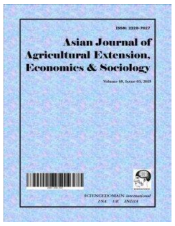

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Assessment of Economic Viability of Engineering Structures as Landslide Protection Measures in Landslide Prone Zones

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Authors' contributions

This work was carried out by author VM in supervision of author DT. Both authors read and approved the final manuscript.

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ABSTRACT

A landslide is a downslope movement of rock or soil, or both, occurring on the surface of rupture. Landslides are just a hazard in an uninhabited place. But, they turn into disasters when they occur in areas of human habitation. Due to increase in population and rapid urbanization, construction activities in hilly terrains have led to rapid expansion. This has led to the frequent landslide hazards in the hilly terrains, mostly in the Himalayan region which experiences bewildering varieties of landslides. The intensity and severity of impacts of the hazards can be minimized if the problem is recognized before the development activity. The tools available for measuring mitigation are risk assessment and economic appraisal methods like cost benefit analysis. The objective of this study was to assess the economic viability of the landslide protection measures. Thus in this study the cost economic benefits of engineering structures were assessed for the benefits as landslide protection measures. It was found that constructing the mitigation structures mitigates the landslides but maintaining the structures prolongs the benefits of the structures for a longer time.

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Keywords: Landslides; mitigation; risk; economics; cost-benefit.

1. INTRODUCTION

Landslide, a frequently occurring natural hazard in the hilly terrains of India, shows preponderance of activity during the monsoon period from July to September and after the snow fall from January to March. The developments that have taken place in the region has disturbed the mountainous ecosystem particularly steep slopes were created when the ground is leveled for housing and road construction. Natural slopes are disturbed due to cutting of roads for constructions purposes, prevention of natural drainage and the changing land use pattern are the factors contributing to landslides. Most of the times it is triggered by high intense down pour [1]. The effects of landslides on people and structures can be lessened by total avoidance of landslide hazard areas or by restricting, prohibiting, or imposing conditions on hazard - zone activity [2]. It is one of the most destructive geological processes which causes enormous damages to the roads, bridges and houses and even loss of lives. The nation will always be vulnerable to natural hazards; therefore, it is only prudent to invest in mitigation. In this context, mitigation should be considered in the broadest possible sense to encompass mitigation projects and processes that relate to enforcing strong building codes and land use and zoning measures as well as developing comprehensive plans that will limit disaster-caused damage and promote reduced losses from such things as disruption of utilities and transportation lifelines [3]. In spite of the theoretical limitations, multi criteria decision or evaluation methods have been employed for many years in order to select the most suitable way of dealing with or altering different environment methods [4]. Mitigation decreases the losses from natural hazards by reducing our vulnerability or by reducing the frequency and magnitude of causal factors [5]. Cost-benefit analysis is a standard tool for determining the efficiency of planned projects [6]. Cost benefit ratio defined that prevention would have been economically convenient compared to a non-preventive and passive attitude, allowing a 30% saving relative to total costs [7].

1.1 Study Area

The study area is Nilgiris district, which is located in Tamilnadu state and lies between the latitudes 11o 10’ and 11 o 43’N and longitudes 76 o 15’ and 77 o 00’E and it covers 2541 km2. The study area falls under the Survey of India toposheets No: 58 A/6, 58 A/7, 58 A/8,58 A/10,58 A/11, 58 A/12, 58 A/14 and 58 A/15. The Nilgiris is situated at an elevation of 2636 meters above Mean Sea Level (MSL).

2. MATERIALS AND METHODS

The Nilgiris district usually receives rainfall from both during south west (June, July) and north east (October, November) monsoons. The South west monsoon contributes to the entire Gudalur, Pandalur, Kundah taluks and a part of Ooty taluks. The North east monsoon contributes to some parts of Ooty taluk, entire portion of Coonoor and Kotagiri taluks. The normal average annual rainfall of the district varies from place to place and is somewhere between 1500 to 3000 mm. The daily rainfall data of the Nilgiris district from 29 rainguage stations for 29 years were collected from the Indian Meteriological Department, Chennai.

The cost of slope stability and soil and water conservation measure structures like retaining walls and Gabbion structures were obtained from the Agricultural Engineering Department, Ooty for analysis. The cost of Rain water harvesting structures was obtained from Collecterate, Coimbatore for analysis. Investment in this infrastructures provide ancillary benefits which offset the cost of transportation, education and health care [8]. The cost of compensation for damages or the relief expenditures on natural calamities by the Government of India was also obtained from the Collecterate, Coimbatore for analysis.

The cost of Gabion check dams includes Rs. 500 for site clearing, earth work excavation of 34 m3 at a rate of Rs. 56/m3 was Rs.1905.00, for structure of 42.82 m3 at a rate of 725 / m3 was Rs. 31044.50 with unforeseen items of Rs. 1550.50 accounted for Rs.35,000.00.

The cost estimation of retaining walls of 2 m height includes Rs. 200 for site clearing, earthwork excavation of 2.90 m3 was Rs. 162.40, cement concrete for foundation of 0.18 m3 was Rs.315.00 and RR masonary with 2.05 m3 was Rs 3997.00 with pointing and plastering of 2.45 m3 was Rs.206.80 which accounts to Rs. 5000 per structure.

The cost estimation of Rain Water Harvesting structures soak pit earth work estimation 1.36 m3 was Rs. 115.00, Collection and supply of sand filling into the basement including cost and conveyance to the site and all labour charges was Rs. 45.00, Brick work in CM 1:5 mix using country bricks ground moulded of size 22x11x7 cm for the following including curing etc., complee complying with standard specifications was Rs. 1022.00, Collection and supply of filling the stones in soakpit including cost and conveyance of materials to the work site and all labour charges was Rs. 862.00, Plastering for supply and fixing of precast RCC cover slab including cost and conveyance was Rs. 1000, Supplying and fixing in position best approved of BIS quality PVC rain water down fall pipes having a pressure of 4 kg/sq. cm including cost of necessary PVC shoe, bend, cast iron gratings of required diameter and special clamps, brass screws, nails, etc., and fixing of cast iron gratings at junction of parapet and the RCC roof slab including finishing neatly etc., complete. The rate shall be inclusive of cast of removable cast iron grating. The PVC pipe shall be fixed in wall with special type of U clamp at the centre of the pipe line in addition to those for more than 3.0 m pipe length, etc., complete complying with standard specification was Rs. 2160.00, Provision for Name Board was Rs. 100.00 and Miscellaneous and Unforeseen charges was Rs. 548.00 respectively which accounts for a total of Rs. 6000.

2.1 Estimated Costs

Estimates of the different landslide mitigation structures components and the project cost are given. These are based on the unit costs of construction adopted by the government.

2.2 Landslide Probabilities

A number of simplifying assumptions are made regarding landslide probabilities. An assumption of whole slope failure has occurred in a location that from then onwards no landslide will occur in the same location. The slope failure occurs in a year that it may not occur again in the same year. This is done to avoid double counting the landslide costs and is consistent with providing a conservative estimate of the intervention benefits.

2.3 Direct Benefits of Risk Reduction

These can be quantified by comparing the expected costs from landslides without intervention having occurred to the expected costs from landslides with the intervention having occurred. The estimation of direct benefits of the intervention involves the translation of these damage potentials into costs and incorporating the probability that these costs will be incurred with and without intervention of the mitigation structures. The estimated total costs include for each house lost, there is a monetary cost in rebuilding it and providing temporary accommodation to its tenants, repair cost and loss of possession cost.

2.4 Present Values of Expected Benefits

The total benefits of the intervention over the expected project lifetime which depends on the degree to which the structures are maintained. Blocked, cracked or disconnected structures will cause the infrastructure to be ineffective or deteriorate more rapidly. Based on experience, it is estimated that with maintenance the lifetime of the structures can be up to 20 to 25 years provided it is functioning properly. Without maintenance the structures may become ineffective after 7 to 10 years based on the structures. About 20 years is the limit for a cost/benefit analysis because of the possible changes in the inflation rate and in the discount rate [9].

Cost benefit analysis was done to test the economic viability of reduction of landslide by construction of loose boulders, Gabion check dams, retaining walls and rain water harvesting structures in the Nilgiris district.

The cost benefit ratio was done using the Present value (Pv) method. The formula for Pv is

$$Pv = \partial_t \cdot P_{LO} \cdot C_D$$

[10] here, ∂t is the discount factor, PLO is the probability of occurrence of landslide in a year and C D is the cost of damages in a year. ∂t, the discount factor is estimated using the formula

$$\partial_t = \frac{1}{(1+r)^t}$$

[10] where; r is the discount rate (or) rate of interest, t is the time period.

Let PA,t the probability of whole slope failure landslide occurring in a year t

qA = 0.1
qA, I = 0.01 if the intervention has occurred, 0.1 otherwise
N = project life time

2.5 Assumption

PA,t = qA,I for t<=t-1, and no landslide has occurred in year i, for all i<t

or = qA for t > N and no landslide has occurred in year i, for all i<t

The present value of the expected costs from future whole slope landslide is calculated by the formula [10]

$$\frac{q_{A,I}c_A(1-[\{1-q_{A,I})/(1+r)]^N}{1-[(1-q_{A,I})/(1+r)]} + \frac{q_A c_A[1-q_{A,I})/(1+r)]^N}{1-[(1-q_A)/(1+r)]}$$

Assessing indirect benefits is by reducing landslide risk by improved drainage and installation of roof guttering which provides a number of additional benefits to the residents by saving in water bills through the harvesting of intercepted rainwater from the roofs, improved access for offices and schools through roads due to reduced flooding and saving of income gain which would have been lost after landslide occurrences for a minimum of 15 days. A discount rate of 12 percent is used based on the upper limit of the bank rates. It is assumed that a 35% reduction in effective rainfall was accounted for the rainfall which would reach the ground and trigger the landslides. An interception of the rainwater, grey water and black water and safer disposal of all would definitely prevent the landslides.

The construction of the loose boulders, Gabion check dam and retaining wall is estimated for time period is 10,20 and 25 years without maintenance and 20,40 and 50 years with maintenance.

The construction of the rain water harvesting structure is estimated to cost Rs. 7000 without maintenance for a time period is 7 years and with maintenance for a time period of 20 years.

Approximately 1100 families affected, 45 killed and 1890 houses were damaged during the landslide and the compensation details were collected for the same. The compensation for the deceased persons is Rs. 1 lakh /-per deceased, loss of body parts is Rs 50,000 /-per person and loss of agricultural land is Rs 15,000 /- per hectare and damage of crops to Rs 6,000/- per hectare. The assistance for damaged houses is for fully damaged/ destroyed houses is Rs 25,000/- per pucca house and Rs 10,000/- per kutcha house and severely damaged houses is Rs 5,000 /- per pucca house and Rs 2,500/- per kutcha house (Source: Office of Rural Development, Disaster Management Cell, Collecterate, Coimbatore).

3. RESULTS AND DISCUSSION

Cost Benefit analysis indicates that the preventive measures to landslide hazard mitigation are economically convenient than a non preventive measures and passive attitude. The total cost to be invested for the constructing the mitigation structures in a particular area and individual structure cost allocated for landslide mitigation measures structure establishment by the government has been obtained from the respective departments and has been used in the study. The works of establishing the structures are carried out by the Hill area developmental programme and by the Office of the Agricultural Engineering department by obtaining the funds from the State and Central Government. The costs for construction for drain works, retaining walls, culverts and rain water harvesting structures for the year 2011 to 2012 were 98.1, 46.8, 129 and 997.63 lakhs.

Soil and water conservation works under taken by the Agricultural Engineering Department in Nilgiris are treating contour bunding with vegetative fencing, terrace support wall, bench terracing works, silvi pastoral development, staggered contour trenching, check dams, drainage line works, dry stone pitching etc. In 2006 to 2007, 341 ha were treated with bench terracing, renovation of existing terraces and staggered trenching works. About 1093 structures and 567 m of terrace support wall and channels were aligned. Under 10th five year plan about 887.50 crores were allocated and 867.15 crore expenditure were done on developmental works. Density of the population was from 165.21 to 765.02 per sq km. Labour charges were from Rs. 300 to 400. Total number of workers both male and female were 3,46,669 according to district handbook0809. Details of compensation for disasters like landslides were obtained and used for the study from the Department of the disaster management wing, Coimbatore. Based on these data cost benefit ratio of the Coonoor micro watersheds were calculated.

3.1 Expected Benefits from Landslide Risk Reduction

It has been found that a loss of 200 crore rupees (Rs) of property and 4 9 lives has been lost in 2009 landslides. Direct benefits from the reduction in landslide like reducing the expected cost of rebuilding damaged homes and replacing lost possession and indirect benefits from improvement in the people's daily life were calculated. Cost benefit analysis is taken up to compare the economic efficiency of various alternatives used to reach a specific objective.

The present value of the expected benefits was calculated at a discount rate of 12%. The Net Present Value (NPP) is an estimation of the effectiveness of the mitigation measures adopted which expresses the present value of total benefits minus the present value of total costs. The Benefit cost ratio expresses the present value of total benefits relative to the present value of total costs. The indirect benefits in reducing landslide risk are by improved drainage and installation of roof water harvesting structures. For a 100 m^2 of roof catchment for an annual rainfall of 600 mm to a height of 0.6 m, the volume of rainfall will be around 60,000 litre (l). If the roof is tiled then the coefficient of roof surface is 0.85 and for metal sheet it is 0.8. Thus the rain water harvested will be 40,800 l. This would meet the drinking water requirement of the members of the family and will ultimately reduce the water bills imposed. The estimated costs and benefits of landslide risk reduction calculation is show in the Table 1.

The present values of the estimated benefits were calculated for 7, 10, 20, 30, 40 and 50 years for retaining walls, check dams, drains and rain water harvesting structures. It shows the present value of the estimated benefits with maintenance exceeds the present value of the estimated benefits of all the structures without maintenance and has been shown in the Figs. 1, 2, 3 and 4.

While surveying the study area and getting relevant information of the landslide mitigation measures, it was found that constructing the structures does play a main role in mitigating the landslides but lack of maintenance of the same reduces its effects in due course. Hence the benefit ratio of the structures were assessed with and without maintenance of the structures.

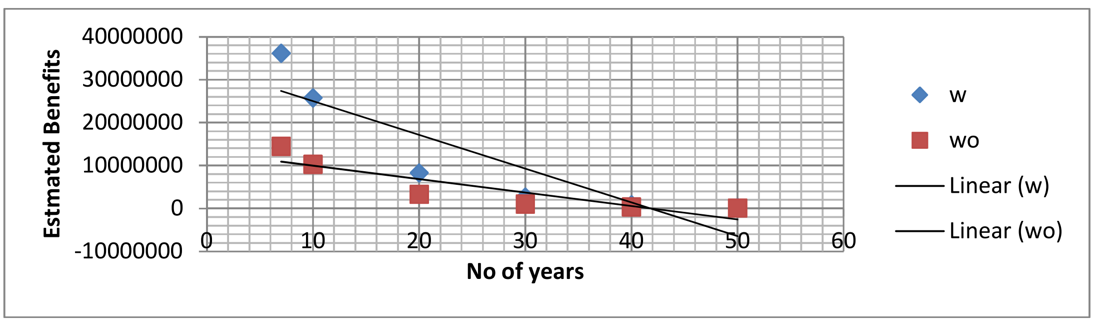

Fig. 1. Estimated benefits of retaining wall with (w) and without (wo) maintenance

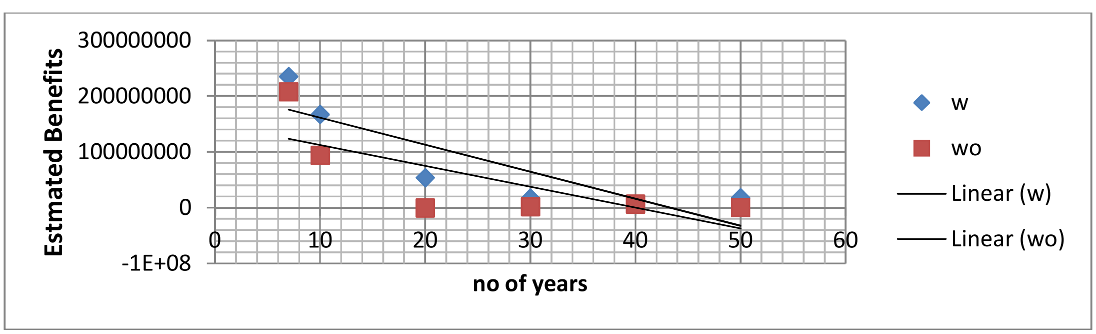

Fig. 2. Estimated benefits of check dams with (w) and without (wo) maintenance

Table 1. Estimated costs and benefits of landslide risk reduction

	Retaining walls (Rs)		Check dams(Rs)		Drain (Rs)		Rain water harvesting structures (Rs)	
	With maintenance	**Without maintenance**	**With maintenance**	**Without maintenance**	**With maintenance**	**Without maintenance**	**With maintenance**	**Without maintenance**
Initial costs	46,80,000	46,80,000	1,28,00,000	1,28,00,000	98,00,000	98,00,000	9,97,63,000	9,97,63,000
Estimated cost of maintenance	11,232	-	3,07,200	-	2,35,200	-	23,94,213	-
Present value, Estimated costs	46,91,232	46,80,000	1,31,07,200	1,28,00,000	1,00,35,200	98,00,000	10,21,57,312	9,97,63,000
Present value, Estimated benefits	82,93,341	1,03,03,143	1,73,56,520	2,15,62,689	1,86,60,017	2,95,96,794	12,65,60,000	18,20,00,000
Net Present Value	36,02,109	56,23,143	45,56,520	84,55,489	8,86,00,017	1,95,61,594	2,67,97,000	7,98,42,688

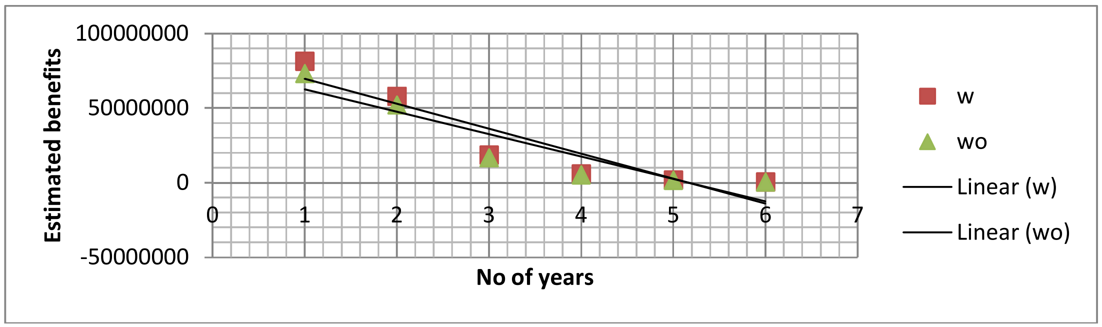

Fig. 3. Estimated benefits of Drains with (w) and without (wo) maintenance

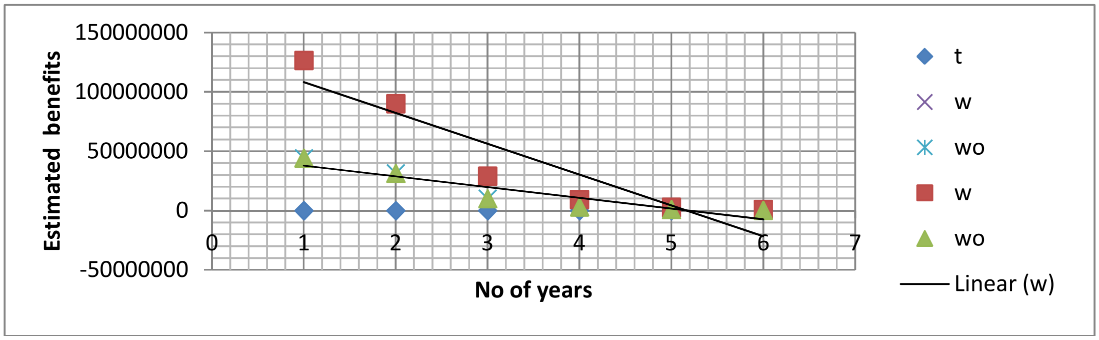

Fig. 4. Estimated benefits of Rain water harvesting structures with (w) and without (wo) maintenance over the number of years (t)

The benefit cost ratio of retaining walls, check dams, drains and rain water harvesting structures were as 2.2, 1.6, 2.9 and 1.7 and lack of maintenance has reduced the ratio to 1.7, 1.3, 1.9 and 1.2 respectively.

It is assumed that the installation of the roof guttering and its connection to the drains will reduce the total volume of rainfall reaching the ground surface by 35%. If the drains intercept the surface water runoff which would otherwise be concentrated at convergence zones and infiltrate in to the ground and trigger landslides, around atleast 50% of the water will be properly drained, thereby reducing the chances of triggering the landslides. It would also improve the efficiency of the structures if it is properly maintained by monitoring and repairing the breaches then and there.

4. CONCLUSION

4.1 Cost Benefit Analysis

The indirect benefits in reducing the landslide risk, is by improved drainage and installation of roof guttering have the potential to bring about a number of additional benefits to the residents. These include

- Savings in water bills through the harvesting of intercepted rainwater from the roofs
- Installation of roof guttering and its connection to the drains reduces the amount of rainfall infiltrating into the slope by the roof of the houses is known to be 35%. This further improves the slope stability.
- Greater reduction in landslide probability would be expected if the grey water and black water interception is also included.
- Thus there will be reduced erosion and flood damage to the property.
- A portion of the rainwater falling on the slopes can be intercepted by contour drains.
- Uninterrupted daily chores like getting to work and school

Direct benefits involves the improvement of the soil stability through construction of retaining walls, check dams for proper disposal of the excess water flow, safe disposal through drains which fails to trigger the landslides thereby increasing the soil stability and reduces the weight of the soil mass and getting water from roof water harvesting for drinking and other purposes. The estimated benefits were found to be more with the maintenance of the structures than that of without maintenance over years. The benefit cost ratio was found to reduce with lack of maintenance over years. With the increase in cost of living, materials and labor cost, care should be taken to increase the economic viability of the structures by maintaining the structures rather than reconstructing after damages.

Comparing the costs of construction with the present value of expected benefits it is justified that the proposed projects are economically viable and hence it is concluded that the cost of maintenance is less compared to the mitigation measures adopted after the disaster and hence it is recommended that after the installation of the structures proper maintenance should be carried in order to get the most benefit out of it.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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