	Travel fare (USD) (per passenger)	Fare difference (USD) to NH 58	No. of vehicles	Additional travel fare (USD)
AR_1	Trekker	1.3	1.20	630	7,700
	Tourist car	2.0	1.80	335	5,360
	Minibuses	0.6	0.56	125	2,083
Total				1,090	15,143
AR_2	Large buses	3.3	2.10	90	7,600
Total ($AR_1 + AR_2$)				1,180	22,743

Table 6 The cost for extra fuel consumption resulting from detouring

Alternate routes	Extra distance covered (km)	Type of vehicles	No. of vehicles	Additional kilometers (km)	Additional fuel (liter)	Additional fuel cost (USD)
AR_1	19	Trekker	630	11,970	798	720
		Tourist car	335	6,365	424	383
		Minibuses	125	2,375	237	214
		Mini trucks	80	1,520	152	137
		Bikes	260	4,940	165	201
Total			1,430	27,170	1,776	1,655
AR_2	83	Large buses	90	7,470	934	842
		Large trucks	115	9,545	1,193	1,076
Total			205	17,015	2,127	1,918

Table 7 Total indirect costs resulting from detouring due to highway closure

Alternate routes	Daily cost (USD)				Cost for 45 days (USD)
	Additional fuel	Additional travel fare	Time loss	Total cost	
AR_1	1,655	15,143	33,734	50,532	227,3940
AR_2	1,918	7,600	20,760	30,278	136,2510
Total	3,573	22,743	54,494	80,810	363,6450

2007). Hence, the relief for three lost lives is 6667 USD. The repair cost of the damaged vehicles was nearly half of their original value, which was approximately 5556 USD. As a result, the direct loss on restoration work, lives loss, and vehicles damage estimated as 299223 USD in Table 8. The total cost of reactivated Kaliasaur landslide including direct and indirect costs of different particulars works out to be 4 million USD approximately; their percentages are shown in Fig. 9.

Table 8 Total direct costs due to restoration work, lives loss and damaged vehicles

Restoration Work on NH 58 (from August 2010 to February 2011)		Lives loss (USD)	Damaged vehicles (USD)	Total cost (USD)
Dozer usage (USD)	Man days (USD)			
279,532	7,468	6,667	5,556	299,223

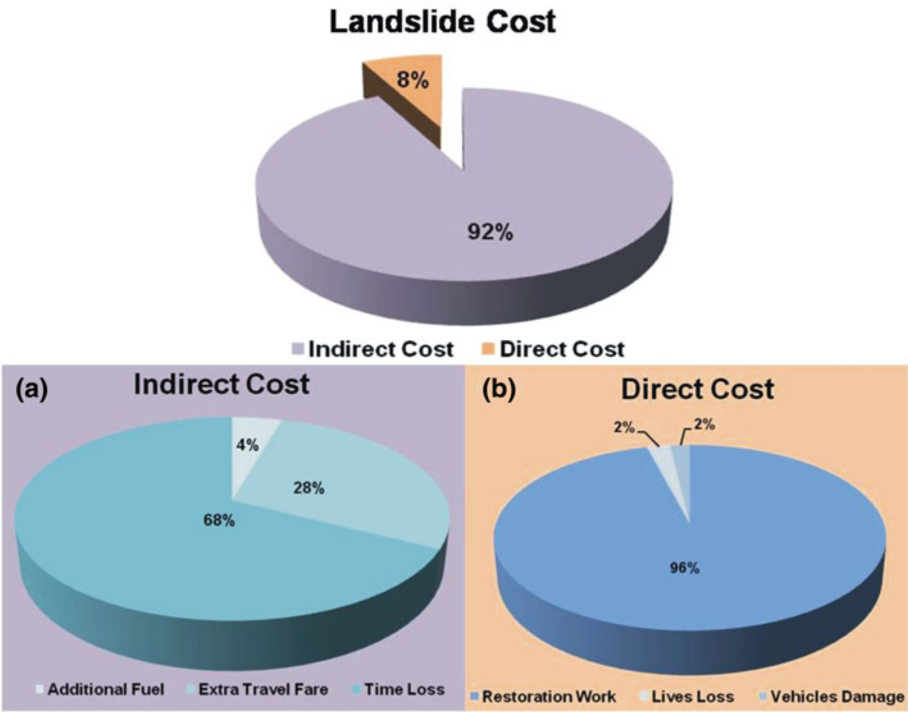

Fig. 9 Each particular cost's percentage in landslide cost, that is, indirect cost (**a**) and direct cost (**b**)

6 Discussion

The cost estimation on detouring and on clearing the debris, and vehicles damage may be not accurate but close to the accuracy. The August to February are not the peak season months when number of tourists are much less than the peak season months from May–August. There were instances when the landslide has happened in the past during June–July–August months. The prices, if calculated, could go much higher. Socioeconomically, it was a tough time for the commuters, especially, tourists who were excessively suffered as they were stranded and forced to detour through alternate routes. During the closure, 17,465 numbers of commuters travelled daily through the alternate routes and paid extra amount averaging 1.42 USD per commuter to reach the destination. Both the alternate routes, that is, AR_1 and AR_2 have distances that are three times greater than that on NH 58. Being a village road the alternate route (AR_1) was not maintained for such kind of traffic and therefore was very risky as well as uncomfortable. The same route was not a better option for heavy vehicles like large buses and large trucks etc. As a result, the heavy vehicles had to follow a better route AR_2 which has distance variation of 83 km and was only the other option for the heavy vehicles. Since vehicles cover longer distance, time loss as well as fuel consumption had to be more. The essential cost on time loss which amounted to 54494 USD contributed more than half sum of the total indirect cost per day resulted from detouring.

7 Conclusion

The study assessed indirect and direct losses incurred due to closure of highway NH 58 in the event of Kaliasaur landslide using unit cost estimation method that will assist to frame impact of the landslide due to disruption in connectivity on the other highways or roads of Garhwal Himalaya. Impact of the closure on the socioeconomic situation has brought out the following issues 1. Greater needs to formulate landslide management strategy to tackle such historic landslides like Kaliasaur. 2. The impact due to Kaliasaur landslide is just indicative as there are several other landslides on National Highway 58 and other subsidiaries in Uttarakhand and large number of landslides in other highways of the country. 3. The socioeconomic impact highlighted is enough to sensitize the people about the need of identifying such historic and recurring landslides and plan a strategy to minimize the impact on people and economy. 4. The study also brings out the importance of socioeconomic impact on account of direct or indirect losses incurred to exchequers. In this study, we did not estimate the associated loss of business at local shop, restaurants, hotels, etc. because the event might have also been fruitful to some petrol pumps and restaurants located on or near vicinity of the alternate's routes and near the landslide site. As a result, such profits are found to be reducing the losses on business in the study area. The indirect cost of the overall impact will be much higher when compared with the direct cost. Therefore, there is a urgent need of a suitable management plan, whether to stabilize the slide with long term remedial measures or avoid it by considering an alternative route.

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