https://doi.org/10.3126/juem.v3i1.84513

ANALYSIS OF THE COST EFFECTIVENESS OF RETROFITTING USING THE BENEFIT-COST RATIO AND THE BREAKEVEN POINT ANALYSIS

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Submission Date: 28 July 2025
Revised Date: 11 August 2025.
Accepted Date: 14 August 2025
Published Date: 20 Sept. 2025

Cite this: Banjara, S. and Shrestha, S., (2025)., Analysis of the Cost Effectiveness of Retrofitting Using the Benefit-Cost Ratio and the Breakeven Point Analysis, JUEM 3(1), 16 – 26, https://doi.org/10.3126/juem.v3i1.84513

ABSTRACT

The retrofitting of buildings has become an important strategy for improving seismic resilience in Nepal after the Gorkha earthquake. The National Reconstruction Authority (NRA) led the effort to rebuild earthquake-damaged infrastructure and included retrofitting as a key way to strengthen weak structures. This study looks at the economic feasibility of retrofitting low-strength masonry buildings by examining the breakeven period and benefit-cost ratio (BCR) in different cost-benefit scenarios for the building that has been retrofitted post-Gorkha earthquake with the assistance of the NRA. Data were gathered through surveys with stakeholders, including homeowners, engineers, and officials, and verified using government cost norms and district unit rates. Benefit estimates came from existing literature and were analyzed using financial metrics like Net Present Value (NPV), Benefit-Cost Ratio (BCR), and Breakeven Point (BEP). The results show that the breakeven period for retrofitting is 7.26 years, which fits well within the usual planning timeframe. Additionally, the benefit-cost ratio stays above one, even when retrofitting costs rise by 20% and expected benefits drop by 20%. These findings highlight the cost-effectiveness and financial sustainability of retrofitting to reduce seismic risks. This study offers useful insights for policymakers, engineers, and stakeholders who want to improve the resilience of Nepal's built environment through targeted retrofitting efforts.

***Key Words**: Retrofitting, masonry buildings, cost-effectiveness, benefit-cost ratio, breakeven point*

Introduction

Masonry buildings made from traditional techniques and low-strength materials dominate the residential areas of rural Nepal and much of the Himalayan region. These structures often lack professional engineering oversight. They do not include essential features for resisting earthquakes, such as proper detailing, anchorage, and paths for lateral loads. Because of this, they are especially prone to collapse during moderate to severe earthquakes. This weakness was tragically highlighted by the Gorkha earthquake on April 25, 2015. It caused widespread destruction and loss of life, especially in districts where informal construction practices were common (National Planning Commission, 2015).

Post-disaster assessments by government and international agencies found that the most damage happened in unreinforced masonry (URM) buildings, particularly those built before modern building codes were enforced (National Planning Commission, 2015). In response, the Government of Nepal started a significant recovery and reconstruction plan by creating the National Reconstruction Authority (NRA). This authority focused on rebuilding vital infrastructure and restoring the country's housing. A key part of this plan was to promote structural retrofitting as a cost-effective and less disruptive option compared to total demolition and reconstruction.

Standardized retrofitting techniques, such as bandages, jacketing, and wire mesh reinforcement, were proposed by national technical committees. These suggestions came from field experience and international guidelines (Nepal Reconstruction Authority, 2021). The retrofitting methods were intended for community use, employing locally available materials and labor to support scalable, non-invasive strengthening solutions in developing areas. However, even though these techniques are technically feasible, their widespread use has not happened yet. The main obstacles include the view that retrofitting is too costly and the lack of clear cost-benefit validation from the end-user perspective (Shrestha, Pradhan and Guragain, 2012)

The district of Makawanpur, located in Nepal's Bagmati Province, is a typical example where weak masonry buildings are common and financial limits restrict major reconstruction efforts. In these situations, figuring out if retrofitting is cost-effective is vital for encouraging its use and for helping with informed choices on policies and funding. It's important to know if retrofitting provides a good return on investment, especially in different financial situations. This information is crucial for governments, NGOs, and homeowners with limited resources who want to ensure the long-term safety of their structures. Ensuring the resilience of critical infrastructure, whether against earthquakes, fire, or other hazards, remains a global challenge. For instance, recent studies have shown that infrastructures are highly vulnerable to fire due to inadequate design considerations (Sharma Gyawali *et al.*, 2025) .This highlights the need for proactive risk reduction measures, such as retrofitting, especially in hazard-prone regions like Nepal.

This study seeks to address this gap by measuring the economic feasibility of retrofitting masonry buildings in the Makawanpur district. It uses well-known financial indicators like Benefit-Cost Ratio (BCR), Breakeven Point (BEP). We collected primary data through structured surveys with homeowners, engineers, and municipal officials involved in post-earthquake recovery. We validated costs using local rates and government standards. We derived benefits from literature and made assumptions about reducing damage, avoiding casualties, and extending building lifespan.

The goals of this study are to evaluate (i) if the cost of retrofitting can be recovered within the expected planning period and (ii) if it results in net economic benefits under different cost and benefit scen arios. This study focuses on residential masonry buildings identified as candidates for retrofitting under the NRA program. The importance of the study is in its ability to provide a model that can be used to assess retrofitting decisions in similar post-disaster situations around the world.

The stakeholders for this research include different levels of government, international donor agencies, structural engineers, construction contractors, and most importantly, homeowners and communities impacted by past or future earthquakes. This study presents a thorough financial analysis based on real data. Its goal is to support decision-making based on evidence and encourage sustainable investment in reducing structural risks in Nepal's housing sector.

1. Related studies on the economic and social dimensions of seismic retrofitting

The retrofitting of masonry buildings in areas prone to earthquakes has been widely studied as a main way to reduce structural vulnerability and protect lives. Many studies show that retrofitting increases a building's ability to endure seismic forces and greatly decreases the risk of collapse (Bothara and Brzev, 2011). However, the high upfront cost of retrofitting is still one of the most mentioned obstacles to its wider use, especially in low- and middle-income countries (Ma'bdeh, 2023). This issue is especially important in Nepal, where rural homeowners often struggle to access credit or government aid. Decision-making usually focuses on short-term financial needs rather than long-term risk management.

Prior research shows the importance of using economic evaluation tools, such as Benefit-Cost Ratio (BCR), Net Present Value (NPV), and Breakeven Analysis (BEP), to support decision-making based on evidence. For instance, Peng et al., (2021) looked at the environmental and economic trade-offs between retrofitting and rebuilding in China. They employed lifecycle analysis and cash flow modeling. Their method involved detailed cost estimation compared to market unit rates and used discounted cash flow projections to estimate returns over a 20-year planning period.

Another important factor influencing retrofitting adoption is how property owners view the cost compared to the benefits. Shrestha, Pradhan and Guragain, (2012) pointed out that many homeowners in Nepal either do not know about retrofitting options or think they cannot afford them. Studies suggest that awareness campaigns, subsidized programs, and demonstration projects could help change public perception and motivate people to take action (World Bank Group and GFDRR, 2015)

These insights shape the current study, which builds on earlier research by using a financial cost-effectiveness approach for retrofitting efforts in Makawanpur, Nepal. The study collects data from government sources and household surveys. It employs BCR and BEP analysis in realistic and challenging scenarios. The goal is to provide a strong economic reason for adopting retrofitting in the local context.

2. Benefit cost ratio, Breakeven point, and Net present Value

Benefit Cost Ratio

The Benefit-Cost Ratio (BCR) is a financial tool used to evaluate the overall value for money of a project or investment. It is calculated by dividing the total expected benefits of a project by the total expected costs. The BCR helps determine whether the benefits of a project outweigh its costs or not (Mishan, 1971; Boardman *et al.*, 2018).

$$BCR = \frac{\text{Present Value of Benefits (PV Benefits)}}{\text{Present Value of Costs (PV Costs)}}$$

Where:

- PVBenefit is the total present value of the expected benefits.
- PVCost is the total present value of the expected costs.

The Benefit-Cost Ratio (BCR) is an important measure of a project's economic viability. It compares the present value of expected benefits to the present value of costs. When the BCR is greater than 1, the project is considered viable because the benefits exceed the costs, showing a good return on investment. If the BCR is equal to 1, the project has reached the breakeven point. Here, the benefits are just enough to cover costs, without making a profit. In contrast, a BCR less than 1 means the costs are higher than the benefits. This makes the project economically unfeasible and unlikely to yield a positive financial result (Boardman *et al.*, 2018) .

Breakeven Point

In a construction project, the Break-Even Point (BEP) represents the stage at which the project's total costs are equal to its total benefits (Sullivan, 2014). At this point, the project has covered all its expenses, including both fixed and variable costs, but has not yet generated any profit.

In technical and financial evaluations, the breakeven point is a key metric for assessing the cost-effectiveness of a project. The breakeven point is the time when the total benefits or savings equal the initial investment. If this point occurs within the planned timeframe, the project is seen as cost-effective. This means the investment will be recovered quickly, allowing for extra benefits or returns during the remaining analysis period. On the other side, if the breakeven point goes beyond the planning period, the project is considered cost-ineffective. In these situations, the investment does not produce enough returns in the given timeframe, which raises concerns about its financial viability and its priority compared to other options. This evaluation is especially important in settings with limited resources where projects need to show both long-term value and quick financial recovery (Boardman *et al.*, 2018).

Both BEP and BCR analyses are essential tools for measuring cost-effectiveness in projects. BEP ensures that a project can at least break even, while BCR assesses the broader economic return on investment. Together, they provide a detailed picture of a project's financial health and its value for money, helping to make informed, cost-effective decisions.

When used together, BEP and BCR analyses offer a comprehensive view of cost-effectiveness. BEP ensures that the project can sustain itself financially, while BCR confirms that the project delivers sufficient value relative to its cost. This combined approach provides a more robust evaluation of a project's financial and economic viability (Sullivan, 2014; Boardman *et al.*, 2018).

Net Present Value

Net Present Value (NPV) is a financial metric used to evaluate the profitability of an investment or project. It is calculated by taking the difference between the present value of cash inflows and the present value of cash outflows over a given period. The present value of future cash flows is determined by discounting them at a specified rate, typically the cost of capital or a required rate of return (Brealey, Myers and Allen, 2020)

Where:

$$NPV = \sum \frac{R_t}{(1+r)^t} - C_0$$

R_t = Cash inflow at time t

r = Discount rate or interest rate

t = Time period (in years)

C_0 = Initial investment or cost

3. Costs and Benefits incurred in retrofitting

Costs incurred in retrofitting

According to (Shrestha, Pradhan and Guragain, 2012)Retrofitting techniques vary in cost depending on their complexity and effectiveness. Splint and bandage costs \$4–6 per sq. ft. for reinforced cement concrete and \$3–5 per sq. ft. for galvanized iron(GI) welded wire mesh, while jacketing ranges from \$6–8 per sq. ft. steel bar mesh \$5-\$7 per sq. ft. for GI welded wire mesh and \$2 per sq. ft. For a polypropylene band.

- Direct cost: Direct cost that is incurred in retrofitting masonry buildings comprises material cost, labor cost, transportation cost, engineering and design fee, permit, and regulatory fees. These costs are also the construction costs of retrofitting (Mishra, 2020).
- Indirect Cost: Indirect cost incurred in retrofitting is the cost of relocation and opportunity cost for the loss of business. But in the case of Nepal, mostly in rural areas cost of loss of business is nominal, and the cost of relocation comprises the major proportion of the indirect cost of retrofitting(Nepal Reconstruction Authority, 2021). Relocation costs typically include expenses such as moving services, packing, temporary housing, travel, and storage, with the average cost depending on distance and complexity of the move.

Benefits of Retrofitting

Seismic retrofitting provides important benefits in lowering the risks linked to earthquakes, especially in fragile masonry buildings found in low- and middle-income countries like Nepal. It improves structural performance, which decreases the chances of collapse and reduces casualties, injuries, and economic losses. Retrofitting is also a cost-effective option compared to rebuilding, often leading to significant decreases in structural damage. Furthermore, it helps maintain the cultural and historical value of buildings by keeping their original form and identity. These advantages make retrofitting a crucial strategy for boosting community resilience in areas prone to earthquakes.

- **Reduction of Casualty and Injury:** It is the major benefit that retrofitting provides. The value of the statistical life of Southeast Asians is considered to be \$0.28-0.63 million (WOrld Bank Group and GFDRR, 2015). The total cost of injury is normally taken as Rs 20,000-1,00,000(Shrestha, 2020)

- **Reduction in structural damage:** Retrofitting is done to promote the structural strength of any building. It is an alternative measure to strengthen building to rebuilding. Retrofitting is expected to reduce expected annual loss by 70%. So, the monetary value considered for reduction in loss as 70% of the cost of rebuilding (Cardone, Flora and Manganelli, 2014).
- **Preservation of Cultural value.:** Retrofitting of a building preserves it's cultural and historical value. It helps to preserve the originality of the building and hence promotes its cultural value. Since we are conducting research only on residential building monitory value for preservation of cultural value is not needed to be considered.

4 . Methods

Study Area

The study area for this research is Makwanpur District, located in Bagmati Province, Nepal. The district covers about 2,426 km² and is divided into ten local units. This includes one sub-metropolitan city, one municipality, and eight rural municipalities. The region suffered major damage during the 2015 Gorkha Earthquake, leading to extensive government-led retrofitting efforts for masonry buildings that are vulnerable to earthquakes. This background makes Makwanpur a suitable case study for evaluating the cost-effectiveness of retrofitting strategies.

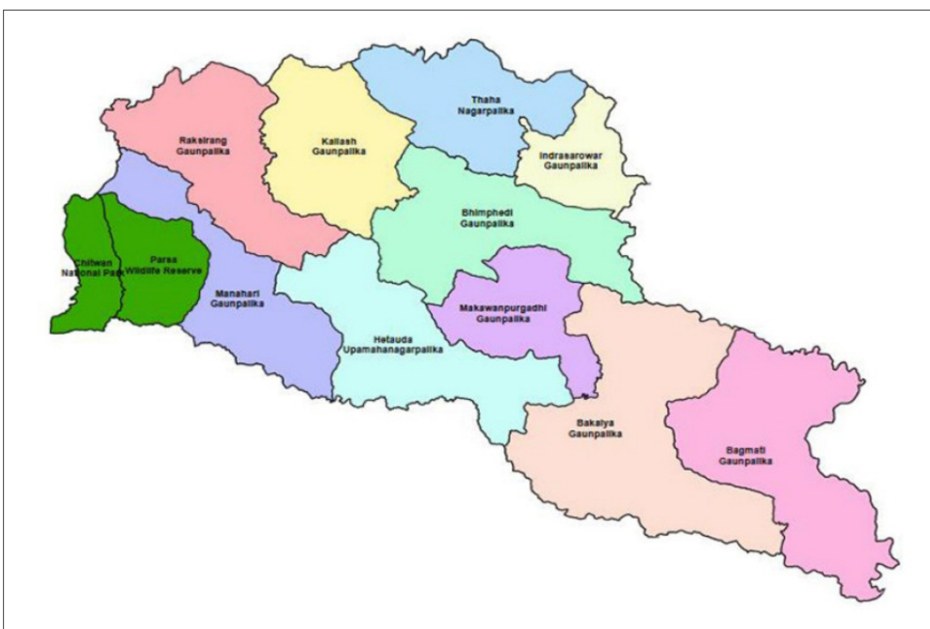

Figure 1: Map of Makawanpur district.

Data Collection

A mixed-methods data collection approach was employed, incorporating both primary and secondary sources to ensure comprehensive and triangulated input for the economic evaluation of retrofitting practices.

- For the access of primary data, a request to CLPIU was made to gather various data related to retrofitting of masonry buildings in Makawanpur district following the Gorkha Earthquake. Reports published in various journals and magazine was accessed. A field survey for the questionnaire and key informant interview was also done, which will assist in primary data collection.
- A questionnaire survey as a primary data collection was carried out among the stakeholders, such as building owners, engineers, and other related authorities. The questionnaire consisted of general information about respondents and several other information which were in the form of a questionnaire.
- Secondary data was collected from several reports published on the website of the National Reconstruction Authority, literature reviews, and related previous studies.

To analyze the cost effectiveness of retrofitting using benefit cost ratio and breakeven point analysis, the cost was calculated from the data obtained from a questionnaire survey, and the data was validated through cost estimation of sample buildings using government norms and district rates. Benefits were accessed through various literature reviews. Through this benefit-cost ratio and the breakeven point of the retrofitted building was analyzed, considering both direct and indirect costs and benefits.

Research Matrix

The research matrix presented in Table 1 reveals the summary of the whole research, showing the linkage between the objectives, data collection, and the data analysis method of this research.

Table 1: Research Matrix

S.N.	Research Objectives	Data Collection	Analysis Method and Tools
1	To analyze the cost-effectiveness of retrofitting using the benefit-cost ratio and breakeven point analysis.	Literature review, journals, questionnaire survey	Statistical analysis, literature review, calculating BCR and BEP, and conducting sensitivity analysis.

4. Results and discussion

Benefit-Cost Ratio

The Benefit-Cost Ratio (BCR) is a common tool to measure the economic efficiency of infrastructure investments, including seismic retrofitting projects (Boardman *et al.*, 2018; Mishra, 2020) .A BCR greater than 1.0 means that the benefits from the investment are greater than the costs, which justifies the economic value of the intervention.

To examine how the BCR responds to uncertainties in retrofitting costs and estimated benefits, we conducted a parametric sensitivity analysis. Table 2 shows the changes in BCR under different scenarios of cost increases and benefit decreases.

The results show that even with a cautious estimate of a 20% increase in retrofitting costs, the Benefit-Cost Ratio (BCR) remains 1.43. This is well above the threshold for economic viability. Likewise, if we cut the estimated benefits by 20%, the BCR falls to 1.37, which still suggests a positive outcome. In the worst-case scenario, where both costs rise by 20% and benefits drop by 20%, the BCR is at 1.15. This still supports the economic reasons for retrofitting projects, even under strict assumptions.

Table 2: Value of Benefit Cost Ratio with % change in benefit or cost

Scenario Type	Change Magnitude	BCR Value
Cost Increase	+5%	1.63
	+10%	1.56
	+15%	1.49
	+20%	1.43
Benefit Reduction	-5%	1.63
	-10%	1.54
	-15%	1.46
	-20%	1.37
Combined Worst-Case	± 20%	1.15

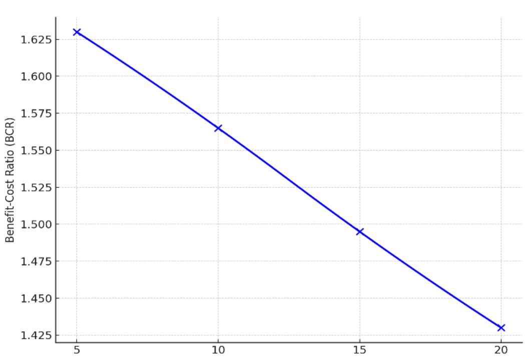

Figure 2(a): Comparison of BCR and % change in cost

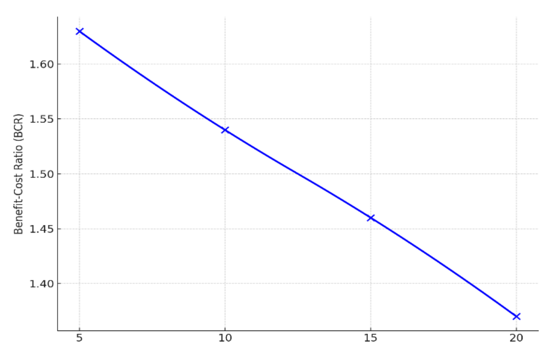

Figure 2(b): Comparison of BCR and % change in benefit

From Figure 2(a) and (b), it has been observed that even though the cost of retrofitting is increased to 20% of the estimated cost of retrofitting, the BCR of retrofitting of the building is well above 1 (1.43). In addition to this, even though the benefit obtained from the retrofitting of the building is decreased by up to 20% of the initial estimated benefit, the BCR is 1. The worst scenario could be the cost being increased by 20% and the benefit being decreased by 20%. In this context as well, BCR is well above 1. This shows that retrofitting of building is cost-effective.

Breakeven Point

The Break-Even Point (BEP) represents the time horizon at which the cumulative benefits of an investment offset the incurred costs. It serves as a critical decision-making metric for assessing the payback period of retrofitting strategies (Peng *et al.*, 2021a)

For this study, the planning period of a retrofitted building is assumed to be 20 years, consistent with standard assumptions used in long-term infrastructure planning (Peng *et al.*, 2021b) The annualized values of benefits and costs were projected over this period, and a temporal analysis was carried out to determine the year in which the benefits surpass the initial investment.

As shown in Figure 3, the cumulative benefit curve intersects the cumulative cost curve at approximately 7 years and 3 months, indicating the break-even point. Post this time horizon, the building continues to generate net economic benefits for the remainder of its service life.

This result confirms that the payback period for retrofitting is significantly shorter than the planning horizon, thus validating the intervention's long-term economic feasibility. Retrofitting not only safeguards life and property in the event of future seismic events but also becomes financially self-sustaining well within its lifecycle.

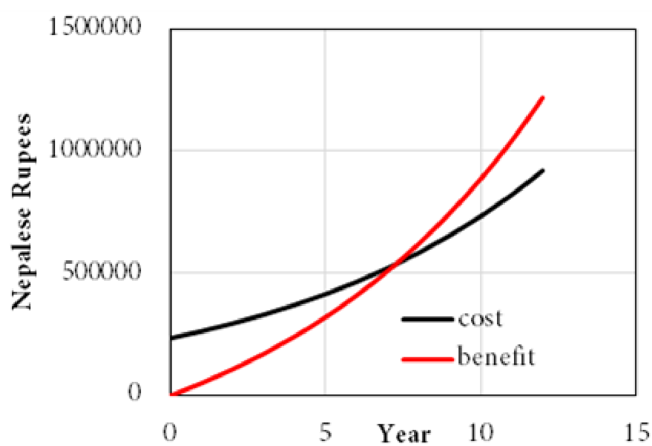

Figure 3: Evolution of cost and benefit of retrofitted buildings with time

It is worth noting that these findings are consistent with international studies, such as those by Mechler, (2016) and Smyth et al., (2004), which have emphasized that investments in seismic mitigation frequently recover their costs within a relatively short duration through avoided losses and enhanced asset resilience. In low-income and disaster-prone regions like Nepal, such economic assessments are vital for prioritizing limited public resources toward interventions that maximize return on investment while enhancing community safety.

5. Conclusions

The findings of this study demonstrate the economic viability of retrofitting masonry buildings in earthquake-prone regions. The breakeven period of around 7 years and 3 months indicates that the initial investment in retrofitting can be recovered within a reasonable timeframe, making it a financially feasible option within standard planning periods. Furthermore, the benefit-cost ratio remains well above 1, even under unfavorable economic conditions where costs increase by 20% and benefits decrease by 20%. This resilience to cost variations underscores the long-term financial advantages of retrofitting over traditional reconstruction methods. By enhancing structural integrity and minimizing potential earthquake-induced damage, retrofitting not only reduces repair costs but also contributes to broader socioeconomic resilience. These results reinforce the necessity of promoting retrofitting as a cost-effective seismic risk mitigation strategy, encouraging its adoption through policy interventions, financial incentives, and increased stakeholder awareness. Future research should focus on optimizing retrofitting techniques to further improve cost efficiency and maximize economic and structural benefits.

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