Nepal Engineering College

Changunarayan-4, Bhaktapur
Phone: 01-5221006
(DAO Bhaktapur Regd No. 552/2060)

VOLUME 18 | ISSUE 1 MARCH 2026

VOLUME 18
ISSUE-I

ISSN NO. 2091-1742

SCITECH NEPAL

Journal of Scientific and Technical Studies

Nepal Engineering College

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Phone: 01-5221006
(DAO Bhaktapur Regd No. 552/2060)

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Editorial's Note

It is with profound pleasure, humility and anticipation that we celebrate the launch of 'SCITECH Nepal', Volume 18 issue I. I would like to extend a very warm welcome to the readership of this journal. I take this opportunity to thank our authors, editors and reviewers, all of whom have volunteered to contribute to the success of the journal.

I believe it is crucial to underscore the significance of research and development in education as a means to enhance the well-being of our communities as it opens the gate to contribute to global knowledge and advance innovative solutions to the numerous challenges that confront us. This journal since the first edition is providing an ideal forum for exchange of information for the researchers, practitioners, and academicians on the most pressing topics. Our objective is to promote and facilitate the dissemination of ideas and research that address the regional and global problems on the various topics.

I welcome contributions that can demonstrate practical usefulness, particularly contributions that take a multidisciplinary approach because many real-world problems are complex in nature. We remain firm in our commitment to publishing scholarly articles. We are always keen to receive feedback from our contributors and readers, and we sincerely welcome their constructive suggestions on how we can enhance the quality of our journal and accommodate the evolving requirements of our community.

I would like to extend my heartfelt appreciation to all our contributors and editorial board members for their unwavering support. I earnestly look forward to your continued collaboration and assistance in advancing knowledge in science and technology.

Durgaprasad Bhandari
Chief Editor

ISSN NO. 2091-1742

SCITECH

Journal of Scientific and Technical Studies

Nepal Engineering College, Pokhara University

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ISSN NO. 2091-1742

SCITECH

Journal of Scientific and Technical Studies

Nepal Engineering College, Pokhara University

Received: May 27, 2025

Accepted: January 30, 2026

DOI: https://doi.org/10.3126/scitech.v18i1.90805

Climate Change induced hazards impact on water sources and adaptation practices in Mulkharga of Kathmandu, Nepal

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Abstract:

Water availability is the major impact which humans will face, especially in developing countries because of climate change. This study analysed the observed and locally perceived climatic variation along with the assessment of impacts of climate induced hazards on spring sources in Mukharka Village of Kathmandu District, Nepal along with the exploration of the local autonomous adaptation practices to withstand these induced hazards and water scarcity. Recoreded monthly rainfall and temperature data were collected from Department of Hydrology and Meteorology of Sundarijal Station and Budhanilkantha station of 24 years (1995 – 2018) and 16 years 1995 – 2010) respectively. Questionnaire survey with 128 households along with a Focus Group Discussion and Key Informant Interviews were conducted. Linear trend analysis of the observed rainfall and temperature was carried out. The obtained trend was corroborated with locally perceived climate variability. Hazard ranking tool was used to prioritize hazards with a likert scale assigning the value of maximum and minimum criteria of possible hazards in the community. The changing pattern of rainfall with decreasing trend with an average of 1.16 mm rainfall per year was observed. The average maximum temperature showed increasing trend with the slope of 0.06°C per year and minimum temperature showed decreasing trend with the slope of 0.02° C per year. Local people have expereined an increase in temperature despite a reduction in monsoon by -3.11 mm per year and winter rainfall by -0.2587 mm per year. They also revealed depletion of water sources resultant of decreased monsoon and winter rainfall patterns along with increase in the frequency of natural disasters. The study area's vulnerability to hazards such as drought and landslides is made clear by the depletion of spring sources, which is a significant concern. Climate variability, characterized by changes in rainfall patterns and temperature, has been found to exert a significant impact on the availability of water resources, including the springs dry up, thereby increasing the risk of Climate-induced hazards such as drought and water scarcity. Local people have adapted various autonomous adaptation practices such as plantation of Alnus nepalensis, construction of storage tanks and implementation of rainwater harvesting to respond to depleting water sources and the hazard that they faced during extreme climatic events.

Key words: Spring sources, Mulkharga Village, Climate variability, Local perception

1. Introduction

Freshwater resources around the world are under immense pressure. Despite the fact that most countries emphasize achieving basic human needs for water, one-fifth of the world population lacks access to safe drinking water (Agarwal, 2000). In addition, the world will have to deal with the impacts of climate variability on water resources (Piao et al., 2010). Climate variability is anticipated to have a net negative impact on freshwater ecosystems and water supplies in almost all parts of the world (Abbaspour et al., 2009). Climate variability impacts on water resources are felt by society, environment and economics. The availability of water is not uniformly distributed, the quality is frequently in question, and the sustainability of the water supply system continues to present challenges.

Approximately one-sixth of the world's population resides in South Asia. Due to their dependence, this population of Bagmati Basin is more vulnerable to the growing effects of climate variability (Dahal, et al., 2016). This is likely due to the unique characteristics of this area, which include steep slopes, rapid river flow and heavy sediment transport, all of which can exacerbate the impacts of climate variability. The overall effects of climate variability on water resources are noted and that the world's hydrological cycle was intensifying, having an influence on both groundwater and surface water supplies (Babel et al., 2014). Proper Water supply services increase water availability, providing a safeguard in times of water shortage, meaning that poor and marginalised are capable to cope with impacts of climate variability. Bain et al., (2014) argues through his article that rural areas around the world are deprived of drinking water, both in terms of quality and quantity. Not only in water scheme scenario, but also in a climate variability scenario, rural areas are more vulnerable to the impacts of climate change. Climate variability and its impacts in rural areas may be complex to project because of several intervening factors. But, it is for sure that, these impacts may originate from extreme events such as floods and landslides. These extreme events directly affect rural infrastructure threatening livelihood. The rural population around the globe lack climate knowledge. They are the ones with less income level depending on everyday labour or agriculture for a living. This limited knowledge and income increase their vulnerability against climate change (IPCC, 2014). Climate variability threatens to increase the frequency, severity and intensity of climate related hazards such as drought, violent storms, heavy rainfall resulting flooding (OECD and FAO, 2017). If rainfall does not occur for a prolonged period, drought occurs. Drought decreases the groundwater recharge reducing water availability in the regions where the community are groundwater dependent. Also, in the locations where community depends on streams, households struggle even to meet least drinking water needs in the dry season since most of the water points dry up and their yield decreases. Pollutants dilution decreases when water is in limited quantity, this reduces the quantity (Calow, et al., 2015). Frequency of drought is projected to increase in many regions where reduced rainfall is projected. However, in some basins, both flood and drought are expected to incur. The land surface in extreme drought is expected to increase ten times from 2008 to 2090s AD (Kundzewicz et al., 2008). According to Bower (2014), landslides damage the infrastructure aimed for water conveyance blocking water supply for communities along with contamination of water sources. Environmental Hazards, for example, landslides in the region of water supply and sanitation system may prompt direct harm to the infrastructure. Degradation because of the landslide in the more extensive catchment increases runoff and diminishes groundwater recharge (UNICEF-GWP, 2017). In Hill and Mountainous area like Nepal, spring sources are one of the primary sources of water for local communities. The depletion of these sources can have severe consequences for the livelihoods and well-being of the local communities. Therefore, it is crucial to address the issues of climate-induced hazards in order to ensure the sustainable management and protection of spring sources. The overall objective of this study was to assess the impacts of climate induced disasters on the local water sources with the documentation of the adaptation strategies of the local people in Mulkharga Village.

2. Methods and materials

2.1 Study area

Mulkharka (Figure 1) is a small village located at an altitude of 1,800 meters above sea level in the Kathmandu District. It is located in the hilly region of Nepal. The Mulkharka has a subtropical climate characterized by hot and humid summers and cool and dry winters. It is located at 27°46’36.29” N- 85°25’56.84” E. The total area of the study site is around 90.53 hectar. The area lies in the conservation zone within the territory of Shivapuri Nagarjun National Park. The village mostly consists of Tamang Community and are mostly dependent on natural resources for their livelihood.

2.2 Research approach and design

This research was primarily concerned with the documentation and analysis of the various impacts and adaptation strategies employed by the local people. Both qualitative and quantitative approaches were used in the research. The qualitative approach was used in survey work to know and understand about villager perceptions of climate variability and the stresses induced. Similarly, a quantitative approach was used to learn about current climatic data obtained from the Department of Hydrology and Meteorology (DHM).

2.3 Data Collection
2.3.1 Primary Data Collection
In this study, the Focus Group Discussion (FGD) was conducted with individuals older than 40 years to gain knowledge on climatic variability, associated hazards and adaptation practices. During the FGD, the participants were assigned to rank the hazard based on criterions of hazard ranking tools. The FGD was conducted in an interactive group setting, where participants were free to talk with each other, using a checklist.
Key informant Interviews were conducted with individuals representing various sectors of society, including member of Buffer Zone User Committee (BZUC), Water and User Sanitation Committee (WSUC) and local women group of Mulkharga. The interviews focused on topics such as the use of water resources, rainfall patterns, induced hazards events and any adaptation practices followed by the community to cope with these hazards. The aim was to gather insights and perspectives from a diverse group of knowledgeable individuals on these issues.
Questionnaire Survey was also conducted in the study area with the required number of sample population determined by using the Cochrane Formula with the fixed household population of 805 with 5 % degree of freedom and 95 % confidence interval. The questionnaire survey was design to understand the perception of local people on climate variability and its consequences on water sources.
2.3.2 Secondary Data Collection

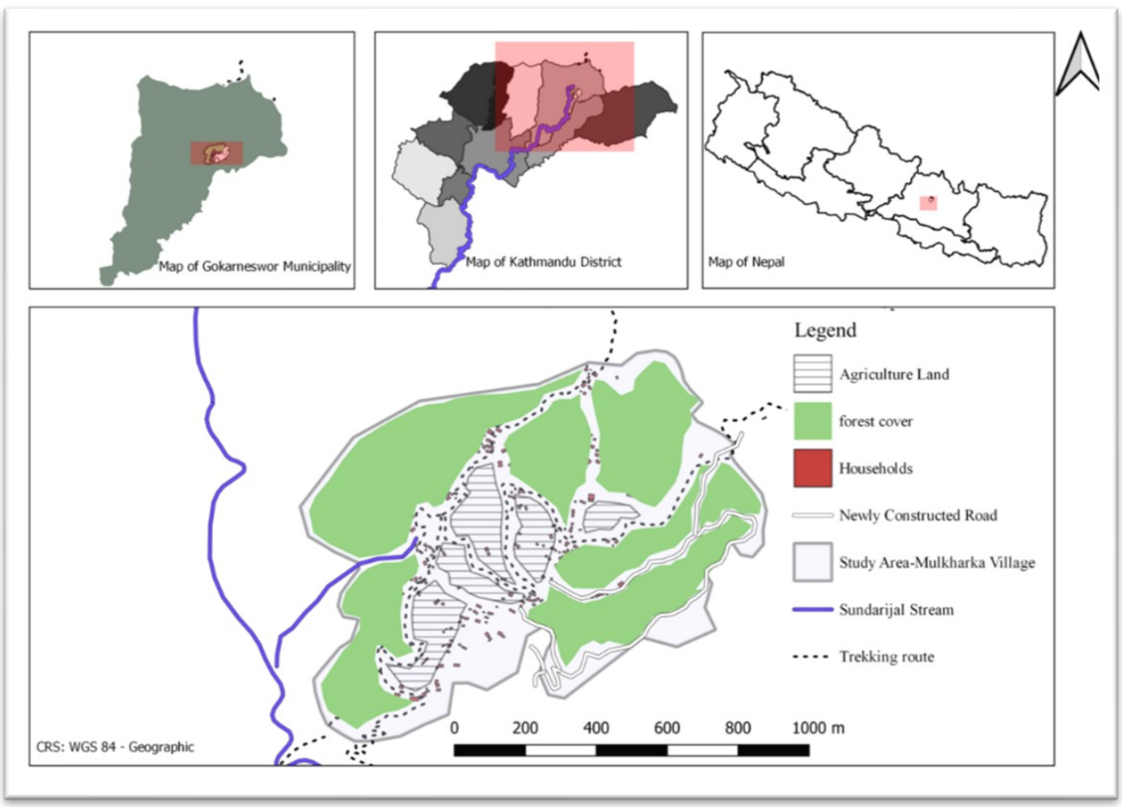


Figure 1 Study Area Map
Twenty four years data from 1995 to 2018 AD on rainfall recorded at Sundarijal Station and sixteen-year data from 1995 AD to 2010 AD on temperature recorded at Buddhanilkantha Station was collected from DHM. The salient features of the meteorological stations used in the analysis are presented in Table 1. The summary of annual rainfall and temperature records were prepared from the monthly records of rainfall and temperature prior to use in analyzing various indices of climatic variability. The missing rainfall data were estimated by simple arithmetic average method. The method involves utilizing rainfall records from three nearby stations simultaneously, where the stations should be uniformly distributed around the station with missing records (Kennedy, 2014). The Simple

Arithmetic Average Method assumes even distribution of rainfall over the area and time period being considered and is the arithmetic mean of the rainfall measurements from a given period of time.

Table 1 Meteorological station details

Index number	Stations	Geographical Coordinates		Elevation (m)	Period of Meterological data
		Latitude (deg min)	Longitude (deg min)		
1074	Sundarijal	27.772695	85.4277003	1658	1995 AD – 2018 AD (Rainfall)
1071	Buddhanikantha	27.764655	85.3522048	1428	1995 AD – 2010 AD (Temperature)

2.4 Data Analysis

Linear Trend Analysis was conducted to examine the trend or direction of change in a time series of data. It involves fitting a straight line to the data and calculating the slope of the line, which can be used to determine the rate of change over time. The departure from average rainfall, also known as departure from normal, is a measure of how much rainfall at a specific location deviates from the average amount that is typically received over a long-term period, such as several decades (Singh et al., 2015). It is calculated by subtracting the average rainfall value for a particular location from the accumulated rainfall amount for that location for a specific period of time. The percentage

$$D\% = (x_i - x_m)/ x_m) \times 100 \%$$

Where, D % = Departure of rainfall

x_m = mean annual rainfall and

x_i = annual rainfall series

A Hazard Ranking tool is a tool used to evaluate the hazard potential to cause harm to human health or the environment (EPA, 2016). It is often used by regulatory agencies to prioritize the assessment and management of hazardous substances. This study used people's experience to rank the climate induced hazards based on the criterion provided in the hazard ranking tool (Table 2). During the FGD, the participants were asked to discuss about the possible occurence of hazards in the study area. They were asked to rank the shortlisted hazards using likert scale assigned value of 0-5. Hazard Ranking tools are commonly used in the field of risk assessment and can be an important tool for identifying and managing potential hazards. Criterions used for the hazards ranking tool in this study included i. The severity of the hazard, ii The likelihood of the hazard occurrence, iii The level of uncertainty associated with the hazard, iv. The susceptibility or vulnerability of the population or community exposed to the hazard, v. The level of exposure to the hazard, vi. The potential for cascading or compound hazards, vii. The potential for adaptation or mitigation and viii. The potential for long-term impacts.

Table 2 Hazard Ranking Tool

	Severity	**likelihood**	**level of uncertainty**	**vulnerability of the population**	**exposure**	**Cascading potential**	**Potential for long term impact**	**Adaptation/ mitigation potential**	**Score**	**Ranking**
Water induced Hazard	0-less severe 5-more Severe	0-less Likehood 5-More Likelihood	0-less 5-more	0-lessVulenrable 5-More Vulnerable	0-less Exposure 5-More Exposure	0-less 5-more	0-less potential for long term impact 5-More potential for long tem impact	0-High adaptive capacity 5-lowest adaptive capacity		

3. Results and Discussion

3.1 Rainfall variability

3.1.1 Average and annual rainfall variability

The mean annual rainfall received over the period was found to be 2132.57 mm at Sundarijal station with a range of annual rainfall amounts from 889.7 to 2867.2 mm (Figure 2). The maximum rainfall occurred in year 1998 and minimum average rainfall occurred in th year 2005. Kripalani et al., (1996) also noted a similar pattern in mean annual rainfall in Kathmandu over the period 1921-1975.

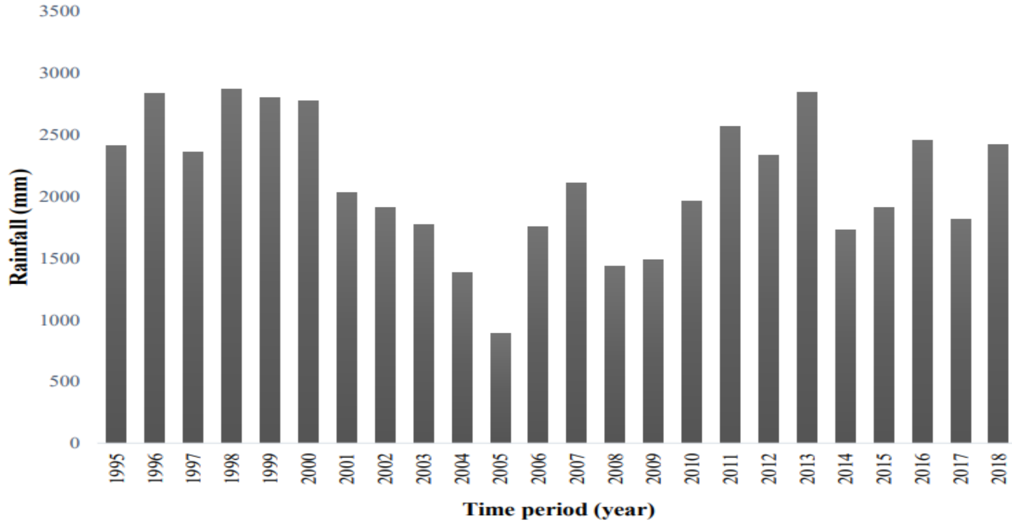


Figure 2 Total annual rainfall in study area

Rainfall departure shows the difference between the actual amount of rainfall and the long term average amount of rainfall for a specific location. A positive departure means that the amount of rainfall received is more than the long-term average, while a negative departure means that the amount of rainfall received is less than the long-term average. Figure 3 illustrate the departure of rainfall from average annual rainfall in the study area within 24 years. The year 1998 recorded the positive departure for the rainfall by 34.45% whilst in 2005, the departure of rainfall was below by 58.28 %, indicating that the amount of rainfall received in that year was below the long-term average.

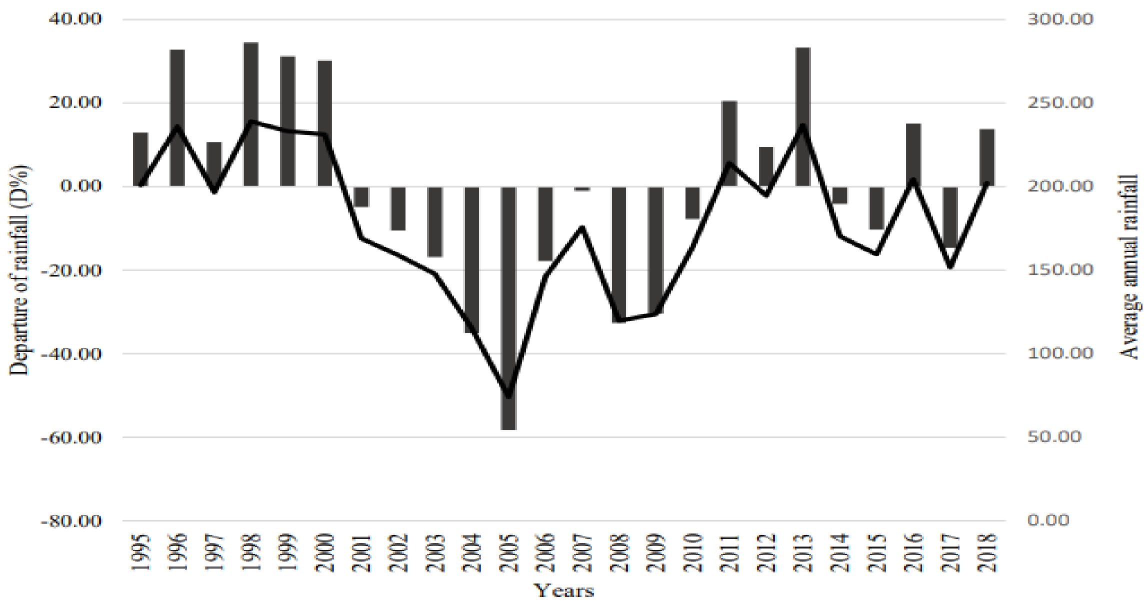


Figure 3 Departure of rainfall from average annual rainfall

The linear trend of average annual rainfall at Sundarijal station shows decreasing trend with an average of 1.16 mm rainfall. The monthly rainfall data showed an overall increasing trend in the month of march and April, with an increase of 0.806 and 0.7296 mm respectively (Table 3). On the other hand, monthly rainfall data showed an overall decreasing trend in the month of July and June with an decrease of 6.95 and 3.763 mm.

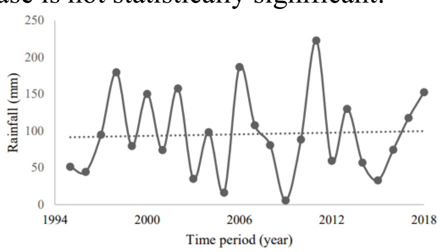
Table 3 Trend of monthly rainfall during 1995-2018 AD

Months	Value of m	Trend
January	-0.491	Decreasing
February	0.251	Slightly increasing
March	0.806	Increasing
April	0.7219	Increasing
May	-0.4399	Decreasing
June	-3.763	Decreasing
July	-6.95	Decreasing
August	-1.4018	Decreasing
September	-1.9689	Decreasing
October	0.106	Slightly increasing
November	-0.5535	Decreasing
December	-0.5356	Decreasing

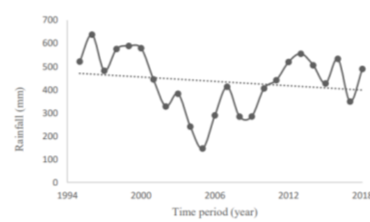
3.1.2 **Seasonal rainfall variability**

Average rainfall of the study area has been classified in four seasons: pre-monsoon (March-May), monsoon (June-Sep), postmonsoon (Oct-Nov), and winter (Dec-Feb). Long term climate data for 24 years have been applied to notice changes in the pattern of pre-monsoon, Monsoon, post monsoon and winter rainfall trend.

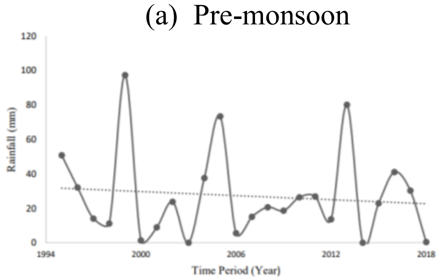
The 1995-2018 temporal trend in pre-monsoonal rainfall (Figure 4a) within the study region exhibits fluctuation in annual rainfall from March to May The maximum observed rainfall event during this time frame occurred in May 2011, reaching a intensity of 457.1 mm. A slight upward trend in mean pre-monsoon rainfall is apparent, although this increase is not statistically significant.



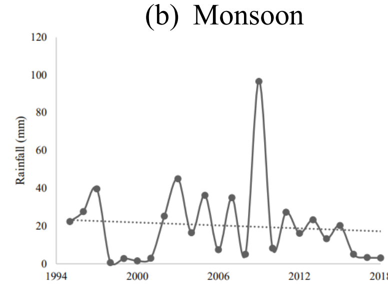
(a) Pre-monsoon



(b) Monsoon



(c) Post-monsoon



(c) Winter

Figure 4 Seasonal monsoon trend

The temporal variability in mean monsoon rainfall (Figure 4b) within the study region exhibits fluctuation in average annual rainfall. The maximum recorded rainfall event during this time frame occurred in August 1996, reaching an intensity of 897 mm, while the minimum recorded in June 2005, with an intensity of 49.7 mm. A decreasing trend in mean monsoonal rainfall is clearly visible, with a slope of -3.11 mm/year. The temporal variability in mean Post-monsoon rainfall (Figure 4c) exhibits a slight downward trend with a slope of -0.39 mm/year. The maximum recorded rainfall event during this time frame occurred in October 1999, with an intensity of 194.6 mm, while the minimum recorded rainfall was in November 2002, totaling 0.4 mm. The temporal trend in mean winter rainfall (Figure 4d) exhibits fluctuation in annual rainfall. The maximum recorded rainfall event during this time frame occurred in January 2009, with an intensity of 290 mm, while the minimum rainfall occurred in December 2001, totaling 0.2 mm. A downward trend in mean winter rainfall is visible, with a slope of -0.2587 mm/year.

3.2 Temperature variability

3.2.1 Annual average minimum and maximum termperature

The average maximum temperatures during winter (Dec-Feb), spring (Mar – May), summer (June-Aug) and autumn (Sep – Nov) seasons in the period 1995-2010 exhibited distinct trends. Specifically, there was an increasing trend in the winter maximum temperature, with an annual increase of 0.1138°C. Similarly, the spring maximum temperature showed an increasing trend, with a yearly increase of 0.0429°C, as did the autumn maximum temperature, with a yearly increase of 0.0434°C. The observed temperature trend for the summer season show increasing trend. The increase in maximum summer temperature was noted to be 0.0625°C per annum. On the other hand, the minimum temperature during the winter season demonstrated a decreasing trend, with a yearly decrease of 0.0244°C. In contrast, there was a slight increasing trend in the minimum temperature during the spring season, with an annual increase of 0.0035°C. The minimum temperature during the summer season also displayed a decreasing trend, with an annuadecrease of 0.0228°C. Nonetheless, there was a slight increasing trend in the minimum temperature during the spring season, with a yearly increase of 0.0444°C.

Table 4 Trend of seasonal maximum and minimum temperature

Seasonal Temperature	Trend	Value of m
Maximum temperature		
Winter	Increasing	0.1138°C
Spring	Increasing	0.0429°C
Summer	Increasing	0.0625°C
Autum	Increasing	0.043°C
Minimum Temperature		
Winter	Decreasing	0.0244°C
Spring	Slightly increasing	0.0035°C
Summer	Decreasing	0.0228°C
Autum	Increasing	0.044°C

3.3 Observed climatic variability and people perception on variability in rainfall and temperature

An analysis of the variability in rainfall and temperature attributes was conducted using linear trend analysis. The results of the analysis revealed a decrease in the annual average rainfall in the study area over a period of 24 years. Specifically, a decreasing pattern was observed for the months of June and July, while an increase was observed for the months of March and April. The local community was also surveyed to gauge their perceptions on the variability of rainfall. The majority of respondents reported a decreasing trend of rainfall in the area and also noted an irregular pattern of rainfall, with a lack of sufficient rainfall even during the monsoon season. The study found that the maximum temperature has been rising and the minimum temperature has been dropping. Additionally, the summer season had an increasing trend in temperature while the winter season had a decreasing trend. The similar trend was also reported by respondents in the study area (Table 5).

Table 5 Comparison of observed and perceived climatic variability

Climate date	**Rainfall and temperature Indices**	
	Observed	**Perceived**
Total rainfall	Decreasing	Decreasing
Monsoon rainfall	Decreasing	Non persistent and decreasing
Winter rainfall	Decreasing	Non persistent
Duration of summer season	Increasing	Increasing
Winter season	Decreasing	Decreasing

3.4 Climate-induced hazard identification and hazard ranking

In order to determine the most significant hazards in the study area, three potential hazards were identified: Flood, Landslides, and Drought (Table 6). The criteria were given higher values if the hazard was considered more severe, with the exception of adaptability potential, which was given more weight if the hazard was considered easier to adapt to. These criteria were used to rank the hazards and to identify which one was most likely to have the greatest impact on the study area. The study revealed that landslides are the most probable hazard in the study area, followed by drought. While floods are the least probable hazard according to the hazard ranking. The hazard ranking assigns 34 points to landslides, indicating landslide a severe hazard with a high likelihood of occurrence, a high level of uncertainty, and other factors related to the hazard. According to Guzzetti et al., (2006) hilly and mountainous alluvial soil are particularly susceptible to landslides due to the soil's tendency for mass movement. According to information obtained from KII and FGDs, the respondent stated that there has been a change in the pattern of monsoon rainfall. Previously, rainfall was of mild intensity for a longer period of time, but in recent years, it has been more erratic. These changes in the pattern have made the slopes more susceptible to landslides. The respondents of KII and FGD stated that the danger of landslides in the area is made worse by human activities, such as the use of heavy machinery during the construction of a roadway in an area that was previously only used for trekking. Chairman of Buffer Zone User Committee (BZUC) added there have been multiple occurrences of landslides since the construction of the road began, indicating that the hazards are not just due to climate factors, but also to human actions.

Drought is the second most probable hazard in the study area, as it regularly leads to a water crisis. In the hazard ranking, drought is given a total of 27 points. The locals remember a time when there was an ample water supply in the area, but now several sources have declined.

Table 6 Hazard prioritization in the study area

Water induced hazards	**Severity**	**likelihood**	**level of uncertainty**	**vulnerability of the population**	**exposure**	**Cascading potential**	**Potential for long term impact**	**Adaptation/ mitigation potential**	**Score**	**Rank**
Flood	1	1	3	3	3	2	1	2	16	3
Landslides	4	5	5	4	4	4	4	4	34	1
Drought	4	3	4	4	4	4	4	0	27	2

3.5 Impacts on water sources

The study area is prone to frequent hazards, particularly landslides, which have been observed to have a significant impact on the hydrogeological conditions. During the KII, it was revealed that several springs, which serve as drinking water sources, have been disrupted or destroyed as a result of landslides events. The Chairman of the BZUC cites anthropogenic activities such as heavy machinery, excavators and bull dozers usage during road construction as a contributing factor to the increased incidence of rockfalls and subsequent spring source loss. The BZUC Chairman theorises that the exacerbation of spring source depletion can also be attributed to the drought conditions perceived by the local people, as evidenced by the decreasing monsoon and winter rainfall patterns. The local community attests that the availability of these water sources has reduced, with the springs now only rejuvenating during the monsoonal season and quickly depleting thereafter. The study analyzed 13 spring sources in the study area. The key informants revealed that 5 spring source being depleted in the years 2012 (attribute to drought), 2013 (attributed to landslides), 2017 (attributed to drought), 2018 (attribiuted to landslide) and 2019 (attributed to road construction). This depeted spring sources are witnessed during the field visit. The main reasons for depletion were found to be drought, landslide, road construction, landslide, and drought respectively for sources 1, 3, 6, 10, and 13 (Figure 5 and Table 7). Additionally, the study found that the landslides that caused the depletion of spring sources 3 and 10 occurred in the months of October, 2013 and August, 2018 respectively. These two month recorded above average rainfall according to DHM data, 160.2 mm and 843 mm (Figure 3). The recorded rainfall are the highest recorded rainfall in two decades time.

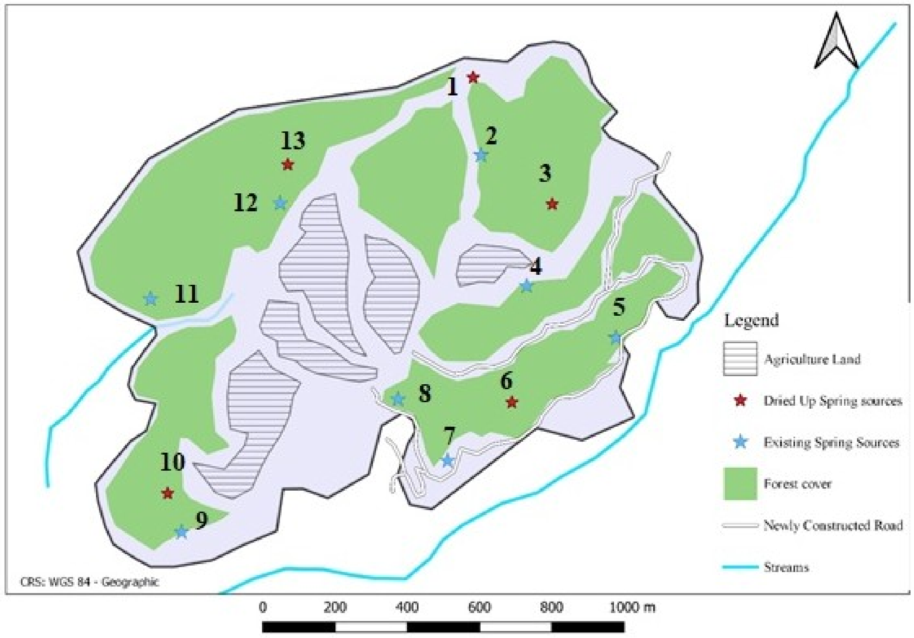


Figure 5 Condition of spring sources

The depletion of spring sources in the study area is a significant concern, as it highlights the vulnerability of the area to climate-induced hazards such as drought and landslides. The findings suggest that extreme rainfall events may be a contributing factor to landslides in the area, which can have a significant impact on water availability and accessibility for the local communities, leading to water scarcity. The study also highlights the importance of considering the impacts of development activities, such as road construction, on water resources. The depletion of spring source 6 due to road construction illustrates the need for integrated water resources management in the planning and implementation of development projects.

Table 7 Details of spring source

Source	Status	Depleted year	Reason for depletion of spring source	Location
1	Depleted	2012	Drought	27°47'4.42"N, 85°26'4.02"E
2	Intact			27°46'58.61"N, 85°26'8.47"E
3	Depleted	2013	Landslide	27°46'52.70"N, 85°26'14.82"E
4	Intact			27°46'44.81"N, 85°26'13.99"E
5	Intact			27°46'41.18"N, 85°26'25.09"E
6	Depleted	2019	Road construction	27°46'31.27"N, 85°26'11.31"E
7	Intact			27°46'30.75"N, 85°26'1.56"E
8	Intact			27°46'26.60"N, 85°25'56.27"E
9	Intact			27°46'18.85"N, 85°25'43.61"E
10	Depleted	2018	Landslide	27°46'32.39"N, 85°25'34.21"E
11	Intact			27°46'49.43"N, 85°25'41.23"E
12	Intact			27°46'53.18"N, 85°25'48.37"E
13	Depleted	2017	Drought	27°46'58.42"N, 85°25'53.13"E

3.6 Adaptation practices by the community to cope with climate induced hazards

The study area has observed decline in annual rainfall and an increase in maximum temperature, which may exacerbate climate hazards such as landslides and drought causing a reduction in spring sources. From field survey and interaction with local people, it was found that the induced hazards are not just due to climate variation, but also from human activities. These hazards have significant effect on water springs (depletion of spring sources, shifting of sources). However, some adaptation processes have been implemented, such as planting *Alnus Nepalensis* (Uttis) which is able to fix nitrogen impriving soil fertility and supporting the growth of other plant species. *Alnus nepalensis* (Uttis) has special characteristics of soil binding, decrease rate of runoff water which reduces the chances of landslides. Compared to landslides, the community has better adaptation practices in place to address drought. They have constructed storage tanks and implemented rainwater harvesting techniques.

The people in the study area have build five rectangular storage tanks nearby spring sources. People have use local materials available within a community to construct tanks. These storage tanks are also used for irrigation as well as other household uses. This can be a cost-effective and sustainable approach, as it reduces the need to import materials and relies on the skills and labor of community members. Storage tanks store water from various sources including rainwater, groundwater, and surface water. Additionally, the use of local resources to build storage tanks can support economic development by creating employment opportunities and building the capacity of community members. Around 35 % of the households have installed traditional rainwater harvesting to store rainwater during wet periods. This measures has increase their water security and reduce their dependence on other sources. Rainwater harvesting is believed to reduce the local dependency on water springs, potentially easing pressure on local water systems. It has also provide a source of irrigation for agriculture, improving crop yields and supporting food security. In addition to these, the local people have been exploring the water sources within the area.

4. Conclusions

The study was undertaken to understand the impact of climate induced hazards on local water sources along with documentation of the adaptation strategies practices by the community to cope with these hazards in Mulkharka Village. The impact of climatic variation has been assessed with decrease in rainfall and increase in temperature. The climatic data shows the fluctuation indicating climatic variability and uncertainity. The study concludes the similarity in the perception of the local people and the observed climatic trend in the study area. Landslides are the most probable hazard followed by drought that greatly affect the hydrogeological conditions of the area. The depletion of spring sources due to these variation in rainfall is a great concern which can have larger consequences for the livelihoods and well-being of the local communities. Some adapation measures for protection of the land and water storage have been implemented along with exploration of new water sources.

REFERENCES

Abbaspour, K.C. *et al.* 2009 'Assessing the impact of climate change on water resources in Iran', *Water resources research*, 45(10).

Agarwal, A. 2000 *Integrated water resources management*. Stockholm: Global Water Partnership. Stockholm, Sweden. ISSN: 1403-5324

Babel, M.S. et al. 2014 'Climate change and water resources in the Bagmati River Basin, Nepal', *Theoretical and Applied Climatology*, 115(3–4), pp. 639–654. Available at: https://doi.org/10.1007/s00704-013-0910-4.

Bain, R., J.A.Wright, E.Christensona & K.Bartram, 2014. Rural:urban inequalities in post 2015 targets and indicators for drinking-water. *Science of the total environment,* Volume 490, pp. 509-513.

Bower, K.M. 2014 'Water supply and sanitation of Costa Rica', *Environmental Earth Sciences*, 71(1), pp. 107–123. Available at: https://doi.org/10.1007/s12665-013-2416-x.

Calow, R., Ludi, E., McKenzie, A. & Kebede, S., 2015. *Climate and environmental risk screening for rural water supply in Ethiopia,* London: Overseas Development Institute.

Dahal, V., Shakya, N.M. and Bhattarai, R. 2016 'Estimating the Impact of Climate Change on Water Availability in Bagmati Basin, Nepal', *Environmental Processes*, 3(1), pp. 1–17. Available at: https://doi.org/10.1007/s40710-016-0127-5.

EPA (2016) *Climate Change Indicators in the United States, 2016. 4th edition*. EPA 430-R-16-004. Washington, DC: U.S. Environmental Protection Agency, p. 96. Available at: https://www.epa.gov/sites/production/files/2016-08/documents/climate_indicators_2016.pdf.

Guzzetti, F. et al. 2006 ‘Landslide hazard assessment in the Collazzone area, Umbria, Central Italy’, *Natural Hazards and Earth System Sciences*, 6(1), pp. 115–131. Available at: https://doi.org/10.5194/nhess-6-115-2006.

IPCC 2014 *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge, UK and New York, NY: Cambridge University Press, p. 1132. Available at: http://www.ipcc.ch/report/ar5/wg2/.

Kennedy, J.J. 2014. A review of uncertainty in in-situ measurements and data sets of sea syrface temperature. *Reviews of Geophysics,* 52(1).pp 1-32

Kripalani, R.H., Inamdar,S and Sontakke, N.A., 1996 Rainfall variability over Bangladesh and Nepal: Comparison and connections with features over India. *International Journal of Climatology.* 16(6). pp 689-703. DoI: 10.1002/(SICI)1097-0088(199606)16:6<689::AID-JOC36>3.0.CO:2-K

Kundzewicz, Z. *et al.* 2008 ‘The Implications of Projected Climate Change for Freshwater Resources and Their Management’, *Hydrological Sciences Journal/Journal des Sciences Hydrologiques*, 53. Available at: https://doi.org/10.1623/hysj.53.1.3.

OECD and Food Agriculture Organization of the United Nations 2017 *OECD-FAO Agricultural Outlook 2017-2026*. Paris: OECD Publishing. Available at: https://doi.org/10.1787/agr_outlook-2017-en.

Piao, S. et al. 2010 ‘The impacts of climate change on water resources and agriculture in China’, *Nature*, 467(7311), pp. 43–51. Available at: https://doi.org/10.1038/nature09364.

Singh, J., Das, S.M and Kumar, A. 2015. Forecasts of rainfall (Departure from normal) over India by dynamic model. *Aquatic Procedia*. 4 pp 764-771. DoI: 10.1016/j.aqpro.2015.02.159

UNICEF-GWP, 2017. *WASH Climate Resilient Development: Local participatory water supply and climate change risk assessment: Modified water safety plans,* s.l.: UNICEF-GWP

ISSN NO. 2091-1742

SCITECH

Journal of Scientific and Technical Studies

Nepal Engineering College, Pokhara University

Received: June 10, 2025

DOI: https://doi.org/10.3126/scitech.v18i1.90810

Accepted: January 30, 2026

Effects of Changing Family Structure in Traditional Newari Dwellings: A Case of Nala

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Abstract

Nala, a traditional Newari settlement located in Kavre District near Bhaktapur, historically known as "Desha" during the Malla period, is renowned for its rich cultural heritage and craftsmanship. However, the settlement is undergoing rapid transformation due to various socio-cultural changes, one of which is the shift in family structure from joint to nuclear families. This paper examines the impacts of changing family structures on the traditional architectural character of Newari dwellings, with particular focus on the front façade. The research adopts a qualitative approach, employing case studies, interviews, focus group discussions, and ethnography as the primary research methods. Qualitative data were further quantified using tools such as MS Excel, and AutoCAD was used for drawing generation and spatial analysis. The study area was concentrated along the procession route of the Mahalaxmi Jatra of Nala, considered the oldest settlement zone. The route comprises 71 houses, of which 40 have undergone vertical division. The findings indicate that the transition from joint to nuclear family structures has led to the equal division of parental property among offspring, resulting in the vertical subdivision of existing houses. Consequently, the frontage of traditional Newari houses is diminishing, and many dwellings are either being left vacant, demolished, or reconstructed using contemporary architectural approaches.

Keywords: Family Structure, Nala, Traditional Newari Dwellings, Vertical Division

1. INTRODUCTION:

Family System

Family refers to a group of individuals connected by blood, marriage, adoption, or a committed partnership. Nuclear families include the father, mother, and children (Fallah & Hojat, 2018). Joint family consists of people generally of 3 generations, Grandparents, uncles, aunties, unmarried sisters, father's sister, and children share a common kitchen (Kumar & Assistant, 2023). Joint family system was prevalent in Nepal during ancient and medieval period (Manandhar, 2020). During the Rana period (1846-1951), the practice of living in nuclear families increased. (Manandhar, 2020). With the ongoing societal change, the nuclear family is increasing and the joint family is on the verge of disappearance. Census 2021 recorded that 47 percent population are living in nuclear family and 53.4 percent in joint/extended family (NSO, 2024).

With the change from a joint family to a nuclear family, the division of ancestral properties equally among the brothers occurs. This cause the vertical division of the ancestral Newari house according to the number of sons. Later the renovation and reconstruction of the traditional newari dwellings according to preference of owners, affect the house both aesthetically and structurally.

The reasons behind the shift from joint families to nuclear families are the influence of Western lifestyle, educational activities, and the pursuit of better job opportunities, among others.

Traditional Newari Dwelling

The traditional Newari dwellings were constructed of locally available materials like brick, mud, wood, etc. The average house with its basic rectangular design is generally about 6 meters in depth, while its length is governed by the size and availability of materials (Korn, 1977). Traditional buildings are considered to be three to four storeys high with floor heights between 1.60m to 2.40m (Suwal, 2020). According to an ancient building regulation, private houses are not allowed to exceed the height of temple.(Schiebler, 1988) During the early –Malla period (until the middle of 16th century), it can be inferred that all the buildings at that time were restricted to two storeys, for the Taleju Temple, the most important temple in Bhaktapur, is itself two storeys high (Scheibler, 1988). Later three-storeyed with pitched roof building style developed with the aim of symmetry in facade design (Figure 1). The early Shah period's (1786-1846) Dwellings were constructed in the classic Newari style of the Malla period, which enlarged in proportion. The need for more space to accommodate the ever-growing family size led to a further rise in the height of the houses. Thus, this period witnessed, fourth or fifth-storey buildings exclusive of the attic (Maharjan, 2017). The traditional architectural style was maintained during the Rana Period, with few modifications to the façade detailing and building materials. After the great earthquake of 1933-1934, are quite often five, and even in some cases, six storeys high. In some cases overextended, from an original room height of 1.60 – 1.90m to 2.50 -2.90m (Scheibler, 1988). The study aimed toexplore variations in the front facade of ancestral housing due to transformation of family structure from joint to nuclear. The study has specific objective to analyze the effects of changes occurring in Newari dwellings facade.

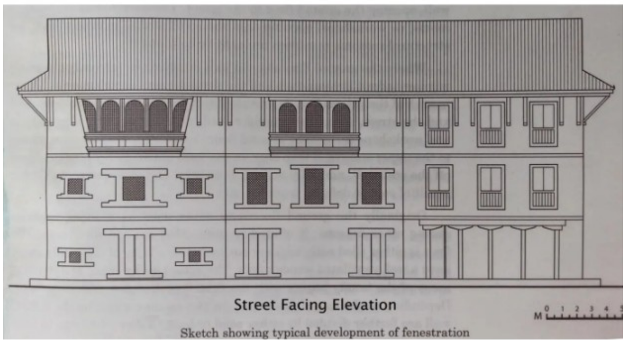


Figure 1Traditional Newari building facade of Malla, Shah and Rana Period (Korn, 1976)

2. Methodology

This study employs a qualitative research approach to investigate the impact of changing family structures on the traditional architectural character of Newari dwellings. The research is centered in Nala, a historic Newari settlement located in the Kavre district.

A case study design was employed to facilitate an in-depth examination of the selected settlement area along the Mahalaxmi Jatra procession route, which is considered the oldest settlement zone. The study is an integration of ethnographic methods, interviews, focus group discussions (FGDs), and field observations that help to understand the context of architectural changes within their socio-cultural framework. The field study was conducted in July 2024.

A purposive sampling strategy was used to select the case houses for in-depth study. Emphasis was placed on those houses that had undergone physical modifications due to family divisions. A total of 71 houses were studied along that historical route, among which 40 houses were divided vertically.

Data collection was conducted using ethnographic field notes, semi-structured interviews, and Focus group discussions. Field notes were collected through field observation and photographic documentation of each house along the street. A semi-structured interview with open-ended questions was conducted to explore the relevant theme.

Focus group discussion organized meeting with local stakeholders, community leaders, and guthi. Discussed the changing pattern of housing and its mitigations.

Data such as the number of vertically divided houses, new constructions, and demolition of dwellings were quantified using Microsoft Excel. Graphical and comparative analysis were conducted using new and old photographs and documentation. Percentages, frequency tables, and visual charts were generated to support qualitative findings. AutoCAD was used to prepare drawings that illustrate changes in façade property division patterns and dwellings demolished after a change in family structure.

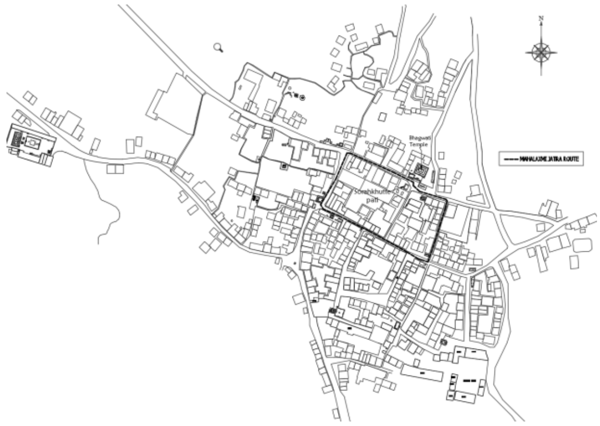


Figure 2 Research area

3. Study Area

Nala is located in the western section of Kavre district, seven kilometers east of Bhaktapur. It lies 25 kilometers east of Kathmandu, accessible by Banepa (2.5 kilometers), and 8 kilometers south of Nagarkot. The two famous rivers Punyamata and Nanyamata flow at south of Nala and meet a few hundred meters below the settlement.

Nala was previously called Nalangram, which indicates that the settlement existence was from the Kirat period. In the silapatra found in the dhungedhara near Bhagwati Temple written that "the dhara was constructed in 715 B.S. during the reign of King Shivadev II by Dhurvasheel & his brother Anagasheel. This indicates that the existence of Nala was also in the Lichhavi Period. During the Malla Period, the "saat gaun" of Kavre was arranged by King Ananda Malla of Bhaktapur which also includes (Shrestha & Shrestha, 1994). Nala is home to one of the four Bhagawati Temples ("Ugrachandi Bhagwati Temple") and one of the four Lokeshwors ("Shristikanta Lokeswor Karumamaya"), demonstrating the connection between Hindu and Buddhist traditions. (Ulak, 2013)

Nala is a Traditional Newari Settlement with a joint family system in the past. (Tamrakar, 2018). Now it's shifting towards a nuclear family due to many reasons. It is clearly shown by the survey done in 2013 for a thesis; 47% of people live in joint families and 53% of people live in Nuclear families(Tamrakar, 2018). As in other traditional Newari towns here, changes in dwelling units can be found concerning changes in the family.

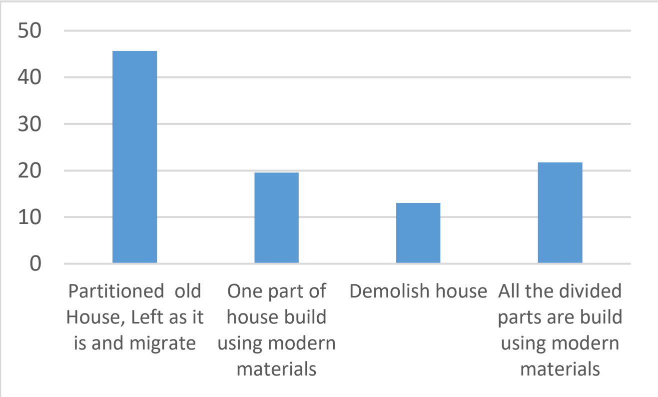
The study will focus on the core of the settlement defined by the Mahalaxmi Jatra Route (Main Jatra) of Nala as shown in Figure 1. The street consists of Traditional, Mixed, and modern types of dwellings. The social system of distributing parental assets equally to sons, as well as the change from joint to nuclear family systems, have supported the vertical division of traditional dwelling units. The study area consists of 18 houses (also including demolished) which are vertically divided and form 46 households.

4. Data Analysis and Discussion

Impact of Vertical Division on Traditional Newari dwellings

As Newars are a patriarchal society, the property transfers from father to son equally. When property division occurs no one wants to leave their traditional house and this leads to the vertical division. In the study area, it was found that the maximum number of vertical divisions was up to 5 parts. It was found that after division four things happened to the house (Figure 3) which affected the traditional architecture of the area.

i. Division and desolation of existing dwellings
ii. Contemporary addition with modern interventions
iii. Complete Demolition of the house



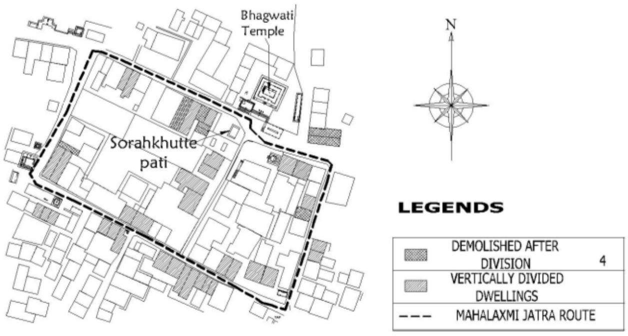


Figure 3 Changes after Vertical Division

Figure 4 Map showing dwellings and vacant land after vertical division

i. Division and desolation of existing dwellings

From Figure 3 it is clear that 45% (maximum) of the houses were partitioned and left out. The owners of the house migrated either to the agricultural land or to the other city. Those dwellings that are visited by the owners are still in livable conditions (Figure 5). And which are not visited by the owners are deteriorating day by day due to lack of maintenance (Figure 6).

Figure 5: Livable condition

Figure 6: Deteriorating

ii. Contemporary addition with modern interventions:

Another 20% case found was after vertical division one owner rebuilt the house using modern materials and the other owner(s) left it as it was (Figure 8). This causes two problems, one is that traditional architecture gets disturbed. Another is houses become structurally weak. New dwellings are taller and use modern materials and their widths are smaller resulting in slender tall houses. Another left part of the house also becomes weak. Both cases are vulnerable during earthquakes.

22% of the surveyed houses are found to be reconstructed using modern materials after vertical division (Figure 10).

These cases have increased after the earthquake of 2015. This has completely disappeared the traditional dwellings.

Figure 8 Partial New Construction

Figure 7 Completely New Construction

iii. **Complete demolition of the house:**

The third case includes 12% of dwellings demolished after vertical division. The reason behind it is migration and shifting to nearer agricultural land, regular maintenance costs are higher so instead the owner demolished it (Figure 12). Another reason is traditional windows cost more and to sell those

Figure 10 Before Demolition

Figure 9 one section demolishes

they demolished the house. This has caused the disappearance of traditional Newari dwellings.

Conclusions:

This study demonstrates a direct and consequential relationship between the shift from joint to nuclear family structure and the transformation of front facades. Qualitative research methods like ethnographic methods, interviews, and focus group discussions reveals that practice of vertical division, driven by equal distribution of ancestral property among heirs, has resulted in two primary outcomes that are; a fundamental fragmentation of the urban fabric and loss of architectural heritage.

Field observation confirms that the resultant changes are not superficial but they catalyze a chain of vacancy, demolition and culturally disconnected rebuilding. The evidence is clear, the changing family structure is the primary driver behind impending loss of Nala's traditional architectural identity, placing its historical character on the verge of extinction.
The social heritage of Newari family is fundamental sustainer of its architectural heritage. Therefore, the disappearance of one accelerates the demise of other.

References

Fallah, E., & Hojat, I. 2018. Family structure and housing Investigating the effect of family structure changes on houses' spatial organization (A case study of the houses of Yazd). Int. J. Architect. Eng. Urban Plan, 28(2), 149–162. https://doi.org/10.22068/ijaup.28.2.149

Family Social Institution. (n.d.). Retrieved September 28, 2025, from https://onlinenotesnepal.com/family

Korn, W. 1977. The Traditional Architecture of the Kathmandu Valley. Ratna Pustak Bhandar.

Kumar, D., & Assistant, R. (2023). DMC Journal: A Peer Reviewed Journal of Interdisciplinary Studies Changes of Family Structure in Nepal. 08(2006), 73–79.

Manandhar, T. 2020. Digu Puja: A ritual to revitalize the family unity among the Newars. Nepalese Culture, 8, 117–126. https://doi.org/10.3126/nc.v8i0.27506

NSO. 2024. National Population and Housing Census 2021: Population Composition of Nepal (First). Government of Nepal. https://www.censusnepal.cbs.gov.np

Schiebler, G. 1988. Building Today in a Historical Context Bhaktapur Nepal. Ratna Pustak Bhandar.

Shrestha, G. L., & Shrestha, J. L. (1994). Nala Desh Ko Parichaya (first). Jeevan Printing Support Press.

Suwal, R. P. 2020. Vernacular Newar Dwelling- Its Construction Technologies and Vertical Functional Distributions. SCITECH Nepal, 15(1), 58–65. https://doi.org/10.3126/scitech.v15i1.49105

Tamrakar, R. 2018. Impact of Modern Development in the Conservation of Nala, Kavre. LAP LAMBERT Academic Publishing,2018.

Ulak, B. N. 2013. Nala and Countryside Tourism. The Gaze: Journal of Tourism and Hospitality, 5, 43–68. https://doi.org/10.3126/gaze.v5i0.15110

ISSN NO. 2091-1742

SCITECH NEPAL

Journal of Scientific and Technical Studies

Nepal Engineering College, Pokhara University

Received: June 10, 2025

DOI: https://doi.org/10.3126/scitech.v18i1.90812

Accepted: January 30, 2026

Seismic Assessment of Rammed Earth Buildings: A Review

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Abstract

Rammed Earth (RE) construction is an ancient green building method that is becoming popular because it is cost effective and eco-friendly. There are different approaches on how one can optimally assess the seismic vulnerability of rammed earth structures. This review aims to understand the parameters that govern the behavior of rammed earth construction in terms of its seismic threat, including the materials, reinforcements and the evaluation procedures. Some of the important techniques such as shake table, FEM, and DEM, to name a few, are described in order to demonstrate the behavior of a RE building during a seismic event. The study establishes that density, elastic modulus and compressive strength are the key material properties which determine the level of seismic resistance required for any particular use. The review includes additional methods of reinforcement, mesh wrapping and textile reinforced mortar (TRM) and the concrete column integration, which are known to enhance the structural performance of Rammed Earth buildings during earthquakes. In order to increase further the seismic resistance of rammed earth-based structures, the review points out the lack of standardized test methods, research on aging effects, as well as search for materials with better performance.

Keywords: IDA, Pushover analysis, Rammed earth, Seismic assessment, Vulnerability

1. Introduction

Rammed earth construction is a method of creating solid walls by compacting subsurface material occasionally stabilized with cement or other binders into successive layers inside temporary formwork (Maniatidis and Walker, 2008). It is also one of the most often used modern earth building techniques. Rammed earth constructions have been there since antiquity; researches conducted in Southwest Asia, Africa and middle east have shown structures dating as far back as 10,000 BCE (Silva et al., 2018). When the Iberian Peninsula was under Islamic rule, RE practices flourished between the eighth and thirteenth centuries (Silva et al., 2018). Roman Pliny the Elder first documented about rammed earth in 79 AD. In 18th century, François Cointeraux popularized rammed earth in Europe with his writings on "pisé de terre". During the 19th century, rammed earth techniques spread to the United States, especially in areas with limited timber (Gramlich, 2013). The locals in the Himalayan range like Ladakh in India, Mustang in Nepal, China, and Bhutan still practice traditional rammed earth construction (Shrestha et al., 2020). Figure 1 shows the areas of earth constructions all over the world.

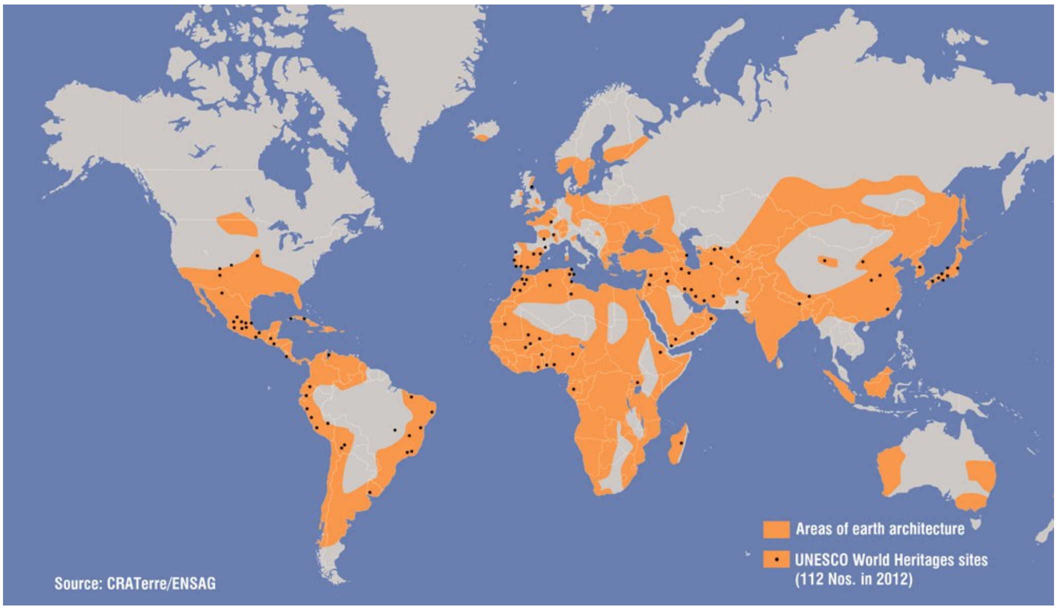

Figure 1: Areas of earth construction around the world (Correia et al., 2013)

2. Numerical Simulations and Experimental Validation

For seismic assessment, one of the most practiced techniques is the Finite Element Analysis (FEM). It permits detailed modeling of the entire displacement of structural components during an earthquake and its effects. Nowamooz and Chazallon (2011) used Cast3M software and FEM to model the non-stabilized rammed earth walls. They focused on L-shaped walls and analyzed the soil water retention, capacity as well as its tension. It was noted that drier walls are able to withstand higher cyclic loads. Using FEM models in DIANA software, Miccoli et al. (2016) used Cast3M software and FEM to model the non-stabilized rammed earth walls. They focused on L-shaped walls and analyzed the soil water retention, capacity as well as its tension. It was noted that drier walls are able to withstand higher cyclic loads.

DEM is another effective method to simulate the mechanical behavior of RE structures, simulating the interaction of discrete elements due to loading conditions, which is mainly needed in seismic performance. A research by Nabouch et al. (2016) evaluated the performance of RE walls using DEM. The analysis, in particular the force displacement relationship study, indicated that RE walls can be safely installed in the low to-medium seismic zone. The study also emphasized avoiding higher stories since these structures amplify seismic movement.

Bui et al. (2020) carried out the analysis of seismic performance by discrete element technique DEM. Both types of reinforced and unreinforced RE walls of one-storey and two-storey buildings under vertical and horizontal seismic loads were modelled. Seismic performance in rammed earth walls was enhanced by incorporating vertical steel rods. Higher the compressive strengths of the materials higher the increase in seismic performance.

A numerical study to investigate the in-plane seismic behavior of rammed earth walls was discussed by (Bui et al., 2018). Seismic performance assessment is a numerical study that models an in-situ RE by DEM and further scales earthquake excitation to assess the seismic behavior, keeping track of drifts for analysis.

In general, numerical models are a powerful tool in seismic performance studies since they can forecast the behavior of buildings subjected to seismic loads. However, such simulations need experimental data to validate them. For this reason, Ramezanpour et al. (2021) verified the FE model of RE walls with quasi-static cycle testing. Indeed, there is effectiveness due to high accuracy because the experimental results are in good accordance with numerical predictions. To evaluate the dynamic behavior of rammed earth walls, Silva et al. (2018) combined destructive and non-destructive testing methodologies to investigate the dynamic behavior of rammed earth walls. It was underlined that an understanding of the failure mechanism and crack propagation is of paramount importance for having a proper view of seismic performance.

Shake table tests involve physically testing structures under earthquake conditions in order to generate data for real-life simulations. In the study by Zhou and Liu (2019) shake table testing was used in simulating the dynamic characteristics, including acceleration and displacement response, under seismic waves of two single-story, ½-scale rammed earth houses. From the results obtained, internal reinforcements improved seismic performance substantially.

Tetley and Madabhushi (2007) considers a discussion on the seismic performance of adobe structures to be relevant in showing how such can be improved by, among others, using plastic carrier bag mesh, wire mesh cages, and steel reinforcing bars. Seismic performance was tested with 1g shaking table tests on the 1:5 scale models of adobe walls comparing the failure accelerations between the better and the unimproved models.

Sen and Saha (2025) show that naturally fibre-reinforced retrofitting of rammed earth houses performs better during earthquakes and showed damage to the unreinforced and cement-stabilized rammed earth house models. One-way shaking table tests of the retrofitted rammed earth model houses without reinforcement.

3. Seismic Assessment Methods of Rammed Earth Buildings

The seismic in-plane performance of rammed earth components and the efficacy of TRM strengthening to increase their seismic resistance are assessed in the work by (Allahvirdizadeh et al., 2019). The study employed incremental dynamic analysis (IDA) and pushover analysis as seismic performance evaluation techniques.

The in-plane seismic performance of mortar-strengthened rammed earth walls that are not strengthened and those that are reinforced with textile is investigated numerically in the study by (Allahvirdizadeh et al., 2019). Nonlinear finite element modeling, encompassing incremental dynamic analysis (IDA) and pushover analysis. Future experimental testing will be carried out in accordance with the results of the numerical modeling.

To characterize the seismic vulnerability of rammed earth walls, Romanazzi et al. (2022) empirically investigate their in-plane cyclic performance. In this paper, in-plane cyclic loading is imposed on a large-scale specimen of a rammed earth wall as part of the approach for seismic performance assessment, while dynamic identification tests were also conducted following the evolution of dynamic properties of the wall and structural damage.

The work by Pennacchio et al. (2022) aims at the influence of traditional construction practices on seismic vulnerability in Bhutanese Vernacular Rammed Earth architecture. The impact of traditional building practices on the seismic vulnerability of Bhutanese vernacular rammed earth architecture is examined in the work by the research cooperation between Politecnico di Torino, Nagoya University, and the Royal Government of Bhutan investigates the local building practice's influence on rammed earth buildings' seismic failure processes. A comparison of past damage assessment studies carried out by the Bhutanese government with the conclusions reached by the researchers on earthquake failure mechanisms. Discussion of conventional building techniques, potential flaws and their effect on seismic failure mechanisms are carried out based on specific criteria. One of the research findings was verified through a full-scale static test carried out on a rammed earth mock-up building.

Static pushover experiments on RE walls by El-Nabouch et al. (2017) demonstrated that reduced vertical strains enhanced in-plane seismic performance, particularly in single-story buildings. The walls' ductile characteristic is advantageous for seismic resilience. The out-of-plane reaction of RE structures was the subject of studies such as (Allahvirdizadeh et al., 2019). They showed that load capacity was greatly increased by strengthening with textile-reinforced mortar (TRM).

4. Reinforcement Techniques and Strengthening Strategies

Since unreinforced rammed earth is brittle, reinforcement is usually added to improve seismic performance. According to Nabouch et al. (2016), rammed earth walls are unsuitable for high seismicity zones and require reinforcement for medium seismicity zones, but they can have enough seismic resistance in low to moderate seismicity zones. Nonlinear force-displacement curves for the rammed earth walls were obtained using discrete element modeling (DEM). Standard acceleration-displacement curves are generated in accordance with Eurocode 8. Superimposition of the force-displacement and acceleration-displacement curves to determine the intersection point (target point), which was then used to assess the seismic performance of the walls under different conditions (vertical load, seismic zone).

The seismic in-plane performance of rammed earth components and the efficacy of TRM strengthening to increase their seismic resistance are assessed in the work by(Allahvirdizadeh et al., 2019).The study employed incremental dynamic analysis (IDA) and pushover analysis as seismic performance evaluation techniques.

The effectiveness of two strengthening approaches and the seismic performance of a vernacular rammed earth building are evaluated in the paper by (Librici et al., 2017). Finite element modelling (FEM) was the seismic performance assessment method employed in this study to numerically characterize the seismic performance of a vernacular rammed earth construction and the effects of two strengthening techniques (a ring beam and textile reinforced mortar) on its seismic performance.

According to Sen and Saha (2025), rammed earth houses that have been modified with natural fiber reinforcement perform better seismically than those that are unreinforced and cement-stabilized. Unreinforced and retrofitted rammed earth model houses were used for unidirectional shaking table tests.

According to the research by Romanazzi et al. (2019), a TRM-based strengthening technique increases the shear strength and stress distribution of rammed earth structures, hence improving their seismic capability. Diagonal compression tests were used to evaluate the seismic performance of rammed earth wall specimens that were both unstrengthened and strengthened using the Textile Reinforced Mortar (TRM) technique, which uses glass fiber or nylon mesh embedded in an earth-based mortar.

The seismic performance of rammed earth walls can be enhanced by the addition of structural columns. A quasi-static experimental study comparing the effects of various structural column reinforcements on the failure shape, bearing capacity, deformation capacity, and energy dissipation capacity of rammed earth walls was the seismic performance assessment method employed in (Zhou and Liu, 2019).

According to Romanazzi et al. (2023), a TRM-strengthening solution enhances rammed earth walls' ductility, energy dissipation, and in-plane shear capacity under cyclic loads. A strengthened rammed earth mock-up was tested under in-plane cyclic loads as part of an experimental program to evaluate seismic performance. Metrics like cracking, damage, displacements, base shear, stiffness, and energy dissipation were assessed, along with the use of simplified analytical models.

4.1. Internal Reinforcement Techniques

- **Concrete Columns and Beams**: Nguyen et al. (2021) presented the influence of RE walls associated with reinforced concrete columns and beams. They concluded that such reinforcement elements had a significant effect on improving earthquake resilience, especially for multistory buildings.
- **Post-Tensioning**: Even though additional research is required in order to clearly define the technique Hamilton III et al. (2006) investigated the application of post-tensioned strengthening in RE walls concluding that it reduces deformations under seismic loading.

4.2. External Reinforcement Techniques

- **Textile-Reinforced Mortar (TRM):** Allahvirdizadeh et al. (2019) utilized TRM reinforcement to enhance out-of-plane seismic performance of RE walls. They showed that TRM reinforcement improves in both displacement and load at failure thus providing a feasible solution to the problems of increasing the seismic resistance of RE structures.

- **Mesh-Wrap Strengthening:** Wangmo et al. (2021) conducted a study on the mesh-wrap strengthening of thinner layers of rammed earth for the improvement of both shear and compressive strength in RE walls.

5. Material Properties

Mechanical properties such as compressive strength, density and modulus of elasticity of rammed earth play a vital role in its seismic performance.

- **Compressive Strength and Density**: Research by Ramezanpour et al. (2021) showed that density, compaction, and the type of material used for constructing RE has significant effects on the compressive strength of the material. Higher density is usually characterized by higher compressive strength.
- **Elastic Modulus**: A study by Bui et al. (2020) illustrated the dependence of the values upon the soil type and moisture content, while also studying the empirical relations between compressive strength and elastic modulus.

Table 1: Mechanical Properties of Rammed earth in different research works

Research works	UCS (MPa)	Density (kg/m^3)	Young's Modulus (MPa)
(Maniatidis and Walker, 2008)	2.46	1850	160
(Lilley and Robinson, 1995)	2	2170	
(Bui and Morel, 2009)	1	1800	90
(Miccoli et al., 2014)	3.73	2190	4143
(Allahvirdizadeh et al., 2019)	1.28	2000	1034

Research works	UCS (MPa)	Density (kg/m^3)	Young's Modulus (MPa)
(Librici et al., 2017)	1	1723	67
(Ramezanpour et al., 2021)	1.17	1940	253.9
(El-Nabouch et al., 2017)	2		763
(Shrestha et al., 2020)	0.85	2028	79.3
(Wangmo et al., 2021)	0.98	1818	102
(Nguyen et al., 2021)	1.14	2104	243
(Bui et al., 2020)	2	2300	400
(Liu et al., 2015)	1.357	2020	57
(Arslan et al., 2017)	1.47		
(Zhou and Liu, 2019)	1.24	2104	243
(Nabouch et al., 2016)	0.97		
(Lepakshi and Reddy, 2020)		1800	
(Liu et al., 2015)	1.357		57

Table 1 shows the various mechanical properties of the rammed earth material in the research done in different settings. These properties play crucial role in the seismic performance of rammed earth buildings.

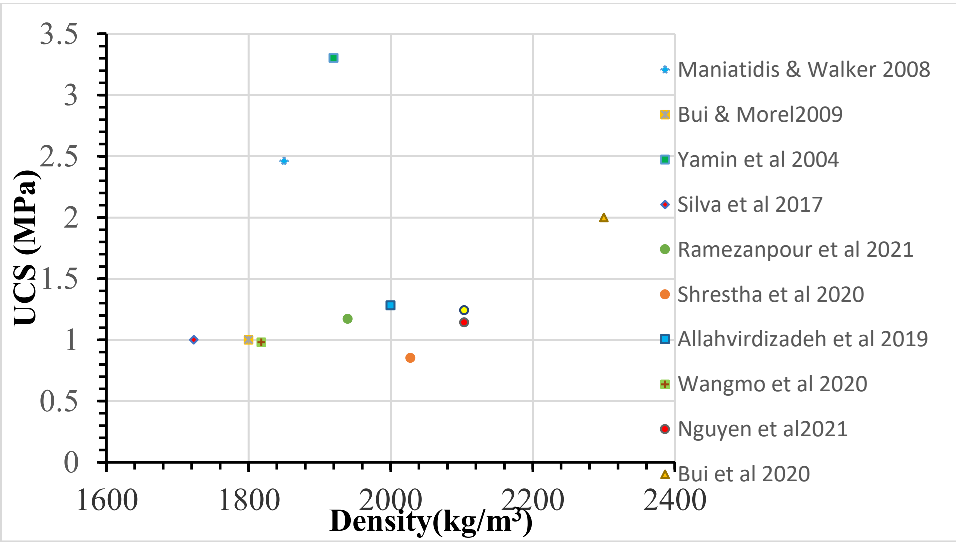

Figure 2: Compressive strength as a function of density

The graph in Figure 2 shows that density (kg/m^2) and UCS (MPa) have a positive correlation. The compressive strength of rammed earth is usually high if density is also on the higher side. The chart shows notable changes in UCS for comparable densities between studies which may be due to difference in testing procedure or different sources of the material but more detailed research into the reasons underlying these variances is also necessary.

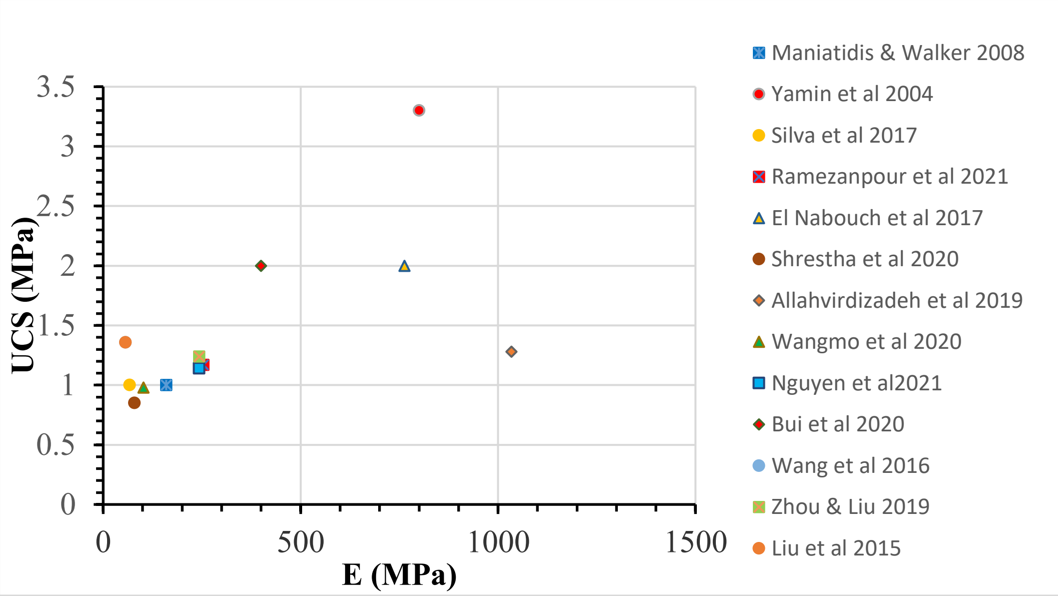

Figure 3: Compressive strength as a function of Young's Modulus

The relationship between Elastic Modulus (MPa) and UCS (MPa) from various research is displayed in Figure 3. Compressive strength and elastic modulus generally correlate positively. Figure 3 exhibits noteworthy variations in Elastic Modulus for comparable UCS values among many investigations suggesting the need for additional investigation to comprehend the fundamental elements behind this fluctuation. This can entail looking at how various soil types, moisture contents, and compaction methods affect the mechanical characteristics of rammed earth. Although the compressive strength values are highly dispersed, we can observe them in the range of 0.7 MPa to 3.5 MPa. These variations can be due to the composition, compaction, density, moisture content, size and shape of the samples being tested. Since there is not a single universally accepted testing procedure, researchers have adopted different strategies according to their local/regional standards and resources available to them.

The particle sizes adopted in various research works on rammed earth are shown in Figure 4. Ciancio et al. (2013) has given limits for particle size distribution and other research works were performed for earth material with PSD curve within these limits. The buildings constructed with rammed earth material having their PSD curves within the limits are expected to perform well during seismic events as well.

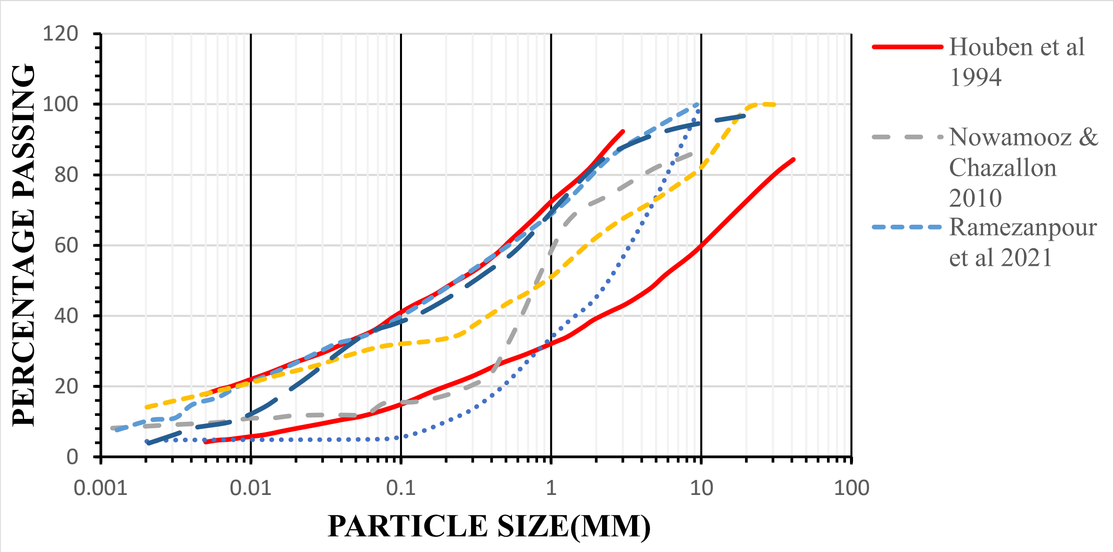

Figure 4: Particle size distribution curve for rammed earth material

6. Conclusion

Rammed earth (RE) construction has been known for its ecological benefits but its application in seismic zones has been quite difficult as this construction method which has historical significance lacks ductility and reinforcements. Computer programs or techniques such as Finite Element Modelling (FEM) or Discrete Element Modelling (DEM) are employed to design rammed earth structures and test the durability of these structures against seismic forces. These models seek validation through experiments such as key tests on shake table, which shows that using external reinforcements such as textile reinforced mortar (TRM) or using reinforcements in the form of concrete columns can significantly improve the seismic performance of these systems.

When looking at the overall effects of RE construction, one must consider the consequences of building material selection such as density and compressive strength as effective strength are also associated with these two features. Although all these can be enhanced through reinforcements, in plane loading situations tend to get most support, whilst out of plane loading instances are typically less stable.

The reinforcement techniques, such as mesh wrapping, post-tensioning, and TRM, have enhanced the resistance of the RE walls to seismic stresses by improving the ductility and shear strength of the RE walls. Certain aspects that require focus in future studies to further enhance seismic resistance in RE buildings are long-term performance, uniformity in testing procedures, and the incorporation of innovative materials. Further developments that could render rammed earth more viable and safer in seismic regions are also possible. Indeed, detailed investigations will be done for different typologies adopted all over the world to provide safety to its residents.

References

Allahvirdizadeh, R., Oliveira, D. V. & Silva, R. A. 2019. Numerical modeling of the seismic out-of-plane response of a plain and TRM-strengthened rammed earth subassembly. *Engineering Structures,* 193**,** 43-56.

Arslan, M. E., Emiroğlu, M. & Yalama, A. 2017. Structural behavior of rammed earth walls under lateral cyclic loading: A comparative experimental study. *Construction and Building Materials,* 133**,** 433-442.

Bui, Q.-B., Limam, A. & Bui, T.-T. 2018. Dynamic discrete element modelling for seismic assessment of rammed earth walls. *Engineering Structures,* 175**,** 690-699.

Bui, Q.-B. & Morel, J.-C. 2009. Assessing the anisotropy of rammed earth. *Construction and building Materials,* 23**,** 3005-3011.

Bui, T.-L., Bui, T.-T., Bui, Q.-B., Nguyen, X.-H. & Limam, A. Out-of-plane behavior of rammed earth walls under seismic loading: Finite element simulation. Structures, 2020. Elsevier, 191-208.

Ciancio, D., Jaquin, P. & Walker, P. 2013. Advances on the assessment of soil suitability for rammed earth. *Construction and Building Materials,* 42**,** 40-47.

Correia, M., Guillaud, H. & Rakotomamonjy, B. Earthen architecture, building cultures and sustainable development-UNITWIN Network. UNESCO Chair-Earthen architecture, 2013.

El-Nabouch, R., Bui, Q.-B., Plé, O. & Perrotin, P. 2017. Assessing the in-plane seismic performance of rammed earth walls by using horizontal loading tests. *Engineering Structures,* 145**,** 153-161.

Gramlich, A. N. 2013. *A concise history of the use of the rammed earth building technique including information on methods of preservation, repair, and maintenance*, University of Oregon.

Hamilton III, H., McBride, J. & Grill, J. 2006. Cyclic testing of rammed-earth walls containing post-tensioned reinforcement. *Earthquake Spectra,* 22**,** 937-959.

Lepakshi, R. & Reddy, B. V. 2020. Shear strength parameters and Mohr-Coulomb failure envelopes for cement stabilised rammed earth. *Construction and Building Materials,* 249**,** 118708.

Librici, C., Oliveira, D. V. & Silva, R. A. M. 2017. Seismic assessment of a vernacular rammed earth building.

Lilley, D. & Robinson, J. 1995. Ultimate strength of rammed earth walls with openings. *Proceedings of the Institution of Civil Engineers-Structures and Buildings,* 110**,** 278-287.

Liu, K., Wang, M. & Wang, Y. 2015. Seismic retrofitting of rural rammed earth buildings using externally bonded fibers. *Construction and Building Materials,* 100**,** 91-101.

Maniatidis, V. & Walker, P. 2008. Structural capacity of rammed earth in compression. *Journal of Materials in Civil Engineering,* 20**,** 230-238.

Miccoli, L., Drougkas, A. & Müller, U. 2016. In-plane behaviour of rammed earth under cyclic loading: Experimental testing and finite element modelling. *Engineering Structures,* 125**,** 144-152.

Miccoli, L., Müller, U. & Fontana, P. 2014. Mechanical behaviour of earthen materials: A comparison between earth block masonry, rammed earth and cob. *Construction and building materials,* 61**,** 327-339.

Nabouch, R., Bui, Q., Plé, O., Perrotin, P., Poinard, C., Goldin, T. & Plassiard, J. 2016. Seismic assessment of rammed earth walls using pushover tests. *Procedia Engineering,* 145**,** 1185-1192.

Nguyen, T.-D., Bui, T.-T., Limam, A., Bui, T.-L. & Bui, Q.-B. 2021. Evaluation of seismic performance of rammed earth building and improvement solutions. *Journal of Building Engineering,* 43, 103113.

Nowamooz, H. & Chazallon, C. 2011. Finite element modelling of a rammed earth wall. *Construction and Building Materials,* 25, 2112-2121.

Pennacchio, R., De Filippi, F., Bosetti, M., Aoki, T. & Wangmo, P. 2022. Influence of traditional building practices in seismic vulnerability of Bhutanese vernacular rammed earth architecture. *International Journal of Architectural Heritage,* 16, 374-393.

Ramezanpour, M., Eslami, A. & Ronagh, H. 2021. Seismic performance of stabilised/unstabilised rammed earth walls. *Engineering Structures,* 245, 112982.

Romanazzi, A., Oliveira, D. V., Silva, R. & Barontini, A. 2023. Effectiveness of a TRM solution for rammed earth under in-plane cyclic loads. *Construction and Building Materials,* 407, 133551.

Romanazzi, A., Oliveira, D. V., Silva, R., Barontini, A. & Mendes, N. 2022. Performance of rammed earth subjected to in-plane cyclic displacement. *Materials and structures,* 55, 54.

Romanazzi, A., Oliveira, D. V. & Silva, R. A. 2019. Experimental investigation on the bond behavior of a compatible TRM-based solution for rammed earth heritage. *International Journal of Architectural Heritage*.

Sen, B. & Saha, R. 2025. Structural stability evaluation of natural fiber retrofitted low-cost rammed earthen houses under seismic loading. *Structural Engineering International,* 35, 286-305.

Shrestha, K. C., Aoki, T., Miyamoto, M., Wangmo, P., Zhang, J. & Takahashi, N. 2020. Strengthening of rammed earth structures with simple interventions. *Journal of Building Engineering,* 29, 101179.

Silva, R. A., Mendes, N., Oliveira, D. V., Romanazzi, A., Domínguez-Martínez, O. & Miranda, T. 2018. Evaluating the seismic behaviour of rammed earth buildings from Portugal: From simple tools to advanced approaches. *Engineering Structures,* 157, 144-156.

Tetley, R. & Madabhushi, G. Vulnerability of adobe buildings under earthquake loading. Proceedings of the international conference on earthquake geotechnical engineering, Greece, 2007. 25-28.

Wangmo, P., Shrestha, K. C. & Aoki, T. 2021. Exploratory study of rammed earth walls under static element test. *Construction and Building Materials,* 266, 121035.

Zhou, T. & Liu, B. 2019. Experimental study on the shaking table tests of a modern inner-reinforced rammed earth structure. *Construction and Building Materials,* 203, 567-578.

Research Article *Volume 18* *Issue 1*

ISSN NO. 2091-1742

SCITECH NEPAL

Journal of Scientific and Technical Studies

Nepal Engineering College, Pokhara University

Received: June 10, 2025

DOI: https://doi.org/10.3126/scitech.v18i1.90813

Accepted: January 30, 2026

Assessing the Impacts of COVID-19 on Nepal's Construction Industry: Insights from Principal Component Analysis

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Abstract:

This study assesses the impacts of COVID-19 in Nepal's construction industry. A total of 387 responses were examined by Principal Component Analysis (PCA) technique with the help of SPSS software. PCA analysis identified five major components, which together accounted for 62.022% of the variation. The most important impact component observed was time and cost overruns, which accounted for 27.342% of the variation and had an eigenvalue of 5.742 with delay in completion of projects as the major indicator with coefficient 0.794. Likewise, the second major impact component was financial restrictions, accounted for 14.267% of the variation and had an eigenvalue of 2.996 with deterioration of financial condition of contractor due to loss in projects as the major indicator with coefficient 0.731. Based on these findings, it is advised deployment of cutting-edge technology, early purchasing of materials and following strict cost control measures would assist to prevent the impacts of COVID-19 on the construction industry.

Keywords: COVID-19, Impacts, Principal Component Analysis, Construction Industry.

1. Introduction

The construction industry contributes about 5.5% to the GDP of Nepal (MOF, 2023). Moreover, the construction industry employs 1 million people i.e., 14% of total employment generation in the country. However, COVID-19 posed an unprecedented threat to the construction industry of Nepal. In order to fight with COVID-19, the government imposed a nationwide lockdown which resulted in the shutdown of construction activities (Shrestha, 2022). COVID-19 severely impacted the construction industry due to which the growth rate of the construction industry of Nepal fell by negative 0.31% in Fiscal Year 2019/20 (Prasain, 2020).COVID-19 caused delay in completion of the project, supply chain problems, workforce shortage and hardship in maintaining health and safety of the workforce (Timilsina et al., 2021). It's been nearly six years of COVID-19 breakout but there have been few researches on impacts posed by COVID-19 in the construction industry of Nepal and this research will try to fill this gap.

2. Literature Review

COVID-19 halted or slowed most of the construction projects and caused low budget spending of the projects. Department of Road is the highest spender of capital budget of Nepal government. But due to COVID-19, it spent only 65% of the allocated budget in F/Y 2019/20 compared to 85% in F/Y

2018/19 (Shrestha, 2022). Construction projects faced delay in completion of projects. Delay of projects doubled in comparison to pre-pandemic level in large construction projects (Brown, 2022). This delay was caused because of the late payment to the contractors, no timely decision making by the consultants, delay in material delivery due to travel restrictions and taking too much time for revision and approval of the document (Nasir, 2022).

Lockdown imposed by the government forced the transportation and aviation industry to shut down. Borders with India and China were closed and all import-export activity stopped except essential goods. Due to this supply chain of construction materials broken down and import of construction materials, for which Nepal is dependent on India, like steel, wires, pipes and paints became difficult (Thapa, 2020). In addition to this, the construction industry faced contractual disputes in the name of compensation for time and cost (Leo and Singh, 2020). Moreover, projects faced hurdles in declaring COVID-19 as the force measure condition of the contract (Hansen, 2020).

COVID-19 caused a hike in the price of materials required for the construction sector. Due to interruption of supply chain and spike in fuel cost due to COVID-19, cost of materials like steel, cement, sand, plywood, bricks etc. escalated up to 40% as per Prakash (2021), which caused the average construction cost of houses to surge by 12%. This led to degradation of financial condition of contractors involved in the construction industry as per Timilsina et al. (2021) and faced losses in their projects (Lagat et al., 2023). To add this, the increase in construction cost was also fueled by change in foreign exchange rate, additional cost for pandemic management works like vaccination, test and more demand than supply of construction materials (Zamani et al., 2021).

Impacts of COVID-19 in the construction sector are restriction in movement of labor, decline in profit, increase in delay of project, cash flow problems, skilled manpower shortages, reduction in labor productivity, extra expenses in site management, site closure and low quality of construction work (Bist et al., 2021). Travel restriction and strict quarantine rules made skilled labor unable to reach worksites which caused labor shortage which poised difficulties in site supervision due to which errors in sites surged (Shrestha, 2022). About 60% of construction companies reported project delay occurred due to workforce shortages (McMurray, 2022). Also, wages of laborers increased dramatically after COVID-19 (NRB, 2023). Furthermore, foreign direct investment reduced sharply in construction projects of Nepal (Khatiwada, 2021).

3. Methodology

Initially, Cronbach's alpha assesses the internal consistency of the components, and a high level of dependability was shown with value of 0.813 (Taber, 2018). Similarly, I-CVI for each individual indicator was found to be >=0.872 and S-CVI for the whole indicator under impact of COVID-19 was 0.902 respectively (Polit et al., 2006).

In order to investigate the impacts of COVID-19 in the construction industry of Nepal, cross sectional design and quantitative research methods were used. Clients, contractors and consultants were targeted populations. A total of 450 professionals were surveyed by preparing questionnaires with adequate review of literature and 387 valid responses were received i.e., 86%. Questionnaires contained a Likert scale and respondents ranked the impacts of COVID-19 in the construction industry of Nepal with their perception, knowledge and experience. The obtained data were processed for analysis. With the assistance of SPSS software, Principal Component Analysis (PCA) was utilized to explore the major components of impacts of COVID-19 in the construction industry of Nepal. All respondents were more trustworthy since they were highly qualified, experienced, and had an appropriate designation in the construction sector as mentioned in Table 1.

4. Result and discussions

Table 1: Demography

Variable	Frequency	Percent	Variable	Frequency	Percent
Types of respondent organization			Position of respondent in organization		
Client	130	33.59%	Office/site engineer	185	47.80%
Contractor	165	42.63%	Site supervisor	150	38.75%
Consultant	92	23.77%	Others	52	13.43%
Education Level			Work Experience (in years)		
Diploma	97	25.06%	1-4	190	49.09%
Bachelors	170	43.92%	4-8	110	28.42%
Masters	70	18.08%	8-12	57	14.72%
Others	50	12.91%	>12	30	7.75%

4.1 Kaiser–Meyer–Olkin (KMO) and Bartlett's tests:

Suitability of data was tested by KMO and Bartlett's tests. KMO sampling adequacy value was obtained as 0.775 which exists in the high range. Moreover, Bartlett's tests obtained a significant value of ($\chi 2$ = 915.451, df = 210, Sig. = 0.000) which showed significant correlation existed between variables and suitable for factor analysis (Shrestha, 2021a) as shown in Table 2.

Table 2: KMO and Bartlett's Test

KMO and Bartlett's Test		
Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		0.775
Bartlett's sphericity test	Approx. X^2	915.451
	Df	210
	Sig.	0.000

4.2 Factor extraction for impacts of COVID-19:

Scree test and eigenvalue were applied to find the components by varimax rotation. According to the results of the Scree test, 5 components were obtained with eigenvalue more than one which have significantly impacted the total variability observed in data as shown in Fig 1. Other factors, which registered minor proportionality of variables were discarded as they were less important (Shrestha, 2021a).

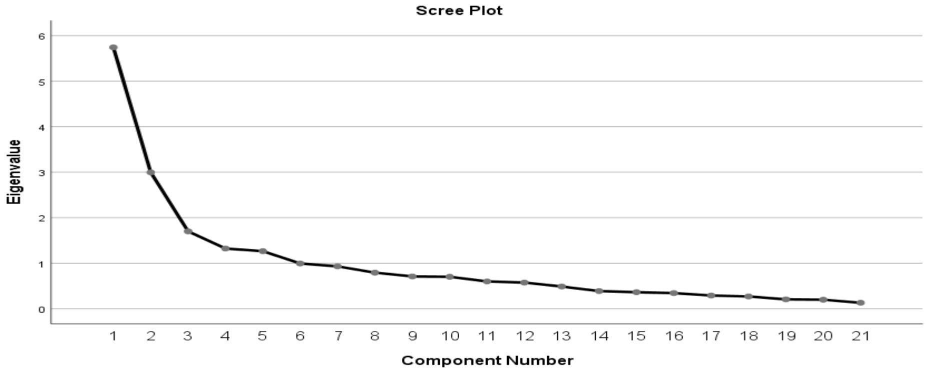

Fig 1: Scree Plot

Table 3: Eigenvalue and total variance explained by the components

Component	Initial eigenvalues			Extraction sums of squared loadings			Rotation sums of squared loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	5.742	27.342	27.342	5.742	27.342	27.342	3.587	17.079	17.079
2	2.996	14.267	41.609	2.996	14.267	41.609	2.713	12.921	30.000
3	1.700	8.096	49.705	1.700	8.096	49.705	2.465	11.736	41.736
4	1.322	6.297	56.003	1.322	6.297	56.003	2.167	10.317	52.053
5	1.264	6.019	62.022	1.264	6.019	62.022	2.093	9.969	62.022
6	0.994	4.732	66.754						
7	0.930	4.429	71.183						
8	0.792	3.772	74.955						
9	0.709	3.378	78.333						
10	0.702	3.341	81.675						
11	0.599	2.853	84.528						
12	0.574	2.735	87.263						
13	0.488	2.322	89.585						
14	0.388	1.847	91.432						
15	0.363	1.727	93.159						
16	0.343	1.633	94.792						
17	0.290	1.381	96.173						
18	0.270	1.284	97.457						
19	0.206	0.979	98.436						
20	0.198	0.941	99.377						
21	0.131	0.623	100						

As per above Table 3, the variance described by first, second, third, fourth and fifth factors are 27.342%, 14.267%, 8.096%, 6.297% and 6.019% respectively with their respective eigenvalues 5.742, 2.996, 1.7, 1.322 and 1.264. Total variance was found to be 62.02 % which accounted for more than 50% as suggested by (Sarstedt and Mooi, 2014).

4.3 Factor rotation and interpretation for impacts created by COVID-19

Table 4: Principal component analysis of impacts of COVID-19 on construction industry

Impacts of COVID-19 on construction industry	Components				
	Time and cost overrun	Financial constraints	Contractual disputes	Construction quality deterioration	Supply chain breakdown
Delay in completion of projects.	0.794				
Low spending of capital budget.	0.759				
Rise in wages of workers.	0.703				
Increase in cost of construction materials.	0.697				
Deterioration of financial condition of contractor due to loss in projects.		0.731			
Additional payments of bank interest and insurance premium by the contractor due to the project being delayed due to COVID-19 lockdown.		0.708			
Reduction in profit of contractors.		0.680			
Difficult to apply force majeure condition of contract.			0.772		
Increase in litigation and contractual disputes.			0.714		
Reduction in quality of construction work.				0.712	
Mistakes and errors in sites due to poor site supervision.				0.695	
Interruption in the supply chain of construction materials inside the country.					0.807
Difficult to import construction materials, equipment and goods unavailable in Nepal.					0.698

As per Table 4, out of 21 impacts only 13 were found to be critical and divided into five components such that remaining 8 impacts were discarded as outliers due to correlation value is taken as greater than 0.60 and according to Kline (2014) factor loading could be regarded as high if it is greater than 0.60.

Component 1: Time and Cost Overrun

The first major impact of COVID-19 in the construction industry of Nepal is "Time and Cost Overrun". It consists of 4 sub-factors i.e., delay in completion of projects, low spending of capital budget, rise in wages of workers and increase in cost of projects which have correlations of 0.794, 0.759, 0.703 and 0.697 respectively as shown in Table 4. Component 1 has 27.342% and 5.742 variance and eigenvalue respectively. This finding aligns previous study which states that COVID-19 caused rise in the construction project duration and costs (Khanal et al., 2020). Also, previous study showed that 91% construction projects were delayed due to COVID-19 as mentioned by Shrestha (2021b) and overall construction project cost surged by 4-5% (Kisi and Sulbaran, 2022).

Component 2: Financial Constraints

"Financial Constraints" is the second major impact of COVID-19. It consists of 3 sub-factors i.e., deterioration of financial condition of contractor due to loss in projects, additional payments of bank interest and insurance premium by the contractor due to the project being delayed due to COVID-19 lockdown, and reduction in profit of contractor having correlations of 0.731, 0.708 and 0.680 respectively as demonstrated in Table 4. Component 2 registers 14.267% of the total variance and has an eigenvalue 2.996. Past study showed that COVID-19 caused a transport ban, rise in operating costs and a significant decline in demand which reduced turnover by nearly 70% and decreased in profit which caused financial difficulties (Minett, 2020).

Component 3: Contractual Disputes

The third major impact of COVID-19 in the construction industry of Nepal is "Contractual Disputes". It consists of 2 sub-factors i.e., difficult to apply force majeure condition of contract, and increase in litigation and contractual disputes which have correlations of 0.772 and 0.714 respectively as displayed in Table 4. Component 3 has variance of 8.096% with an eigenvalue 1.7. Previous research also states that claims and disputes have hiked by 80% due to COVID-19 as per Olanrewaju et al. (2023) which occurred due to issue of time extension and cost compensation.

Component 4: Construction Quality Deterioration

"Construction Quality Deterioration" is the fourth most major impact of COVID-19 in the construction industry of Nepal. It contains 2 sub-factors i.e., reduction in quality of construction work, and mistakes and errors in sites due to poor site supervision having correlations of 0.712 and 0.695 respectively as represented in Table 4. Component 4 comprises 1.322 as eigenvalue and 6.297% as total variance. Past study also stated that travel restrictions forced technical and skilled workforce to reduce their frequency of site visit as stated by Mishra et al. (2023) which resulted in mistakes and error in sites thus reducing quality of works (Bist et al., 2021).

Component 5: Supply Chain Breakdown

The fifth major impact of COVID-19 in the construction industry of Nepal is "Supply Chain Breakdown". It consists of 2 sub-factors i.e., interruption in supply chain of construction materials inside the country, and difficult to import construction materials, equipment and goods unavailable in

Nepal which have correlations of 0.807 and 0.698 respectively as presented in Table 4. With an eigenvalue 1.264 and Component 5 has variance of 6.019% respectively. Earlier study by Moosavi et al. (2022) also resembles that COVID-19 had made severe impacts and interruptions on the supply chain system through production halt, distribution disbalance and cost escalation of raw materials (Emmett, 2024). Due to the closure of the border, imports-export activity of the country disturbed which and supply of construction materials and manpower got broken down (Khan et al., 2022).

4.4 Reliability of retained components:

To examine reliability of 5 components, Cronbach's alpha test was carried out. The α obtained values were ranging from 0.701 to 0.839 which indicated greater reliability as values are > 0.7 suggested by Taber (2018) as mentioned in Table 5.

Table 5: Cronbach's Alpha value.

Components	**Cronbach's Alpha**
Time and cost overrun	0.839
Financial constraints	0.796
Contractual disputes	0.701
Construction quality deterioration	0.730
Supply chain breakdown	0.798

5. Conclusion and Recommendation

COVID-19 had a severe impact on the construction industry of Nepal. This study explored impacts of COVID-19 in the construction industry of Nepal and categorized it into five principal components; time and cost overrun, financial constraints, contractual disputes, construction quality deterioration and supply chain breakdown with variation of 27.342%, 14.267%, 8.096%, 6.297% and 6.019% respectively. It is recommended that policymakers should proactively act in such a pandemic by formulating pragmatic plans and policy so that less harm will occur. Likewise, proper communication and collaboration should be ensured between stakeholders. In addition to this, application of modern machines and equipment should be increased with adaptation of the latest technology. Furthermore, the government should support the construction projects and facilitate them by waving taxes, prolonging loan paying time, providing special monetary packages and not stopping construction works of projects where chances of transmission is low. Moreover, stakeholders should prepare scientific strict cost control measures, contingency plans, inventory and inspection plans so that the construction industry will be less impacted. Additionally, Building Information Modeling (BIM) should be implemented in construction projects of Nepal.

6. Practical Implications

This research helps the construction management body of knowledge by investing impacts of COVID-19 to the construction industry of Nepal. The exact depth of impact posed by COVID-19 to the construction industry of Nepal shown by this paper will assist strategist and policy formulators of government and relevant authority to act, plan and reduce impact for similar situations in future.

References

Bist, T. C., Neupane, U. & Shahi, P. B. 2021. Impact of COVID-19 pandemic on construction sector of Nepal. *IOSR Journal of Mechanical and Civil Engineering,* 18**,** 25-30.

Brown, A. 2022. Construction project delays up 100% due to Covid.

Emmett, T. 2024. The lasting impact of COVID-19 on the Australian construction sector.

Hansen, S. Does the COVID-19 outbreak constitute a force majeure event? A pandemic impact on construction contracts. Journal of the civil engineering forum, 2020. Universitas Gadjah Mada, 201-214.

Khan, J., Ishizaka, A. & Mangla, S. K. 2022. Assessing risk of supply chain disruption due to COVID-19 with fuzzy Vikorsort. *Annals of Operations Research***,** 1-26.

Khanal, N., Singh, S. K., Dhungel, S. & Wagley, S. 2020. Impact of COVID-19 on the Construction Sector of Nepal. *AMC Indian Journal of Civil Engineering,* 3**,** 37-43.

Khatiwada, Y. K. J. E. J. o. N. 2021. Foreign Direct Investment in Nepal: Status and Way Forward. 44**,** 93-112.

Kisi, K. P. & Sulbaran, T. 2022. Construction cost and schedule impacts due to COVID-19. *Journal of Legal Affairs and Dispute Resolution in Engineering and Construction,* 14**,** 04522024.

Kline, P. 2014. *An easy guide to factor analysis*, Routledge.

Lagat, D. K., Njuguna, M., Mutanu, M., Mwende, A., Magak, A. & Nyakondo, S. 2023. Impact of COVID-19 on the Construction Industry Performance: A Case of Contractors in Kenya. *American Journal of Industrial and Business Management,* 13**,** 735-750.

Leo, U. & Singh, R. 2020. Covid-19 and contractual disputes in India. *Available at SSRN 3720741*.

McMurray, T. 2022. Supply chain, labor shortages complicate growing construction market.

Minett, A. 2020. The Impact of COVID-19 on the Construction Industry.

Mishra, K., Pokharel, A. & Aithal, P. 2023. Safety Measures Implemented at Site during COVID-19: A Case from Nepal. *International Journal of Management, Technology, and Social Sciences (IJMTS), ISSN***,** 2581-6012.

MOF 2023. Nepal Economic Survey 2022/23.

Moosavi, J., Fathollahi-Fard, A. M. & Dulebenets, M. A. 2022. Supply chain disruption during the COVID-19 pandemic: Recognizing potential disruption management strategies. *International Journal of Disaster Risk Reduction,* 75**,** 102983.

Nasir, M. 2022. Construction project delay due to the COVID-19 pandemic. *Journal of Surveying, Construction and Property,* 13**,** 1-11.

NRB 2023. Nepal Rastra Bank economic buletin 2023. National salary and wage index.

Olanrewaju, A., Anavhe, P. J. & Chu, H. C. 2023. Disputes and claim management during the COVID-19 crisis: The lessons learned. *Journal of Legal Affairs and Dispute Resolution in Engineering and Construction,* 15**,** 04522054.

Polit, D. F., Beck, C. T. J. R. i. n. & health 2006. The content validity index: are you sure you know what's being reported? Critique and recommendations. 29**,** 489-497.

Prakash, V. 2021. Building material prices hit the roof.

Prasain, K. 2020. As pandemic slows down economic activities, construction sector hits a brick wall.

Sarstedt, M. & Mooi, E. 2014. *A concise guide to market research*, Springer.

Shrestha, N. 2021a. Factor analysis as a tool for survey analysis. *American Journal of Applied Mathematics and Statistics,* 9**,** 4-11.

Shrestha, P. 2022. Third wave may stall construction activities, another setback for economy.

Shrestha, S. 2021b. The Impact of COVID-19 on Construction Project in Nepal. *Journal of Advances in Civil Engineering and Management,* 4**,** 1-4.

Taber, K. S. J. R. i. s. e. 2018. The use of Cronbach's alpha when developing and reporting research instruments in science education. 48**,** 1273-1296.

Thapa, P. 2020. *Assessment of Impact of COVID-19 Lockdown on Nepal's Construction Sector Based on Selected Construction Projects.* Pulchowk Campus.

Timilsina, S. P., Ojha, S. K. & Dhungana, B. R. 2021. Impact of covid-19 on construction industry of Nepal. *Modern Economy,* 12**,** 1232-1244.

Zamani, S. H., Rahman, R., Fauzi, M. & Yusof, L. Effect of COVID-19 on building construction projects: Impact and response mechanisms. IOP conference series: earth and environmental science, 2021. IOP Publishing, 012049.

Research Article Volume 18 Issue 1

ISSN NO. 2091-1742

SCITECH NEPAL Journal of Scientific and Technical Studies

Nepal Engineering College, Pokhara University

Received: June 10, 2025
Accepted: January 30, 2026

DOI: https://doi.org/10.3126/scitech.v18i1.90818

PET Water Bottle Recycling via Enhancing Concrete's Characteristics

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Abstract:

The escalating global crisis of plastic wastes, coupled with the industry's demand for sustainable materials highlights the need for innovative recycling solutions. This study investigates the use of recycled polyethylene terephthalate (PET) bottle fibers as a sustainable additive in concrete to mitigate the environmental impact of single-use plastics that often remains in landfills for extended periods. PET bottles were selected for their recyclability and environmental efficiency. They were collected, cleaned and then processed into fibers of size 50 mm x 2.5 mm. These fibers were then incorporated into concrete at proportions of 0%, 2%, 3%, and 4% by volume. The mechanical performance of the resulting concrete was assessed using cube, beam and cylindrical molds to measure compressive, flexural and tensile strengths after 28 days of curing in accordance to Indian Standard procedures. Five distinct mixes were tested, enabling a systematic analysis of PET fiber content's influence on concrete behavior. Experimental results showed a decline in workability as PET fiber percentage increased thus indicating a trade-off between sustainability and fresh concrete performance. Compressive strength decreased by an average of 48.01% at 4% PET fiber content, while tensile strength remained stable at 3% but diminished at 2% and 4%. these findings underscore the potential of PET fiber-reinforced concrete as a sustainable solution however its mechanical properties requires careful consideration for practical applications.

Keywords: Recycling, PET fiber, Environmental economics, Concrete, Concrete's strength.

1. Introduction

Rapid industrialization and urbanization have spurred extensive infrastructural development in order to meet growing societal demands and consequently have also intensified waste management challenges (Salman & Abbas, 2021). One promising solution is to recycle construction and plastic waste into alternative construction materials and energy sources. This research aims to investigate the incorporation of polyehylene terephthalate (PET) bottle fibers into non-structural concrete as a sustainable strategy to address two pressing challenges: the increasing demand for construction materials and the growing issue of plastic waste management.

With the increase of technology, for comfort, and ease of life, there has been increasing uses of plastic goods, replacing the traditional metal, glass, wood, and natural fiber. Among the plastic group, Polyethylene Terephthalate (PET) has rapidly replaced glass and metal uses due to its light weight, strength, cost-effectiveness, and ease in molding into different shapes and sizes. Being cheaper in cost, it can be thrown mostly after a single use which results in the large uses of PET and has also been the burden of waste management, in the context of Nepal.

Technological advancements have widely increased the use of plastic goods. Among these plastic groups, polyehylene terephthalate (PET) has emerged as a prominent substitute for traditional packaging materials like glass and metal, primarily due to its lightweight nature, mechanical strength, cost-efficiency and versatility in molding into different forms. The affordability has also facilitated widespread single-use applications, especially in the beverage and food packaging industries (Somwanshi et al., 2022). Globally. Plastic consumption has surged form 5 million tons in the 1950s to over 100 million tons by the early 2000s (Chavan et al., 2018). In Nepal, PET bottles-widely used in food and beverage packaging due to its clarity, inertness and resistance to microbial attacks, these products have posed significant challenges for waste management systems, contributing to environmental degradation and emphasizing the urgent need for sustainable disposal and recycling strategies.

Despite these challenges, PET is recyclable and recycling represents the most environmentally efficient method of reuse. However, effective recycling requires substantial investment in infrastructure and technology. This study evaluates the feasibility of recycling PET bottles by integrating their fibers into concrete, proposing a cost-effective and eco-friendly approach to mitigate Nepal's growing PET waste burden while addressing construction material needs. By examining the mechanical and physical properties of PET fiber-reinforced concrete, the research seeks to establish its potential as a resource-efficient solution to solid waste accumulation.

2. Research Objectives

The primary objective of this research is to comprehensively investigate the impact of incorporating Polyethhylene Terephtalate (PET), as an aggregate replacement on the mechanical properties of concrete. This study will focus on assessing the changes in the workability, flexural strength and compressive strength of the concrete mixes containing PET. A comparative analysis will be conducted to determine the efficiency and viability of PET-modified concrete relative to the conventional concrete mixtures.

3. Materials and Methods

Materials used in this study are detailed in Table 1. PET fibers were sourced from discarded water bottles, which were collected, cleaned, and manually cut into strips measuring 50 mm in length and 2.5 mm in width. The 43-grade Ordinary Portland Cement (OPC) was used. Fine aggregate consisted of good-quality sand with a maximum particle size of 4.75 mm, while the coarse aggregate ranged from 4.75 mm to 20 mm. Potable water was used for mixing and curing.

Table 1: Descriptions of the materials used

S.N.	Materials	Descriptions
1.	Polyethylene Terephthalate (PET) fibers	Wasted water bottles collected, washed, and cut manually into 50mm long and 2.5 mm wide in size
2.	Cement	43 grade OPC
3.	Fine Aggregate	4.75mm downsize good quality sand
4.	Coarse Aggregate	Particle fall within 20 mm and 4.75 mm i.e. retained on 4.75 mm size sieve and passing through 20 mm sieve
5.	Water	Potable water

The concrete mix was prepared manually by mixing PET fibers of size 50mm x 2.5mm with a cement, sand and aggregate mixture with a volumetric ratio of 1:1.5:3 (cement: sand: aggregate). the water cement ratio was maintained at 0.5 for all mixed. Five distinct concrete mixes were developed: a control mix with 0.00% PET fibers and four experimental mixes containing 2%, 3%, 4%, and 5% PET fibers by volume.

For each mix, two specimens of each type were prepared: cubes (150 mm x 150 mm x 150 mm) for compressive strength tests, beams (100 mm x 100 mm x 500 mm) for flexural strength tests and cylinders (150 mm diameter x 300 mm height) for splitting tensile strength tests. The specimens were casted, compacted and cured for 28 days under standard conditions.

The mechanical properties of the PET fiber-reinforced concrete were evaluated after 28 days of curing in accordance with the Indian Standard Testing procedure. Compressive strength was determined using the cube specimens as per IS516, flexural strengths using the beam specimens as per IS516 and splitting tensile strength using the cylinder specimens as per IS5816.

The proposed work schedule for the laboratory experiments is presented in Table 2, detailing the number of samples for each PET fiber percentage and specimen type.

Table 2: Proposed Work Schedule of the Lab Work

S.N.	PET	Number of Samples		
	%	Cube	Beam	Cylinder
1	0	2	2	2
2	2	2	2	2
3	3	2	2	2
4	4	2	2	2
5	5	2	2	2

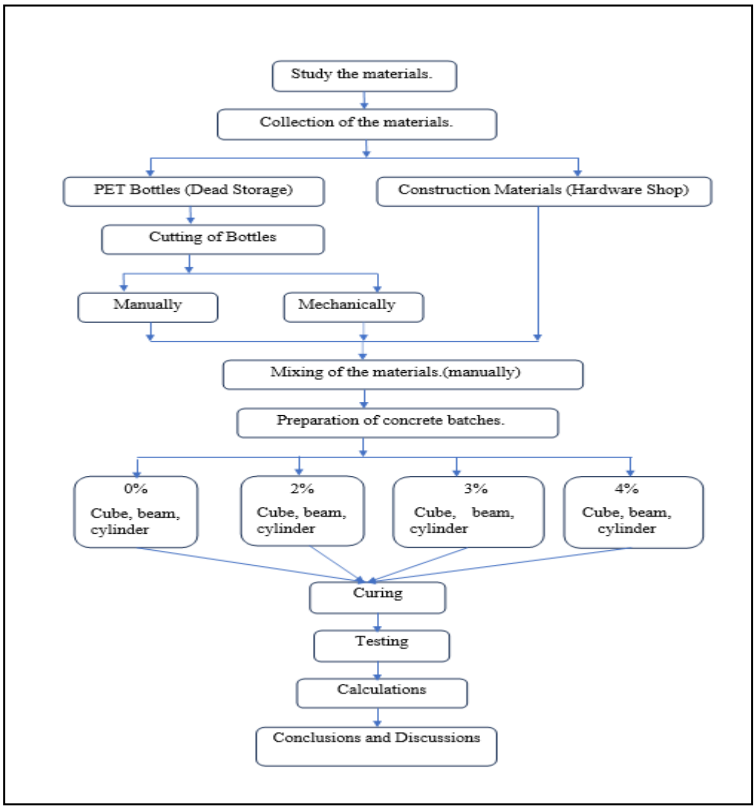

Figure 1: Research Methodology

The overall research methodology is illustrated in Figure 1, which outlines the steps from material collection to testing and analysis.

4. Result and Discussions

4.1 Workability

The Workability of concrete mixes were evaluated using the slump test. The control mix (0.00% PET fibers) achieved the highest slump value of 10 mm, while the mix with 4% PET fibers recorded the lowest value of 5 mm. A consistent decrease I workability was observed as PET fiber content increased as shown in Figure 2. This decline could be due to fiber bridging effect, which restricts the mobility of the mix by occupying voids and enhancing internal cohesion.

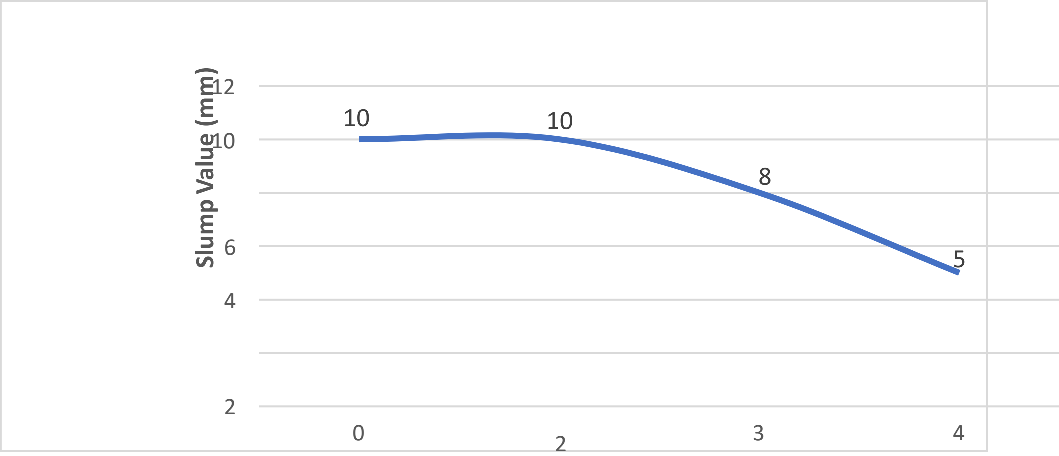

Figure 2: Slump Value vs PET Fiber Content

4.2 Mechanical Properties

4.2.1 Compressive Strength

The compressive strength of concrete decreased significantly with the incorporation of PET fibers. Compared to the plain concrete mix, reductions of 40.79% at 2% PET fibers, 40.63% at 3% and 62.63% at 4% were observed. Despite these declines, the compressive strength remained above 8.55 N/mm2 across all mixes as shown in Figure 4. The substantial reduction suggests weak bonding between the small, non-corrugated PET fibers and the concrete matrix, impairing the mix's ability to withstand compressive loads.

4.2.2 Tensile Strength

The split tensile strength displayed a varies response to PET fiber content. At 2% PET fibers, tensile strength decreased by 15.21% relative to the control mix. At 3% PET fibers, it matched the tensile strength of plain concrete, but at 4% it dropped by 38.58%. this trend is shown in Figure 4 and suggests that 3% PET fibers may represent an optimal content where the fibers reinforce the concrete without excessively disrupting the matrix.

4.2.3 Flexural Strength

Flexural strength exhibited a consistent decline with increasing PET fiber content. Reductions of 32.10% at 2%, 49.67% at 3% and 67.32% at 4% were recorded compared to the control mix. These results indicate that the PET fibers used in this study do not enhance bending resistance, possible due to increased porosity or poor fiber distribution within the concrete.

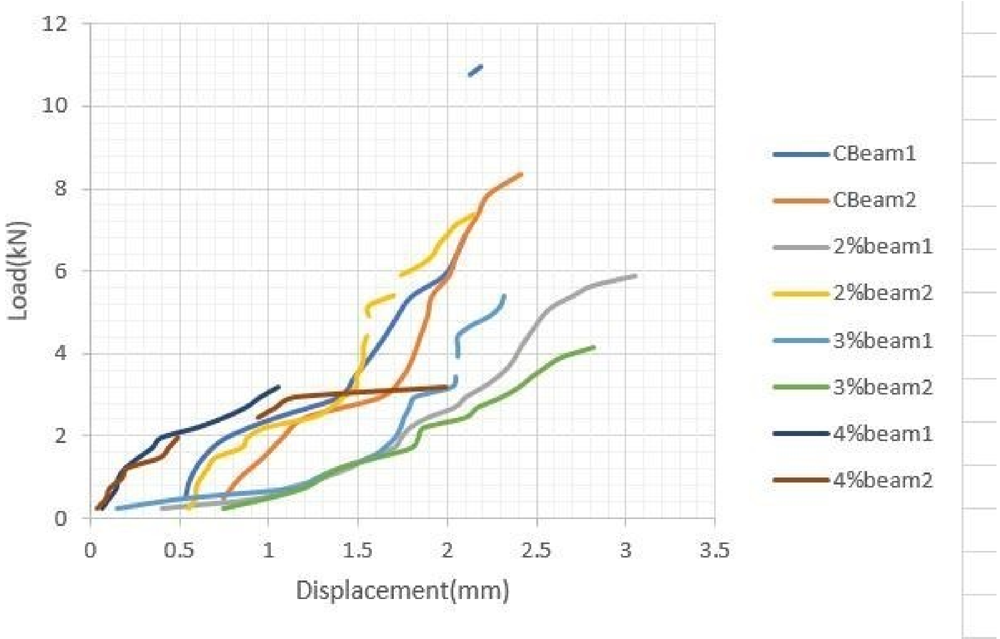

Figure 3: Load-Displacement Curve

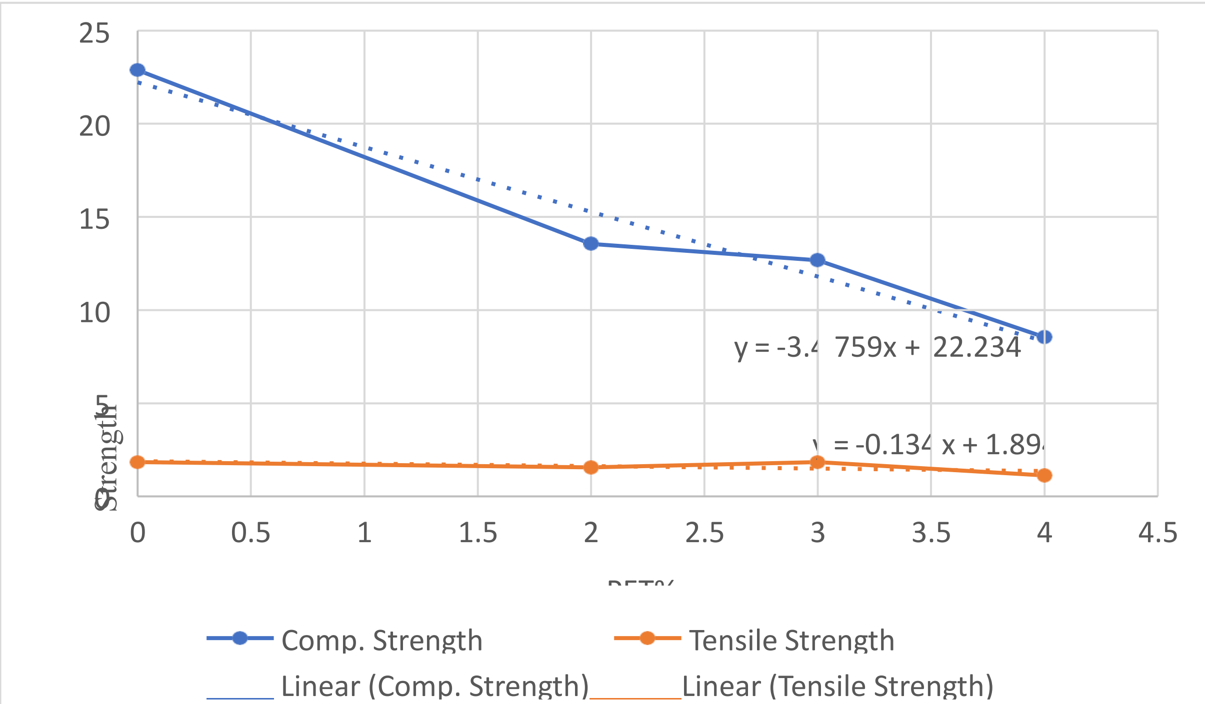

Figure 4: Compressive and Tensile Strength Curve

4.3 Discussions:

The primary aim of this study was to optimize the use of PET bottle fibers in concrete to reduce environmental pollution from discarded plastics, especially in the urban and semi-urban areas, while determining their suitability for structural and non-structural applications. The findings offer valuable insights on the performance of PET fiber-reinforced concrete.

The observed decrease in workability with higher PET fiber content is due to the fiber bridging effect, which restricts mix flow. For compressive strength, the significant reductions across all PET fiber percentages highlight the limitations of small, non-corrugated fibers that exhibit weak bonding with concrete matrix. In contrast, larger, corrugated fibers might improve bonding and strength, though they were not tested in this study. The tensile strength results indicate that stability of 3% PET fibers suggests a potential optimal fiber content where reinforcement benefits are maximized. However, the overall reductions in compressive and flexural strengths indicate that PET fiber-reinforced concrete is less suitable for structural elements under compressive or bending loads, where strengths typically exceeds 15 N/mm2. Instead, the minimum compressive strength of 8.55 N/mm2 at 4% PET fibers exceeds the typical requirement for non-structural applications, such as pedestrian walkways (5-7 N/mm2), making it a viable option for such uses (Khan, 2024).

These findings align with the study's sustainability goals by demonstrating that PET fibers can be repurposed in concrete, reducing waste while offering practical applications in non-structural contexts. The consistent trend of decreasing strength with increasing PET fiber content as shown in Figure 4 supports the hypothesis that excessive fiber incorporation adversely affects concrete performance, likely due to segregation, increased porosity or poor-fiber matrix interactions.

5. *Hypothesis Tests*

The study hypothesized that the mechanical properties of concrete would improve with the addition of PET fibers up-to a certain percentage, beyond which they would decline. The results partially validate this hypothesis: tensile strength remained stable at 3% PET fibers but decreased at 2% and 4%, while compressive and flexural strengths consistently declined with increasing fiber content. This aligns with existing literature (Kim et al., 2010; Khalid et al., 2018) on fiber-reinforced concrete, confirming the hypothesis for tensile strength but not compressive or flexural properties.

6. Conclusions

Based on the results and observations made in an experimental research study, the following conclusions are drawn.

a) Workability: Increasing PET fiber content reduces workability due to the fiber bridging effect.
b) Compressive Strength: An average reduction of 48.01% was observed with up to 4% PET fibers.
c) Tensile strength: Tensile strength matches plain concrete at 3% PET fibers but decreases at 2% and 4%.

d) Optimal Use: A 3% PET fiber content is recommended for non-structural concrete applications, balancing performance and sustainability.

References

Chavan, Mukesh, Shubham Tamhane, Sunil Chavan, and Rushikesh Phuge. 2018. "Manufacturing of Pavement Block by Using Waste Plastic and Sea Sand." *Research Journalof Engineering and Technology (IRJET)* 5 (03).

Khalid, F. S., Irwan, J. M., Ibrahim, M. H. W., Othman, N., & Shahidan, S. (2018). Performance of plastic wastes in fiber-reinforced concrete beams. Construction and Building Materials, 183, 451–464. https://doi.org/10.1016/j.conbuildmat.2018.06.122

Khan, S.A. Enhancing the mechanical properties of fibre-reinforced concrete through sustainable mix design: effects of fibre type and dose. Discov Civ Eng 1, 88 (2024). https://doi.org/10.1007/s44290-024-00087-7

Kim, S. B., Yi, N. H., Kim, H. Y., Kim, J.-H. J., & Song, Y.-C. (2010). Material and structural performance evaluation of recycled PET fiber reinforced concrete. Cement and Concrete Composites, 32(3), 232–240. https://doi.org/10.1016/j.cemconcomp.2009.11.002

Panimayam, S. A., P. Chinnadurai, R. Anuradha, K. Pradeesh, and A. Umar Jaffer. 2017. "Utilisation of Waste Plastics as a Replacement of Coarse Aggregate in Paver Blocks." *International Journal of ChemTech Research* 10 (8).

Salman A Mohammed Al-Dhaheri and Abbas M Burhan 2021 IOP Conf. Ser.: Mater. Sci. Eng. 1105 012089

Shahidan, Shahiron. 2018. "Concrete Incorporated with Optimum Percentages of Recycled Polyethylene Terephthalate (PET) Bottle Fiber." *International Journal of Integrated Engineering* 10 (1).

Somwanshi, D., Sharma, V. P., Sharma, S., & Jain, K. (2022). A Literature Review on Mechanical Properties of Waste PET Bottle Based Fibre. IOP Conference Series: Earth and Environmental Science, 1084(1), 012069. https://doi.org/10.1088/1755-1315/1084/1/012069

Research Article *Volume 18* *Issue 1*

ISSN NO. 2091-1742

SCITECH NEPAL

Journal of Scientific and Technical Studies

Nepal Engineering College, Pokhara University

Received: June 10, 2025

DOI: https://doi.org/10.3126/scitech.v18i1.90814

Accepted: January 30, 2026

Obstacles in Implementing Safety Management System in Nepalese Construction Projects

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Abstract

The rapid growth of construction activities in Nepal has led to an increase in accidents and fatalities. Construction projects are inherently risky due to the use of heavy equipment, power tools, and involvement of workers from various backgrounds. Safety management systems (SMS) help to mitigate these risks and hazards, which are in early stages in Nepal. The main purpose of the study is to find out the major obstacles in implementing SMS in construction projects. A total of 368 completely filled responses were collected and Principal Component Analysis (PCA) was used for analysis. Twenty-two obstacles were identified through an extensive review of the literature which were divided into five components using PCA. It was found that poor safety culture explained the most variation, accounting for 38.890% of the overall variance, with an Eigen value of 8.556. This study concludes that SMS are an essential tool in managing safety in construction projects, but their implementation requires careful planning, training and resources which will further help to improve SMS practices in similar projects.

Keywords: Construction Projects, Obstacles, Occupational Health and Safety, Principal component analysis, Safety Management System

Introduction

Construction safety means construction workers and tools are risk and accident free as work is performed. It checks how the construction worker's body, mind and social interactions are (Adhakari et al., 2020). Around the world, the construction industry is considered one of the most dangerous. Accidents are more common in the construction sector than in any other area (Elsebaei et al., 2020). Data from a number of developed countries shows that construction workers are much more likely to die on the job than workers in other industries (ILO, 2009). About one worker dies every ten minutes as a result of an industrial accident and about 60,000 accidents happen each year in the construction sector globally (Patel, 2021). It is predicted that 20,000 industrial accidents occur in Nepal every year which cause the deaths of 200 people (Gautam and Prasain, 2011).

Proper safety at work in construction relies on management techniques called construction safety management. The health of all workers and avoiding dangers or mishaps at the project depends on this being done right (Thanaraj and Priya, 2019). An OHS management system and a safety management system are basically the same concepts (Robson et al., 2007). SMS follows a planned system for safety management by requiring accountability, organizational structures, rules and procedures (ICAO, 2007).

The growth and development of Nepal largely depend on the construction industry. Nepal's construction industry has seen rapid growth because the government has made infrastructure development a top priority. Nearly one-tenth of the country's GDP is generated by the construction industry which is the biggest non-agricultural employer and provides jobs for people facing seasonal unemployment, underemployment and unemployment (FCAN, 2022).

Nepal has made significant strides in enhancing safety management, evident through the establishment of key laws and regulations. The Occupational Health and Safety Act, 2074 (2017) and the National OSH Policy, 2019 both make it clear that the country values OSH. A crucial development is the creation of the National OSH profile, showcasing Nepal's dedication to aligning its OSH system with global standards, such as the intention to ratify the ILO Convention 155 on Occupational Safety and Health Convention, 1981. This reflects the government's progressive approach to strengthening national OSH measures in line with international norms. Nepal's government has created the Department of Labor and Occupational Safety (DLOS) within the Ministry of Labor, Employment, and Social Security. DLOS is entrusted with implementing and enforcing safety regulations in workplaces. Its responsibilities include monitoring workplaces for compliance, conducting safety inspections, and offering training and education in safety management. The Occupational Safety and Health Centre (OSHC) in Nepal supports and governs the safety and health of workers across the country. OSHC reaches its targets by writing, discussing and applying policies, standards and regulations that keep the workplace safe and healthy. The government has also implemented a National Building Code (NBC) 114 to ensure safety standards are met during construction. Overall, while progress has been made in improving safety management in Nepal, there is still work to be done to ensure that all workers are protected and that safety regulations are enforced effectively (ILO, 2022).

Despite having various national and international safety policy, provisions and guidelines like National OSH policy 2076, labor law 2017, OSH guideline by Department of Local Infrastructure (DOLI), NBC 114, OSHA, ISO 45001:2018 etc., the majority of Nepalese construction companies currently face one of the biggest obstacles: incorporating OHS into everyday operations and decision-making. If the domestic enterprises are not ready and fail to establish health and safety benchmarks, they could lose their competitive advantage to foreign companies if they don't improve (Shrestha, 2018). Therefore, this study aims to assess the obstacles in implementing a safety management system (SMS) in Nepalese construction projects for improving safety management.

Literature Review

Developing countries deal with far more issues when it comes to making safety standards inclusive, unlike wealthy countries that have worked very hard to achieve this. There have been a lot of studies looking at the barriers countries experience when putting safety measures into place (Gibb and Bust, 2006). Employers' or organizations' unique cultural characteristics may be the source of implementation challenges and issues with SMS (Lappalainen, 2017).

A typical project team usually had a project manager, safety officer, safety supervisor, project engineer and foreman. Project team members, with the exception of safety officials, typically focused on the quantity and quality of work completed for some firms with comparatively weak safety cultures. As a result, the majority of the project team members delegated responsibility for safety to the safety officer or another qualified safety professional, and they gave safety a lower priority than other work obligations. Most construction companies have tight client-awarded work schedules, which makes it challenging to implement safety procedures. The project team may be resistant to change because they believe that the SMS's established procedures are sometimes redundant and unneeded. Moreover, having many staff members leave, subcontractors blocking progress, poor knowledge of OSH among the government and public, the client and the Labor Department not acting to improve OSH, focusing on minimum requirements instead of safety, lack of effort to foster ongoing improvements, absence of appropriate equipment for safe work practice could all stop SMS implementation in Hong Kong (Yiu et al., 2019, Yiu et al., 2018).

Previous research looked at the hindrances to the growth of health and safety management systems in Nigeria's construction sector and found the main reasons to be inefficient regulatory authorities which don't offer proper models and guidance on occupational health and safety management systems (OHSMS). A control structure is necessary for OHSMS because it will allow for a clear allocation of duties to various management levels and workplace units. It also gives management the ability to fully oversee its work processes. An organization's top management's leadership in health and safety is essential because it ultimately supports the use of resources and moderates' engagement with other key organizational concerns. Absent or ineffective communication among the stakeholders were also identified as a barrier in implementing SMS (Kamoli et al., 2021).

Past study highlighted the problems with introducing SMS in the Indian construction industry and found that businesses are less likely to invest in health and safety because of budgetary limitations. Safety training takes a lot of time, which has a significant impact on work flow and raises injury rates. The project team's lack of adequate safety knowledge or risk concepts, strict project timeline, absence of a safety officer or supervisor, insufficient dedication to OSH, safety concerns are not known to high management. Another factor cited as a barrier to SMS implementation was the failure to maintain accident records (Murugasamy et al., 2020).

OHSAS 18001 was less effective in places with poor safety culture and it is commonly believed that bad safety culture can develop from a society that does not highly value OHS or from managers who have poor concerns for safety (Ghahramani, 2016).

Methodology

The research targeted obstacles in adopting SMS in construction projects in Nepal, through quantitative research and a cross-sectional approach. From the previous literature review, we listed 22 obstacles in implementing SMS. Both exploratory factor analysis (EFA) and confirmatory factor analysis (CFA) were used in the questionnaire's formulation. In order to assure content validity, a pretest survey comprising five academic experts was also carried out to verify the clarity of the questions and based on their feedback received, the questions were then adjusted. The front-line employees and managers of construction projects (i.e., project/contract manager, contractor, safety officer, project engineer, site engineer, overseer, supervisor, etc.) with better safety knowledge throughout Nepal were the study group that was targeted. Out of 400 questionnaires distributed, 368 responses were received. A Google form, private emails, face-to-face interviews, and telephone interviews were among the methods utilized to gather data. The questionnaire was mainly based on Likert's scale of five ordinal measures (5= strongly agree; 4=agree; 3=No opinion; Disagree= 2; strongly disagree=1).

The participants were requested to arrange the reasons for slow adoption of SMS in construction projects by measuring their frequency of occurrence, based on their personal experience. After completion of data collection: processing, cleaning and preparing of data was carried out for analysis. PCA on SPSS was used to find out the obstacles in implementing SMS in Nepalese construction projects.

Result and Discussion

PCA analysis was performed. The analysis for this study started by making sure the data was suitable, then pulling out the factors using the maximum value method and ended by rotating and interpreting the factors.

a) Assessment of the Suitability of the Data for obstacles in implementing SMS

Factor analysis uses KMO to evaluate how suitable a data set is for the analysis. In the same way, a determinant score, a correlation matrix and the Bartlett's test are produced to check whether factor analysis will work with the available data (Shrestha, 2021, Acharya et al., 2024).

Table 1 KMO and Bartlett's Test for obstacles in implementing SMS

Kaiser-Meyer-Olkin Sampling Adequacy Measure		0.879
Bartlett's Sphericity Test	Approx. Chi-Square	2147.253
	df	231
	Sig.	0.000

Researchers can use the KMO test to find out if the data are right for factor analysis. In other words, it evaluates whether the sample size is sufficient. Bartlett's Test of Sphericity was applied to check if the PCA is valid. Good sampling is shown by a KMO value between 0.8 and 1.0, moderate by a value of 0.70 to 0.79 and mediocre by 0.6 to 0.69. Should KMO be less than 0.6 because of poor sampling, corrective action is necessary. With sample sizes of between 100 and 200, the average value ought to remain between 0.5 and 0.6, while samples of less than 100 should have an average above 0.6 (Shrestha, 2021, Acharya et al., 2024).

Several variables in the correlation matrix are strongly correlated as shown by the very significant result ($p < 0.001$) from the Bartlett's test of sphericity. This time, significance is less than 0.0001 and the test value is recorded as 2147.253. The set of data could be studied using factor analysis since the value is less than 0.05 (Shrestha, 2021, Acharya et al., 2024).It was determined that the factor number is, KMO value 0.879; Bartlett value χ 2 =2147.253; df=231 (p=0.00) in the scale consisting of 22 items. Table 1 shows that the KMO statistics value is equal to 0.879 > 0.7, indicating that the factor analysis and sample are suitable for the data.

b) Factor Extraction for obstacles in implementing SMS

Scree Test and Kaiser's Criterion (Eigen Value) are both applied in this study to decide how many factors should be kept. A result concerning the question, "What are the obstacles in implementing SMS in Nepalese construction projects?", is presented here. For this reason, the 22 challenges in executing SMS at construction sites were added to the PCA analysis. Only the parts of the data with eigenvalues that are 1.0 and higher were preserved in this case. Varimax was applied to reduce the number of substantial factors and raise the amount of variance in the model. A scree plot displays the values of factors or principal components from a multivariate statistics study as a line of data. A scree plot was utilized to decide on how many factors or principal components to hold in an FA or PCA. According to figure 1 of the scree plot, five latent variables have an Eigen value that is above 1.

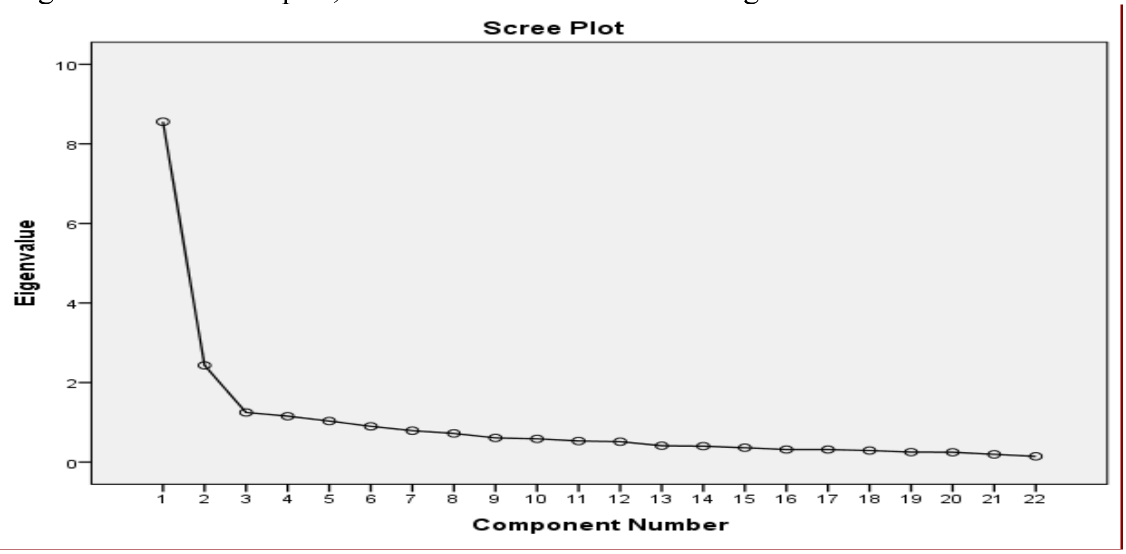

Fig 1: Scree plot for obstacles in implementing SMS in Construction projects

In Figure 1, eigenvalues were plotted on the y-axis and the twenty-two extracted component numbers are plotted on the x-axis in the order they were pulled out. Eigenvalues get bigger when started to retrieve them, with larger factors appearing first. Knowing which factors to keep is done by examining the scree plot. Most of the variation in the data can be linked to five components, where each has an eigenvalue above one. The last elements are regarded as not very significant because their contribution to total variability is tiny (Shrestha, 2021, Acharya et al., 2024).

Table 2 Eigen values (EV) and Total Variance Explained Extraction Method: Principal Component Analysis for obstacles in implementing SMS

Components	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	8.556	38.890	38.890	8.556	38.890	38.890	4.955	22.523	22.523
2	2.432	11.053	49.943	2.432	11.053	49.943	2.922	13.284	35.806
3	1.247	5.669	55.612	1.247	5.669	55.612	2.850	12.954	48.760
4	1.153	5.241	60.854	1.153	5.241	60.854	2.326	10.573	59.333
5	1.033	4.694	65.548	1.033	4.694	65.548	1.367	6.215	65.548
6	0.898	4.084	69.632						
7	0.789	3.587	73.218						
8	0.722	3.280	76.499						
9	0.609	2.766	79.265						
10	0.585	2.657	81.922						
11	0.530	2.407	84.329						
12	0.513	2.332	86.661						
13	0.411	1.869	88.530						
14	0.401	1.821	90.351						
15	0.362	1.646	91.997						
16	0.316	1.436	93.433						
17	0.316	1.436	94.869						
18	.290	1.320	96.189						
19	.251	1.143	97.331						
20	.247	1.124	98.455						
21	.195	0.887	99.342						
22	.145	0.658	100.000						
Extraction Method: Principal Component Analysis.									

Total variance explained and eigenvalue values are shown in Table 2. In this study, principal component analysis was used to extract factors in the data. In this investigation, principal component analysis was used which is the factor analysis method. 22 linear components are recognized in the data set before extraction takes place. The data set with an eigenvalue greater than one includes five different linear components after being extracted and rotated. The five factors together explain 65.548% of the overall variance found. It is suggested that at least half (50%) of the total variance in the data should be accounted for by the chosen factors.

The outcome demonstrates that five factors account for 65.548% of the common variance among twenty-two variables. As the KMO value (0.879) supports, factor analysis is a valid choice for analyzing these variables. The first idea is that the final solution will only find up to five components. Five factors were found to have an eigenvalue greater than one within the study's scope. Factor one explains 38.890% of the variation, with Eigen value 8.556; factor two explains 11.053%, with Eigen value 2.432; factor three 5.669%, with Eigen value 1.247; factor four 5.241%, with Eigen value 1.153; and factor five 4.694%, with Eigen value 1.033.

c) Factor Rotation and Interpretation for obstacles in implementing SMS

Rotation Method: Varimax with Kaiser Normalization

Rotation converged in 9 iterations

Table 3 Extraction Method: Principal Component Analysis for obstacles in implementing SMS

Obstacles in implementing SMS	Components				
	Poor safety culture	Lack of Resources	Poor project management and leadership	Lack of knowledge and awareness	Inadequate government support
Putting a low priority on safety	0.819				
Inadequate training	0.743				
Absent or ineffective communication among the stakeholders	0.732				
Inadequate commitment to OSH	0.678				
Poor OSH attitude of the project team	0.638				
Lack of maintenance of records of accidents	0.633				
Lack of investment on OSH		0.725			
Tight project schedule		0.684			
No safety officer/in charge		0.638			
high rate of employee turnover			0.757		
Subcontractor obstruction			0.681		
Lack of maintenance and availability of construction equipment			0.650		
Government and society have poor understanding of occupational safety				0.848	
Inadequate safety knowledge or risk concepts for the project team				0.691	
High management is not aware of safety issues				0.670	
A lack of professional support from the Labor Department and client in promoting OSH at the frontline level					0.641
Inefficient regulatory authorities					0.617

According to the findings, only 17 obstacles in implementing SMS were identified as major critical out of 22 obstacles in implementing SMS. All of these obstacles were subdivided into 5 components as shown in table 3 above.

Table 4 Cronbach's alpha for second order component analysis for obstacles in implementing SMS

Component	Cronbach's Alpha
Poor safety culture	0.857
Lack of resources	0.704
Poor project management and leadership	0.818
Lack of knowledge and awareness	0.714
Inadequate government support	0.702

Internal consistency was checked for all factors by calculating Cronbach's alpha (α). Cronbach's alpha should be over 0.7 in order to be considered adequate (Baggio and Klobas, 2011). In Table 4, the component Poor safety culture, Lack of resources, Poor project management and leadership, Lack of knowledge and awareness, Inadequate government support have Cronbach's alpha values 0.857, 0.704, 0.818, 0.714 and 0.702 respectively, which attested to the statistical techniques' high degree of reliability. It demonstrates that the variables are internally consistent because they show a correlation with the grouping of their components.

Component 1: Poor safety culture

Poor safety culture is marked as component one and is considered a major challenge in introducing SMS in construction projects which contains six items that strives for putting a low priority on safety, inadequate training, absent or ineffective communication among the stakeholders, inadequate commitment to OSH, poor OSH attitude of the project team, lack of maintenance of records of accidents and have a correlation of 0.819, 0.743, 0.732, 0.678, 0.638, 0.633 correspondingly with component 1. The variable 'Poor safety culture' accounted for 38.890% of the variation in scores, with an Eigen value of 8.556. In this component, six items had the strongest average positive agreement, because their total variance and Eigen value were high. According to Ghahramani (2016), the system's effectiveness was reduced by a poor safety culture. and it is asserted that poor safety culture may result from societal attitudes that place a low priority on OHS, manager's poor attitudes towards safety. Many other past studies also proved that inadequate commitment to OSH, putting a low priority on safety, absent or ineffective communication among the stakeholders, inadequate training, poor OSH attitude of the project team, lack of maintenance of records of accidents hinders the implementation of SMS in construction projects (Kamoli et al., 2021, Yiu et al., 2019, Murugasamy et al., 2020).

Component 2: Lack of resources

In addition, the second component called 'Lack of resources' identified as a significant hurdle to executing SMS in construction projects, accountable for 11.053% variance with an Eigen value of 2.432. This component had three different items including lack of investment on OSH, tight project schedule, no safety officer/in charge and had correlation of 0.725, 0.684, 0.638 correspondingly with component 2. According to Yiu et al. (2018) potential difficulties were identified based on the state-of-the-practice review and structured interviews and insufficient resources; tight work schedules were found as the key challenges to the effective SMS implementation. It is the job of management to secure enough resources such as skilled workers, time, finances, proper work methods, facilities, tools and machinery, to ensure a SMS is carried out in construction projects (Murugasamy et al., 2020, Yiu et al., 2018).

Component 3: Poor project management and leadership

The component 3 is marked as the third critical obstacle named 'poor project management and leadership' in implementing SMS in construction projects. It contains three items namely high rate of employee turnover, subcontractor obstruction, lack of maintenance and availability of construction equipment which have a correlation of 0.757, 0.68, 0.650 correspondingly with component 3. This component explained 5.669 % of the total variance and had an Eigen value of 1.247. Yiu et al. (2019) classified poor project management and leadership as an obstacle in implementing SMS and identified that high rate of employee turnover, subcontractor obstruction as top obstacles to implementing SMS in the construction industry. Additionally, past study show that unavailability of suitable construction equipment for site work as an obstacle in implementing SMS in the construction industry (Yiu et al., 2018).

Component 4: Lack of knowledge and awareness

Component 4 is regarded as the fourth crucial obstacle and is identified as 'Lack of knowledge and awareness' in implementing SMS in construction projects. It contains three items namely Government and society have poor understanding of Occupational safety, inadequate safety knowledge or risk concepts for the project team, High management is not aware of safety issues and have a correlation of 0.848, 0.691, 0.670 correspondingly with component 4. This component was explained with total variance 5.241 % and Eigen value 1.153. Sánchez et al. (2017) identifies poor safety awareness and knowledge of stakeholders involved as the major challenges in implementing SMS in construction projects. Another past study by Murugasamy et al. (2020) found that lack of knowledge about safety at a top level lowers the organization's capacity to understand and manage risks. A lack of awareness about OSH by both government officials and the public was stated as a challenge to implementing SMS (Yiu et al., 2019).

Component 5: Inadequate government support

The component 5 is marked as the fifth critical obstacle named as 'Inadequate government support' in implementing SMS in construction projects. It contains two items namely lack of professional support from the Labor Department and client in promoting OSH at the frontline level, and inefficient regulatory authority has a correlation of 0.641, 0.617 correspondingly with component 5. It explains 4.694% of the total variance and has Eigen value 1.003. Yiu et al. (2018) and Kamoli et al. (2021), also shows that lack of professional support from the Labor Department and client in promoting OSH at the frontline level, Inefficient regulatory authority makes difficult in implementing SMS.

Conclusion

The obstacles in implementing SMS in construction projects were identified and divided into five components i.e., poor safety culture, lack of resources, poor project management and leadership, lack of knowledge and awareness, inadequate government support. Results have shown that the "poor safety culture" component has been ranked in the first position as obstacles in implementing SMS in construction projects. This indicates that "poor safety culture" by construction professionals and government organizations will lead to obstacles in implementing SMS. Hence for the SMS to be implemented properly, careful planning, teamwork, stakeholder involvement, adequate training, and enough resource allocation is needed.

Practical Implications

Better understanding of the obstacles associated with SMS implementation in construction projects is the goal of this study. Future research on construction site safety will be motivated by this work. With proper concentration on these identified obstacles, each construction project or organization can upgrade their SMS implementation practice, mainly in underdeveloped countries like Nepal. Safety should be considered as everyone's responsibility, cooperative efforts and stakeholder involvement in safety programs and awareness-raising are necessary for the system's successful development and implementation. Appropriate models and guidelines for SMS should be provided by policy makers or governmental regulatory bodies, and sufficient monitoring and auditing should be carried out to ensure the system is continuously improved.

References

Acharya, M., Sukamani, D., Bhatta, B. & Regmi, K. 2024. Assessment of Safety Practices in Commercial Building Construction Projects in Nepal. *Saudi Journal of Civil Engineering,* 8**,** 213-224.

Adhakari, E. R., Mishra, A. K. & Joshi, E. K. R. 2020. Causative Factor of Accidents in Commercial Buildings of Bharatpur Metropolitan City. *Saudi Journal of Civil Engineering,* 4**,** 101-112.

Baggio, R. & Klobas, J. 2011. Quantitative Methods in Tourism: A Handbook.

Elsebaei, M., Elnawawy, O., Othman, A. & Badawy, M. 2020. Elements of Safety Management System in the Construction Industry and Measuring Safety Performance – A Brief. *IOP Conference Series: Materials Science and Engineering,* 974**,** 012013.
FCAN. 2022. *Federation of Contractors' Association of Nepal (FCAN)* [Online]. Available: https://fcan.org.np/ [Accessed september 19 2022].
Gautam, R. P. & Prasain, J. N. 2011. Current situation of occupational safety and health in Nepal. *General Federation of Nepalese Trade Unions (GEFONT) Man Mohan Labour Building, GEFONT Plaza, Putalisadak, Kathmandu, Nepal*.
Ghahramani, A. 2016. Factors that influence the maintenance and improvement of OHSAS 18001 in adopting companies: A qualitative study. *Journal of Cleaner Production,* 137**,** 283-290.
Gibb, A. & Bust, P. 2006. *Construction health and safety in developing countries*, European Construction Institute.
ICAO, S. 2007. Safety management manual. *ICAO. Geneva*.
ILO 2009. World Day for Safety and Health at Work 2009 FACTS ON safety and health at work.
ILO. 2022. *National Occupational Safety and Health Profile for Nepal–2022* [Online]. Available: https://www.ilo.org/wcmsp5/groups/public/---ed_protect/---protrav/---safework/documents/policy/wcms_867993.pdf [Accessed March 12 2023].
Kamoli, A., Hamid, R. A. & Mahmud, S. H. 2021. Barriers to the development of occupational health and safety management systems in the nigerian construction industry. *J. Inf. Syst. Technol. Manag,* 6**,** 90-99.
Lappalainen, J. Overcoming obstacles to implementing SMS. 2017. International Transport Forum Discussion Paper.
Murugasamy, M., Sakthivel, M. & Shanmugam, V. I. Study on barriers in the implementation of safety management systems in construction projects. AIP Conference Proceedings, 2020. AIP Publishing LLC, 040002.
Patel, U. 2021. Construction Safety Management in Construction Project. *International Journal for Research in Applied Science and Engineering Technology,* 9**,** 435-440.
Robson, L. S., Clarke, J. A., Cullen, K., Bielecky, A., Severin, C., Bigelow, P. L., Irvin, E., Culyer, A. & Mahood, Q. 2007. The effectiveness of occupational health and safety management system interventions: a systematic review. *Safety science,* 45**,** 329-353.
Sánchez, F. A. S., Peláez, G. I. C. & Alís, J. C. 2017. Integral diagnosis of occupational health and safety management in Colombian construction companies. *Journal of Construction in Developing Countries,* 22**,** 101-116.
Shrestha, A. K. 2018. *A Business Case for Health & Safety Management at Workplace* [Online]. Available: https://www.spotlightnepal.com/2018/06/28/business-case-health-safety-management-workplace/?fbclid=IwAR2oRH5RGWlFAKku6DtZbLvGtnMs9HjxCgYaZZrpYcP6kdNTRuD2MhRkwJU [Accessed Feburary 26 2023].
Shrestha, N. 2021. Factor analysis as a tool for survey analysis. *American Journal of Applied Mathematics and Statistics,* 9**,** 4-11.
Stephen, C. & Hunt, B. 2002. Safety management systems in Hong Kong: is there anything wrong with the implementation? *Managerial Auditing Journal*.
Thanaraj, M. S. & Priya, M. 2019. Effective safety management in construction. *International Research Journal of Engineering and Technology,* 6**,** 832-836.
Yiu, N. S., Chan, D. W., Shan, M. & Sze, N. 2019. Implementation of safety management system in managing construction projects: Benefits and obstacles. *Safety science,* 117**,** 23-32.
Yiu, N. S., Sze, N. N. & Chan, D. W. 2018. Implementation of safety management systems in Hong Kong construction industry–A safety practitioner's perspective. *Journal of safety research,* 64**,** 1-9.

Research Article Volume 18 Issue 1

ISSN NO. 2091-1742

SCITECH NEPAL Journal of Scientific and Technical Studies

Nepal Engineering College, Pokhara University

Received: May 27, 2025

DOI: https://doi.org/10.3126/scitech.v18i1.90819

Accepted: January 30, 2026

Distribution, Habitat Preference and Conservation Threats of Porcupine (*Hystrix* Spp.) in Mahankal Rural Municipality, Lalitpur Center for Postgraduate Studies, Nepal Engineering College, Pokhara University, Nepal

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Abstract

Porcupines play important ecological roles as ecosystem engineers, yet their distribution, habitat preference, and conservation challenges remain poorly documented in Nepal. This study assessed the distribution of porcupine burrows, habitat characteristics, human–porcupine conflict, and conservation threats in Mahankal Rural Municipality, Lalitpur. Primary data were collected through field surveys, burrow counts, household questionnaires (n = 85), key informant interviews, and focus group discussions. A total of 55 porcupine burrows were recorded across 12 randomly selected quadrats (500 m × 500 m), yielding an average burrow density of 18.33 burrows km^{-2}. Burrow distribution was strongly associated with proximity to cropland and forest edges, while fewer burrows occurred near roads and permanent water sources. Crop depredation emerged as the principal source of human–porcupine conflict, with a mean annual economic loss of NRs 9,488.24 per household, primarily affecting maize and potato. Despite economic losses, local attitudes toward porcupines were predominantly positive and significantly influenced by occupation, age, and gender. Habitat loss, land-use change, and infrastructure development were identified as major conservation threats. The study highlights the need for site-specific mitigation measures and landscape-level planning to reduce conflict while maintaining suitable porcupine habitat.

Keywords: Porcupine, burrow density, habitat preference, human–porcupine conflict, crop damage

1. Introduction

Porcupines (Family: Hystricidae) are among the largest rodents in the world and are widely distributed across Asia and Africa. They are nocturnal, burrowing mammals characterized by modified hairs forming defensive quills (Prater, 1980; Nair & Jayson, 2019). In South Asia, three species are commonly recognized: *Hystrix indica*, *Hystrix brachyura*, and *Atherurus macrourus* (Molur et al., 2005). In Nepal, two species occur—the Indian crested porcupine (*Hystrix indica*) and the Himalayan porcupine (*Hystrix brachyura*)—both currently listed as Least Concern on the IUCN Red List, although regional declines have been reported due to habitat loss and exploitation (Amori et al., 2016; Lunde et al., 2016; Molur et al., 2005).

Porcupines exhibit broad habitat tolerance, occupying rocky hillsides, forests, shrublands, grasslands, plantations, and agricultural landscapes (Amori et al., 2016). They typically inhabit natural caves or excavated burrows and prefer well-drained soils for denning (Marina & Zubaid, 2015; Mukherjee et al., 2017). As ecosystem engineers, porcupines influence soil structure and plant community composition through burrowing and selective herbivory (Sweitzer & Berger, 1992, 1997). Their diet consists mainly of roots, tubers, bark, fruits, grains, and cultivated crops, reflecting their generalist feeding strategy (Gutterman, 1982; Prater, 1980; Pervez et al., 2009).

Despite their ecological importance, porcupines are frequently regarded as agricultural pests because of crop raiding behavior. Studies across South Asia have documented significant economic losses due to depredation of maize, potato, wheat, and vegetables (Hussain, 2004; Khan, 2013; Ashraf et al., 2021). Human–porcupine conflict tends to intensify in forest–agriculture interfaces where suitable shelter and abundant food resources coexist (Lovari et al., 2017; Mukherjee et al., 2018). In Nepal, increasing human–wildlife conflict has been linked to habitat fragmentation, land-use change, and expansion of agricultural land into forest margins (GoN, 2014; Shrestha, 2007).

Urbanization and infrastructure development are widely recognized as major drivers of biodiversity loss globally (McKinney, 2006; Grimm et al., 2008). Habitat degradation, fragmentation, poaching, and retaliatory killing have been identified as key threats to porcupine populations across their range (Molur et al., 2005; Brooks et al., 2010; Heinrich et al., 2020). In human-dominated landscapes, porcupines often adapt to modified habitats; however, such adaptation frequently increases conflict with local communities.

In the southern part of Kathmandu Valley, particularly in Mahankal Rural Municipality, recent expansion of private and family forests—especially plantations of *Taxus mairei*—has altered habitat structure and food availability. These landscape changes may influence porcupine distribution, burrow site selection, and conflict patterns. However, empirical information on porcupine ecology and human–porcupine conflict in this region remains limited.

Therefore, this study aimed to: (i) assess the distribution and density of porcupine burrows; (ii) examine habitat characteristics influencing burrow site selection; (iii) quantify the extent of human–porcupine conflict and associated crop losses; and (iv) identify major conservation threats in Mahankal Rural Municipality, Lalitpur.

2. Study Area

2.1 Geographic Location

The study was conducted in Mahankal Rural Municipality (RM), located in the southern part of Lalitpur District within the Kathmandu Valley, Nepal. The municipality lies approximately 40 km from Lalitpur Metropolitan City and ranges in elevation from 1,500 to 2,300 m above sea level. Geographically, the area extends between approximately 27°25′–27°35′ N latitude and 85°20′–85°26′ E longitude. Administratively, Mahankal RM comprises six wards. The present study focused on the former Village Development Committees (VDCs) of Gotikhel and Kaleshwor, which together cover approximately 24.02 km² and include 698 households (Figure 1).

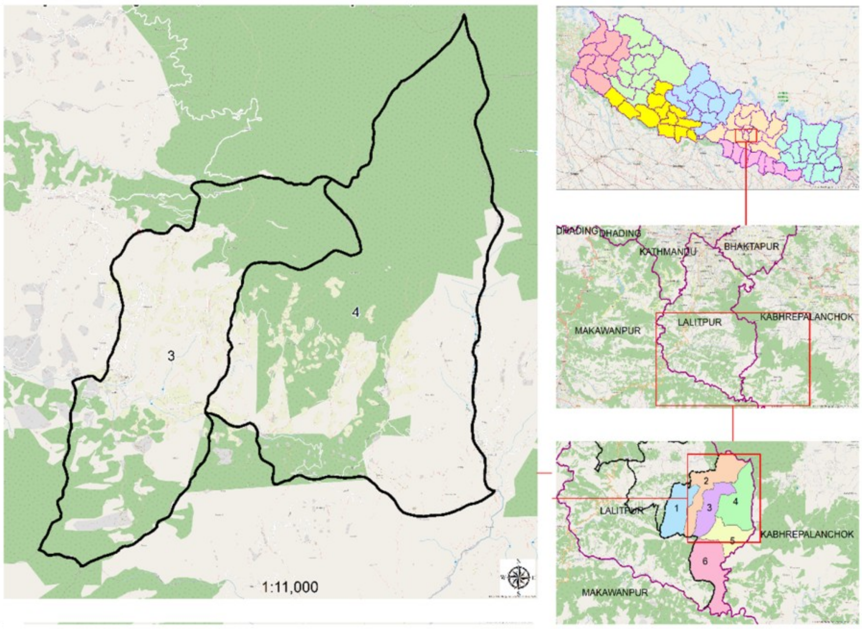

Figure 1: Study area showing Gotikhel and Kaleshwor in Mahankal RM

2.2 Topography and Climate

The study area is characterized by rugged topography with steep forested slopes (approximately 25°–40°) and moderately sloping agricultural land (15°–25°). Settlements are typically distributed along road corridors following ridge lines and ghat roads. The climate ranges from warm temperate to cool temperate. Mean annual temperatures vary from approximately 2.3 °C in winter to 23.4 °C in summer, while annual rainfall ranges between 1,400 and 2,000 mm. The monsoon season contributes the majority of annual precipitation, influencing vegetation growth and agricultural productivity.

2.3 Vegetation and Land Use

The area supports mixed temperate forests dominated by *Shorea robusta*, *Schima wallichii*, *Castanopsis indica*, *Pinus* spp., and *Taxus mairei*. Non-timber forest products (NTFPs) such as *Lokta*, *Pasanbed*, *Sugandhawal*, *Jatamasi*, and *Nagbeli* are also present. Mahankal RM is particularly recognized for private and family forest plantations of *Taxus mairei* (locally known as Lauth salla), which have expanded in recent years (Koirala, 2022). This expansion has altered habitat structure and vegetation composition in forest–agriculture interfaces.

Land use is primarily divided into forestland and agricultural fields. Agricultural practices include cultivation of maize, wheat, potato, vegetables, and fodder crops. The close proximity of cropland to forest edges creates a mosaic landscape that potentially provides both shelter and foraging opportunities for wildlife, including porcupines.

2.4 Socioeconomic Characteristics

Agriculture and livestock rearing constitute the main livelihoods of local residents. A significant proportion of households are engaged in commercial vegetable farming, milk production, green tea cultivation, and processing of dairy products such as *khuwa*. In recent years, many households have increasingly invested in *Taxus mairei* cultivation as a high-value medicinal plant species (Koirala, 2022). Such land-use transitions may influence wildlife distribution and patterns of human–wildlife interaction.

At the national level, habitat loss, land-use change, and infrastructure expansion have been recognized as major drivers of biodiversity decline in Nepal (GoN, 2014). These broader landscape-level dynamics provide an important context for understanding porcupine distribution and conservation challenges within Mahankal RM.

3. Data Collection Methods

3.1 Field Survey and Burrow Assessment

A field survey was conducted to record porcupine burrows and associated indirect signs. Twelve quadrats (500 m × 500 m; 25 ha each) were randomly selected using GIS. Each quadrat was systematically searched for active burrows, identified based on the presence of quills, footprints, fecal matter, and feeding signs. Geographic coordinates of burrows were recorded using GPS. Distances from burrows to cropland, forest edges, roads, households, and water sources were calculated for habitat analysis.

3.2 Socioeconomic Survey

A total of 85 households were surveyed using semi-structured questionnaires, following Arkin and Colton's sampling formula at a 95% confidence level. Additionally, four focus group discussions and five key informant interviews were conducted to gather qualitative information on crop damage, mitigation practices, and conservation threats.

4. Results and Discussion

4.1 Burrow Density in the Study Area

A total of 55 porcupine burrows were recorded across 12 quadrats (500 m × 500 m each), covering 3 km^2. The average burrow density was 0.183 burrows ha^{-1}, equivalent to 18.33 burrows km^{-2} (Figure 4.2). Considering that porcupines are generally solitary except during breeding (Van Aarde, 1985; Olson & Lewis, 1999), and that 1–4 individuals may occupy a burrow during the reproductive season (Mustikasari et al., 2019), the study area likely supports a substantial local population.

The recorded density is higher than estimates from Keoladeo National Park, India (3.21 ± 1.32 individuals km^{-2}; Mukherjee et al., 2018), Pakistan (6 km^{-2}; Siddique, 2004), and South Africa (2.6 burrows km^{-2}; Bragg et al., 2005), but comparable to higher estimates reported from semi-arid India (Sharma, 2001). Variations in density may reflect differences in habitat quality, food availability, predation pressure, and anthropogenic disturbance (Woods, 1973; Alkon, 1999). The mosaic of cropland and private forest in Mahankal RM likely provides abundant forage and shelter, supporting higher burrow densities.

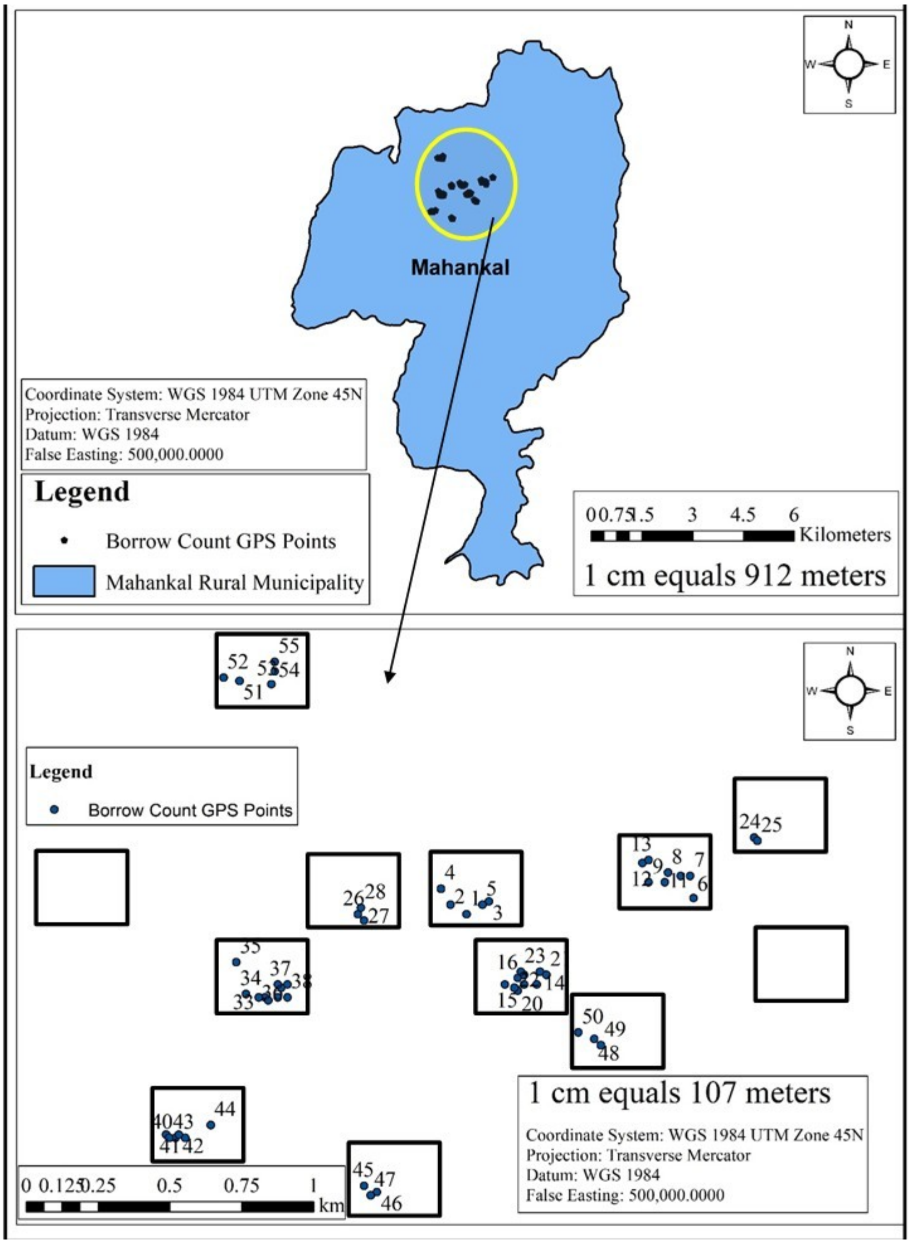

Figure 2 Distribution of burrows of Porcupine in study area

4.2 Distribution of Burrows Across Quadrats

Burrows were recorded in 10 out of 12 quadrats, indicating widespread distribution across the landscape. Most burrows were located near forest–agriculture interfaces, suggesting that porcupines exploit cultivated areas for food while relying on adjacent forest patches for denning and refuge. Such edge-associated distribution has been documented in suburban and agricultural landscapes (Lovari et al., 2017; Mukherjee et al., 2017).

4.3 Habitat Characteristics Influencing Burrow Distribution

4.3.1 Distance from Water Sources

Burrow distribution showed a weak relationship with proximity to water sources, with the highest proportion (38.2%) recorded at 600–800 m from water (Figure 3). Fewer burrows were observed in close proximity to permanent water. Porcupines are known to tolerate relatively dry environments and do not require frequent access to open water (Shapiro, 1949; Zeiner et al., 1988). Preference for well-drained soils has been reported in Malaysia and India (Marina & Zubaid, 2015; Mukherjee et al., 2017), supporting the present findings that waterlogged areas are less suitable for burrowing.

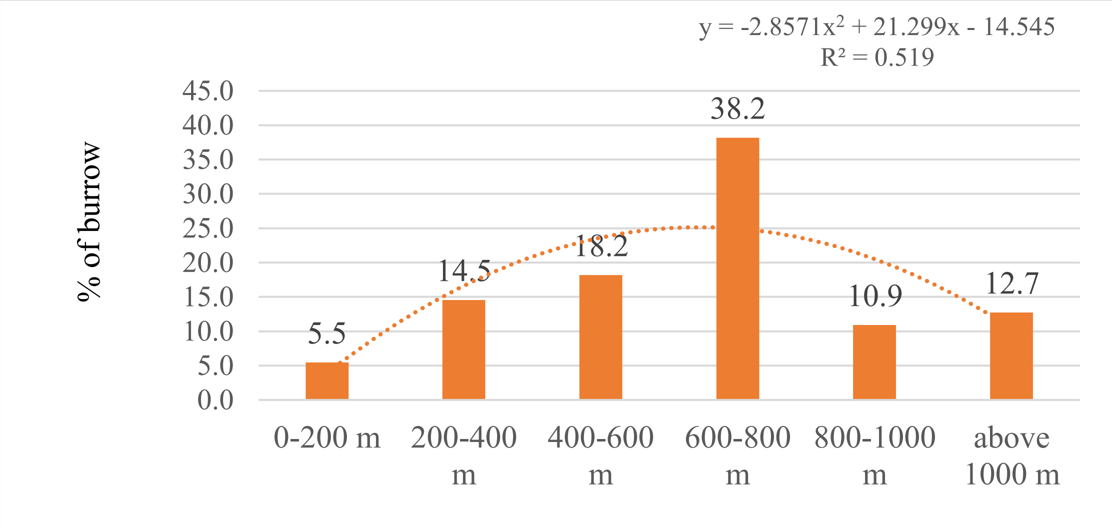

Figure 3 Distance from burrow to water resources

4.3.2 Distance from Households

Burrow occurrence increased with distance from households up to 400–600 m and declined beyond 800 m (Figure 4). Although porcupines can persist near human settlements, they tend to select den sites with reduced direct disturbance (Tinelli & Tinelli, 1980; Monetti et al., 2005). The hilly terrain and linear settlement pattern along roads may influence this spatial pattern, as increasing distance from one settlement may simultaneously decrease distance to another.

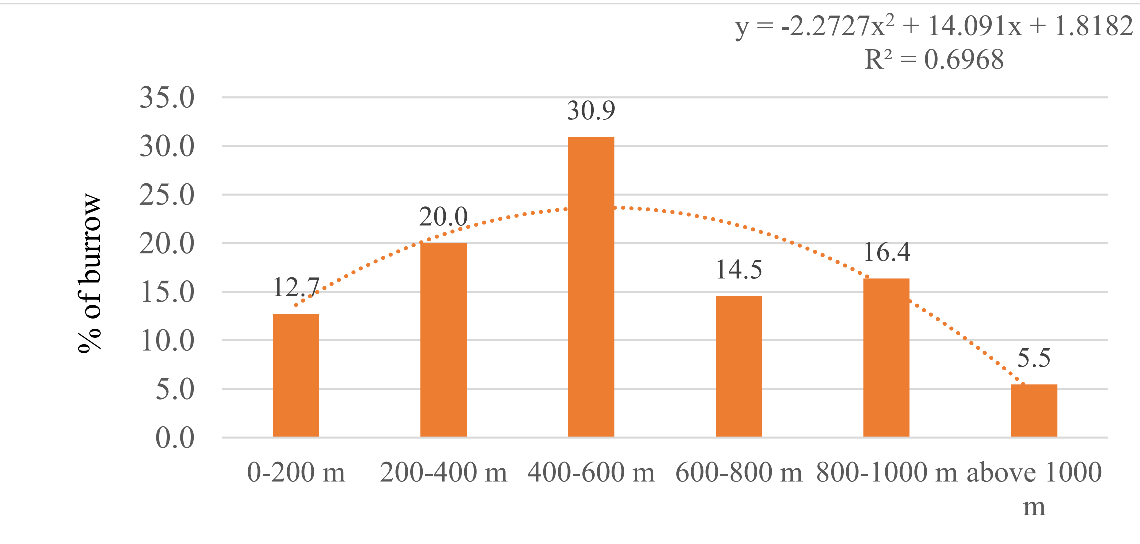

Figure 4: Distance from burrow to households

4.3.3 Distance from Cropland

Approximately 38.2% of burrows were located within 200 m of cropland boundaries. A strong positive trend ($R^2 \approx 0.85$) indicated that burrow density was highest near cultivated land (Figure 5). Similar patterns have been reported where Indian crested porcupines exploit agricultural crops while maintaining burrows in nearby non-cultivated areas (Lovari et al., 2017; Mukherjee et al., 2017). Agricultural fields provide high-energy food resources such as maize and potato, reducing foraging costs and increasing habitat suitability (Alkon, 1999).

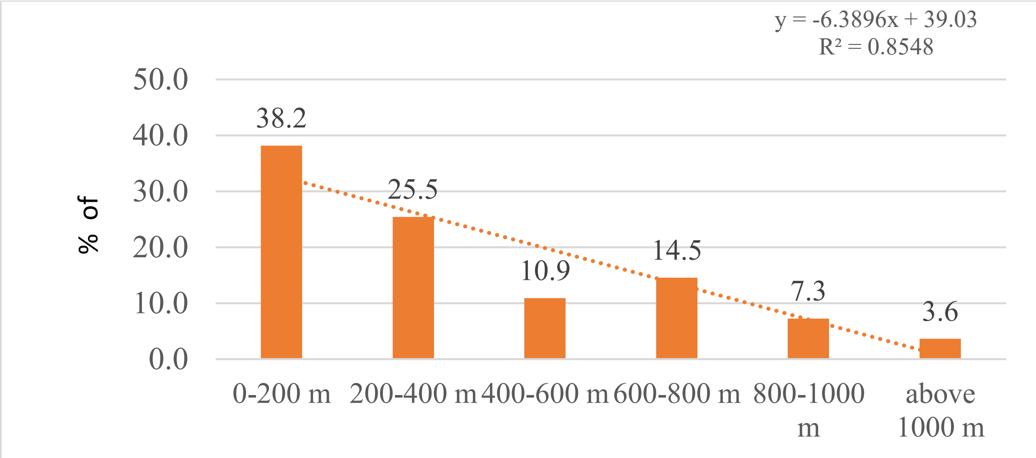

Figure 5: Distance of burrow from crop land

4.3.4 Distance from Forest Edges

Nearly 80% of burrows were located within 0–400 m of forest areas, indicating strong dependence on forest cover for shelter. The distribution trend ($R^2 \approx 0.82$) suggests that optimal sites occur where cropland and forest patches intersect (Figure 6). Forests provide protective cover, stable microclimatic conditions, and denning sites (Woods, 1973; Amjad et al., 1990). Thus, porcupines appear to rely on a forest–farm mosaic rather than exclusively forested habitats.

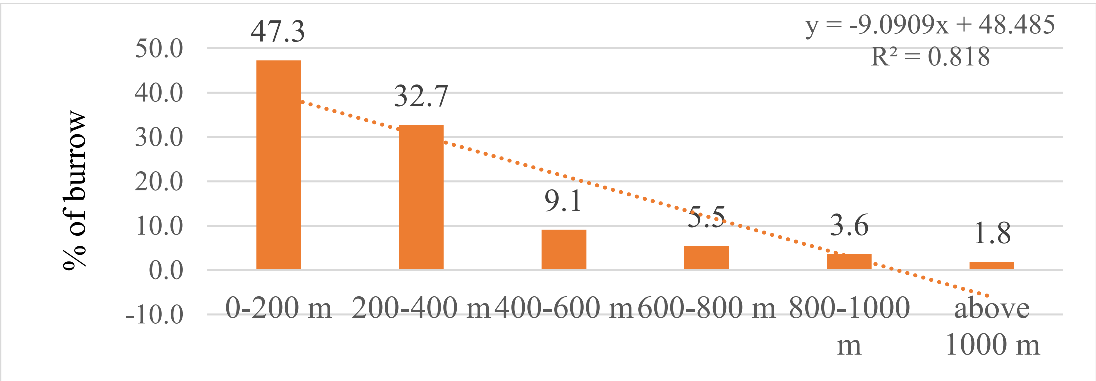

Figure 6 : Burrow distribution along forest

4.3.5 Distance from Roads

Most burrows (81.9%) were recorded 600–800 m away from roads. Burrow frequency declined in areas closer to roads, indicating avoidance of vehicular disturbance and noise (Figure 7). Roads are known to alter wildlife movement and behavior (Forman & Alexander, 1998; Seidler et al., 2015), and hunting with dogs can increase stress and spatial displacement in porcupines (Mori, 2017). Reduced disturbance at intermediate distances likely explains higher burrow densities in those zones.

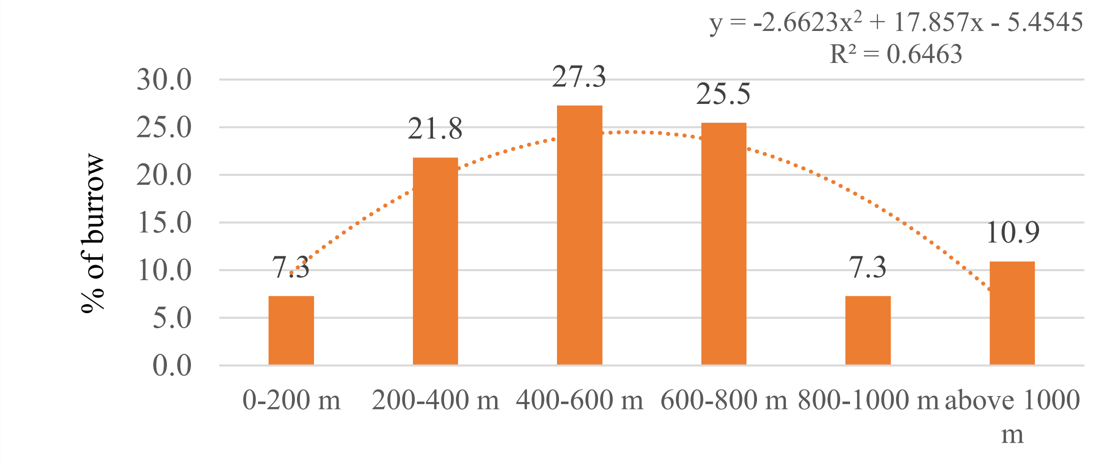

Figure 7: Burrows along roadside

4.4 Human–Porcupine Conflict and Crop Damage

Porcupine was identified as a major nocturnal crop raider, alongside wild boar. Mean annual crop loss was estimated at NRs 9,488.24 per household, with maize accounting for 39% of total loss, followed by potato (26%) and vegetables (14%) (Table 1). Damage to *Taxus mairei* seedlings was also reported. Similar patterns of maize-dominated crop loss have been documented in Nepal and Pakistan (Kaway, 2011; Ashraf et al., 2021).

Table 1: Total Crop loss per year per households

Crops	Total loss per year (NRS)	Total loss in %
Wheat	93000	12%
Maize	311000	39%
Potato	208000	26%
Lauth salla *(Taxus mairei)*	51500	6%
Vegetables (cauliflowers, cabbage, etc.)	116000	14%
Others (Jai grass, Amriso)	27000	3%
Total crop loss per year	806500	100%
total crop loss per year per HHs	9488.24	

Crop raiding represents a significant component of human–wildlife conflict, directly affecting livelihoods and shaping local perceptions of wildlife (Priston, 2008; GoN, 2014). Although economic loss in Mahankal RM is moderate compared to some protected areas, repeated seasonal damage may intensify retaliatory behavior.

4.5 Mitigation Measures Adopted by Farmers

Farmers reported multiple mitigation strategies, including night guarding, shouting, chasing with fire, throwing stones, and use of dogs (Table 2). The use of dogs received the highest satisfaction ranking (mean score 8.9/10), either alone or combined with guarding. Similar community-based deterrence methods have been reported in Nepal (Ghimire et al., 2022; Sherchan & Bhandari, 2017).

Despite the effectiveness of dogs, guarding is labor-intensive and increasingly constrained by labor shortages due to migration. Electric fencing and reinforced barriers have been recommended elsewhere as effective deterrents (Schemnitz, 1994), but such measures were not widely implemented in the study area.

Table 2: Response of respondents on strategies used to cope crop raiding

Techniques used to chase porcupine	No of respondent	% of respondents	Average Satisfaction rank out of 10
Guarding	14	16.5	7.8
Using Dogs	15	17.6	8.9
Both Guarding using dogs	30	35.3	8.7
Chasing and shouting	15	17.6	6.2
chasing with fire and shouting	20	23.5	6.4
Shouting, chasing, throwing stones	25	29.4	6.48
All of above	8	9.4	9
Don't use any techniques	20	23.5	
	147	172.9	

Note: The total percentage is higher than 100 since respondents choose more than one options.

4.6 Community Attitudes and Trends of Conflict

Among respondents, 64.7% expressed positive attitudes toward porcupines, particularly those engaged in *Taxus mairei* cultivation, whereas 28.2% (primarily cash crop farmers) held negative perceptions. Chi-square analysis revealed significant associations between occupation and attitudes toward porcupines (χ^2 = 48.325, df = 10, p < 0.001), and between occupation and perceived trend of crop damage (χ^2 = 57.237, df = 10, p < 0.001). Age was significantly associated with perceived crop damage trends (χ^2 = 56.96, df = 6, p < 0.001), while gender showed significance only in relation to crop damage perception (χ^2 = 6.699, df = 2, p = 0.04). Education, income, and landholding size were not significantly associated with attitudes (Table 3).

Table 3: Result of chi square test between different category with attitude towards porcupine

SN	Category	P value	$\chi2$	d f	CV
1	Occupation with. Perception towards porcupine	**0.00**	48.325	10	18.307
	Occupation with trend of crop damage	**0.00**	57.237	10	18.307
2	Gender with perception towards porcupine	0.76	0.55	2	5.99
	Gender with trend of crop damage	0.04	6.699	2	5.99
3	Education with perception towards porcupine	0.76	3.499	6	12.59
	Educations with trend of crop damage	0.74	3.373	6	12.59
4	Age with perception towards porcupine	0.23	8.098	6	12.59
	Age with trend of crop damage	**0.00**	56.96	6	12.59
5	Land property with perception towards porcupine	0.11	5.05	4	9.48
	Land property with trend of crop damage	0.57	7.65	4	9.48
6	Income with perception towards porcupine	0.28	10.384	6	12.59
	Income with trend of crop damage	0.11	4.7756	6	12.59

These findings indicate that livelihood dependence strongly shapes perceptions of wildlife, consistent with broader patterns observed in human–wildlife conflict studies in Nepal (Shrestha, 2007; Pradhan et al., 2011). Positive attitudes among *Taxus* cultivators may reflect lower relative crop loss compared to vegetable farmers.

4.7 Conservation Threats to Porcupines

Respondents identified infrastructure development and habitat loss as the most significant threats (>90%), followed by crop alteration (70%), habitat fragmentation (66%), poaching (64%), and interspecific competition (58%) (Figure 8). Habitat loss and fragmentation are widely recognized as primary drivers of porcupine decline (Molur et al., 2005; Brooks et al., 2010). National assessments in Nepal similarly highlight land-use change and human–wildlife conflict as major biodiversity threats (GoN, 2014).

Expansion of roads, settlement areas, and agricultural intensification in Mahankal RM may further fragment habitats and increase human–porcupine interactions. Although porcupines demonstrate adaptive capacity in modified landscapes, sustained habitat degradation and retaliatory killing could negatively affect long-term population stability.

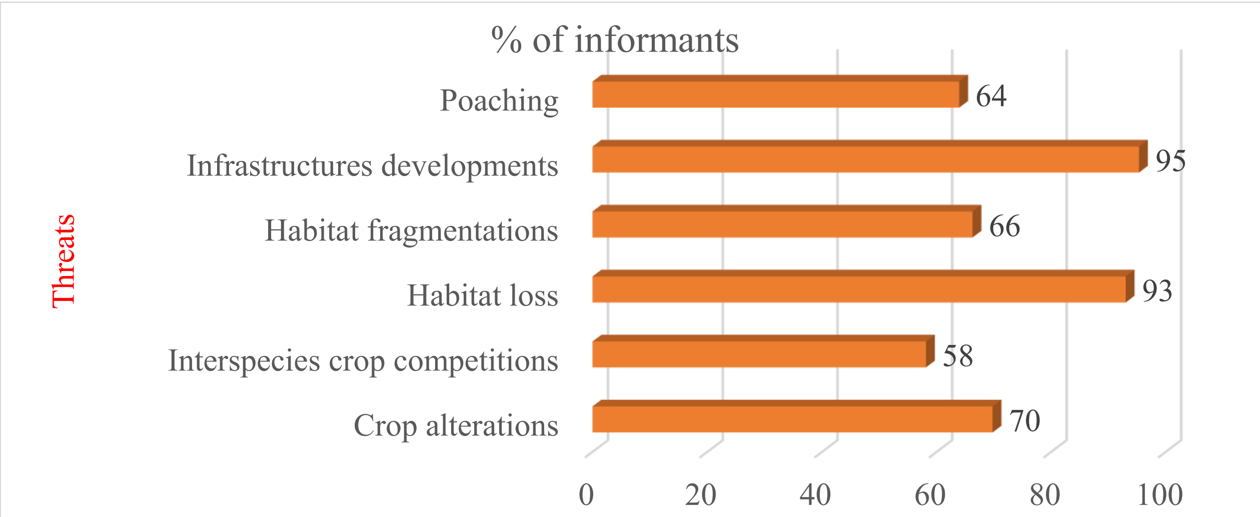

Figure 8: Main causes of threats to the porcupine

5. Conclusion

Mahankal Rural Municipality supports a relatively high density of porcupines, reflecting the availability of suitable habitat at the forest–agriculture interface. Porcupines preferentially establish burrows near cropland and forest edges while avoiding roads and waterlogged areas. Human–porcupine conflict, primarily through crop depredation, imposes notable economic losses on households, although community attitudes toward porcupines remain largely positive. Habitat loss and infrastructure development pose major conservation challenges. Effective conflict mitigation, awareness programs, and habitat-sensitive development planning are essential to ensure the long-term coexistence of porcupines and local communities.

References

Alkon, P.U. 1999 'Microhabitat to landscape impacts: crested porcupine digs in the Negev Desert highlands', *Journal of Arid Environments*, 412, pp. 183–202.

Amjad, R.K., Aslam, H.M., Beg, M.A. and Khan, A.A. 1990 'External characteristics and density of the crested porcupine burrows in forest plantations', *Pakistan Journal of Agricultural Sciences*, 271, pp. 1–6.

Amori, G., Hutterer, R., Kryštufek, B., Yigit, N., Mitsain, G. and Palomo, L. 2016 *Hystrix indica*. The IUCN Red List of Threatened Species 2016.

Ashraf, R.Z., Ahmad, B., Shafique, F., Hassan, M.U., Asim, N., Muhammad, M.W. and Sheikh, N. 2021 'Evaluation of economic loss caused by Indian crested porcupine *Hystrix indica* in agricultural land of Muzaffarabad, Pakistan', *Brazilian Journal of Biology*, 83, e247395.

Bragg, C.J., Donaldson, J.D. and Ryan, P.G. 2005 'Density of Cape porcupines in a semi-arid environment and their impact on soil turnover', *Journal of Arid Environments*, 612, pp. 261–275.

Brooks, E.G., Roberton, S.I. and Bell, D.J. 2010 'The conservation impact of commercial wildlife farming of porcupines in Vietnam', *Biological Conservation*, 143, pp. 2808–2814.

Forman, R.T.T. and Alexander, L.E. 1998 'Roads and their major ecological effects', *Annual Review of Ecology and Systematics*, 29, pp. 207–231.

Ghimire, S., Devkota, D., Dhakal, S.C. and Upreti, B.R. 2022 'Effectiveness of crop and livestock protection methods against wildlife damage', *Journal of Agriculture and Forestry University*, pp. 165–175.

GoN 2014 *Nepal National Biodiversity Strategy and Action Plan 2014–2020*. Kathmandu: Government of Nepal.

Grimm, N.B., Faeth, S.H., Golubiewski, N.E., Redman, C.L., Wu, J., Bai, X. and Briggs, J.M. 2008 'Global change and the ecology of cities', *Science*, 3195864, pp. 756–760.

Heinrich, S., Toomes, A. and Gomez, L. 2020 'Valuable stones: the trade in porcupine bezoars', *Global Ecology and Conservation*, 24, e01204.

Kaway, C. 2011 *Crop depredation by small mammals: a case study of porcupine Hystrix indica in Shivapuri National Park*. MSc thesis. Tribhuvan University, Nepal.

Khan, A.A. 2013 'Bio-economic impacts of vertebrate pests on crops', *Proceedings of Pakistan Congress of Zoology*, 33, pp. 75–108.

Koirala, T.P. 2022 *Status, growth and regeneration pattern of yews Taxus mairei in Lalitpur District*. Pokhara University, Nepal.

Lovari, S., Corsini, M.T., Guazzini, B., Romeo, G. and Mori, E. 2017 'Suburban ecology of the crested porcupine', *European Journal of Wildlife Research*, 63, 1–10.

Lunde, D., Aplin, K. and Molur, S. 2016 *Hystrix brachyura*. The IUCN Red List of Threatened Species 2016.

Marina, M. and Zubaid, A. 2015 'Porcupine burrow distribution in relation to soil types', *Malayan Nature Journal*, 671, pp. 24–32.

McKinney, M.L. 2006 'Urbanization as a major cause of biotic homogenization', *Biological Conservation*, 127, pp. 247–260.

Molur, S., Srinivasulu, C., Srinivasulu, B., Walker, S., Nameer, P.O. and Ravikumar, L. 2005 *Status of South Asian non-volant small mammals*. Coimbatore: Zoo Outreach Organization.

Monetti, L., Massolo, A., Sforzi, A. and Lovari, S. 2005 'Site selection and fidelity by crested porcupines for denning', *Ethology Ecology & Evolution*, 172, pp. 149–159.

Mukherjee, A., Kumara, H.N. and Bhupathy, S. 2017 'Determinants of occupancy and burrow site selection by Indian crested porcupine', *Current Science*, 113, pp. 2440–2448.

Mukherjee, A., Kumara, H.N. and Bhupathy, S. 2018 'Environmental determinants of activity variation of Indian crested porcupine', *Mammalia*, 825, pp. 449–459.

Mustikasari, I.A., Withaningsih, S., Megantara, E.N., Husodo, T. and Parikesit 2019 'Population and distribution of Sunda porcupine', *Biodiversitas*, 203, pp. 762–769.

Olson, R.A. and Lewis, A.M. 1999 *Porcupine ecology and damage management techniques*. University of Wyoming Extension.

Pervez, A., Ahmad, S.M., Lathiya, S.B. and Khadijah, E. 2009 'Food habits of Indian crested porcupine', *Pakistan Journal of Zoology*, 414, pp. 287–294.

Prater, S.H. 1980 *The book of Indian animals*. Mumbai: Bombay Natural History Society.

Pradhan, N.M., Williams, A.C. and Dhakal, M. 2011 'Current status of Asian elephants in Nepal', *Gajah*, 35, pp. 87–92.

Priston, N. 2008 *Modelling primate crop-raiding*. PhD thesis. University College London.
Schemnitz, S.D. 1994 *Porcupines*. Denver: Colorado State University Extension.
Seidler, R.G., Long, R.A., Berger, J., Bergen, S. and Beckmann, J.P. 2015 'Identifying impediments to long-distance mammal migrations', *Conservation Biology*, 291, pp. 99–109.
Shapiro, J. 1949 'Ecological and life history notes on the porcupine', *Journal of Mammalogy*, 303, pp. 247–257.
Shrestha, R. 2007 *A case study on human–wildlife conflict in Nepal*. WWF Nepal.
Siddique, M.M. 2004 'Relative density of porcupine *Hystrix indica* population', *Pakistan Journal of Biological Sciences*, 7, pp. 671–675.
Sweitzer, R.A. and Berger, J. 1992 'Size-related effects of predation on habitat use and behavior of porcupines', *Ecology*, 73, pp. 567–875.
Sweitzer, R.A. and Berger, J. 1997 'Sexual dimorphism and intrasexual selection in porcupines', *Canadian Journal of Zoology*, 756, pp. 847–854.
Tinelli, A. and Tinelli, P. 1980 *Le tane di istrice e di tasso*. Rome: Presidenza della Repubblica.
Van Aarde, R.J. 1985 'Reproduction in captive female Cape porcupines', *Journal of Reproduction and Fertility*, 752, pp. 577–582.
Woods, C.A. 1973 'Erethizon dorsatum', *Mammalian Species*, 29, pp. 1–6.
Zeiner, D.C., Laudenslayer, W.F., Mayer, K.E. and White, M. 1988 *California's wildlife*. Sacramento: California Department of Fish and Game.