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Post-earthquake reconstruction: Managing debris and construction waste in Gorkha and Sindhupalchok Districts, Nepal

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ABSTRACT

The 2015 Mw 7.8 Gorkha Nepal Earthquake had severely damaged buildings producing massive amount of debris. This paper assessed the amount of debris generated and construction waste during post-earthquake housing reconstruction in the earthquake most affected two districts. The study was carried out between April 2017 to December 2019, in Gorkha and Sindhupalchok districts of Nepal. The questionnaire survey were conducted in 17,814 households (Gorkha: 4896 and Sindhupalchok: 12,918) that were reconstructed after the earthquake. The sample household was selected randomly and the amount of debris and waste generated from each household was visually estimated. A z-test was performed to determine the quantity of debris and waste generated in each household at district as well as local administrative level. The result showed significant difference between the total amounts of debris generated in two districts - Gorkha ($m = 17.03\ m^3$/HHs; SD = ± 10.15) and Sindhupalchok ($m = 21.61\ m^3$/HHs; SD ± 8.92). Construction waste that was produced in construction sites in Gorkha and Sindhupalchok were 1.11 m^3/HHs and 1.59 m^3/HHs respectively. Proper management of debris and waste was lacking due to the absence of policies and guidelines on debris and waste in Nepal. However, individuals reused 57.96% of generated debris for housing reconstruction. The study recommends for preparation of debris and waste management plan for the future reconstruction activities.

1. Introduction

Disaster causes the damage of property, collapse of buildings and infrastructures (Lindel and Prater, 2003) resulting in the production of massive quantity of debris (Karunasena, 2011). Management of demolished parts and waste is one of the great challenges after earthquake, especially in earthquake affected rural areas of Nepal. Due to the lack of disposal site and limitation of financial resources, reusing construction material of demolished part (debris) and construction waste has attracted considerable attention. A study showed with proper demolition and recycle technology, 80–90% of the total debris from the demolished buildings can be recycled and are also economically feasible [17]. Moreover, these recycling technologies can easily implemented and controlled. Rafee et al. [32] indicated that the estimation of debris is a highly important strategy for debris and waste management. Effective debris management during recovery and rebuilding has valuable impacts on social, financial and environmental aspects [6]. Removal of debris in the earthquake affected areas was the first priority [11] and was organized through the local government in Gujarat Earthquake [15]. However, the household and local government are not well capacitated enough to respond to such catastrophic evidence and immediate service delivery for debris removal and its management [1]. This paper presents the use pattern of debris during the reconstruction of houses in Nepal.

Nepal is considered as a vulnerable nation to the earthquake and its aftermath. United Nations Development Programme [30] considered Nepal as the 11th most earthquake prone nation in the world. This was proven right on 25 April 2015 at 11:56 AM local time (+5:45 GMT) when the 2015 Mw 7.8 Gorkha Nepal Earthquake of 7.8 moment magnitude (Mw) shocked Barpak of Barpak Sulikot Gaunpalika (GP) of Gorkha District. Similarly, on 12 May 2015, a 6.8 Mw earthquake hit Sindhupalchok District causing a mass shockwave throughout 14 mid and high hill districts of Nepal [22]. Combined with several aftershocks, these devastating events claimed 8700 lives and massively destroyed houses and infrastructures [22]. The destruction was widespread dismantling residential buildings, religious and public infrastructures. Large population were left homeless who sought shelter either in makeshift tents or tarpaulin [7]. Although Nepal had faced the similar earthquakes in the past in 1255, 1505, 1934, 1980 and 1988 with magnitude higher than 6.5, but could not stop the destruction [18]. Similar to past earthquake events, many houses were buried and local residents were made homeless with huge economic losses and long term social effects.

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Earthquakes cause different levels of damages. One such example is subsequent production of significant volume of debris from the demolished building [2]. Around 755,549 residential houses were damaged by the earthquake [22], resulting in production of high amount of debris. The potential to recycle or reuse the debris is sometimes overlooked to clear affected areas quickly [21]. However, during the process of reconstruction is underway, the major challenge and opportunity is the management of debris at individual HH and local administrative level. In addition to varied geographical challenges in Nepal, there is a lack of awareness and preparedness among the individuals, scarcity of proper technology, lack of proper disaster management plan and coordination among agencies to carry out debris management at such magnitude [18].

Post-disaster debris cleanup and management in developing countries are mostly done manually, resulting in difficulties to mankind those who are already suffering from the stress of the disaster [28]. Generally, the debris is dumped in landfills which can be costly both environmentally and economically [10,19]. It is observed that additional land for the reconstruction of house in the affected area is inadequate and enough resources to move to other places. Therefore, to continue the process of reconstruction, it poses the urgency for the removal of debris.

A study showed that infrastructure in the rural villages of Nepal was adversely affected in comparison to the towns and cities mostly because of the inferior quality of houses [22]. The predominant house type - unreinforced masonry (especially mud mortar) house, were largely destroyed due to its seismic vulnerability [23]. Among all houses affected, fifty-eight percent of them were with low strength masonry made either from stone or brick masonry with mud mortar, without seismic-resilient features. These intrinsically weak and brittle buildings suffered widespread damage and collapse throughout the 14 districts that experienced intense ground shaking [23].

Debris management begins with the removal and temporary storage of debris near the site. The final phase of debris management happens during reconstruction, as the debris is either disposed or recycled for use during reconstruction [21]. Most portion of debris, from a demolished house, can be reused for reconstruction or making temporary shelter, retaining walls, boundary and land reclamation in shallow areas. Reducing and reusing earthquake related debris has financial and environmental advantage which can reduce the overall cost of debris management and reconstruction process [6,17,21]. Moreover, in the rural area, people use bare hands to remove debris, which is also the ignorance of risk to one's health. Debris removable in rural areas is usually done with no or minimal safety equipment that can cause minor or major injuries, resulting to infection [7]. Therefore, reconstruction could be hindered [2]. Nonetheless, post disaster debris and waste management is an important aspect, however, the government of Nepal and its agency (National Reconstruction Authority, NRA) has not paid enough attention towards its implementation. There is lack of study prioritizing the assessment of generated debris generated due to earthquake and construction waste produced during housing reconstruction. This study focuses on the household level debris and waste management practice which is significant and can provide insight value in debris and waste management plan in the future.

The main objectives of this paper are- (i) to assess the amount of debris and waste generated from the demolished house, and (ii) to measure the reuse status of the debris and waste during the housing reconstruction using predesigned questionnaire in two districts of Nepal. To our knowledge, this study for the first time, is the reflection of the debris and waste management practice in Nepal. The findings presented here will help to prioritize the debris and waste management practices in future calamities.

2. Methodology

The study were conducted in two adversely affected mid-hill districts of Nepal (Gorkha and Sindhupalchok) between the periods of April 2017–December 2019 (Fig. 1). Gorkha lies 145 km in the west to the country capital (Kathmandu) whereas Sindhupalchok lies 82 km east.

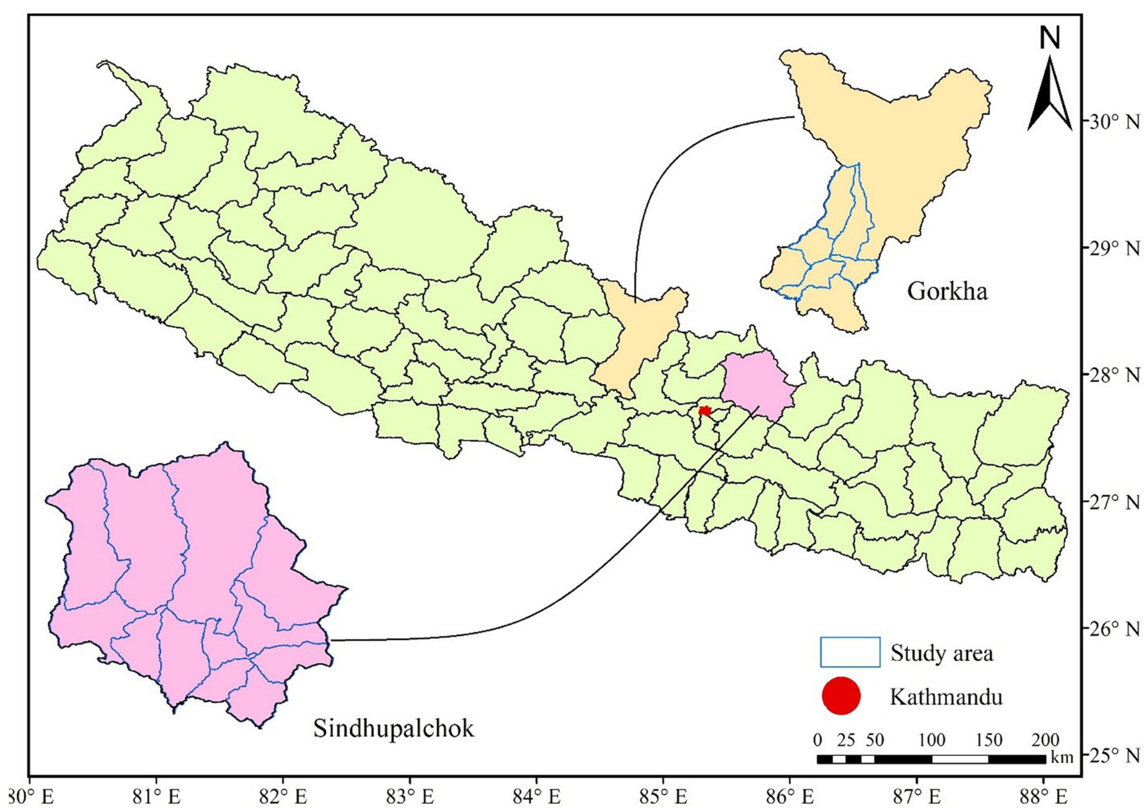

Fig. 1. Map of study area.

2.1. Questionnaire survey

The questionnaire survey was conducted by the assigned Technical Assistance Team (TA Team), which comprises a team of one Social Mobilizer (SM) and a Civil Engineer. Information was collected from the households (HHs) identified as reconstruction beneficiaries by NRA. Random sampling technique was used for the survey.

This survey were conducted in 18 wards of five local administrative levels of Gorkha and 91 wards of 12 local administrative levels of Sindhupalchok district. Four GPs and 1 nagarpalika (NP) of Gorkha and nine GPs and three NPs of Sindhupalchok were the study sites (Fig. 1). The survey was done in each ward at quarterly-basis. Twenty seven HHs were surveyed in each quarterly period by assigned SMs of TA team in each ward.

During the survey period, priorities were given to the houses that were under construction during the time of the TA Team's visit to gather information related to debris and waste management. However, during the time of survey, it was not feasible to find 27 under construction houses in a ward. Therefore, the houses that were newly constructed were also included in the survey. The questionnaire included information like- general information (includes the demographic information of the house, information on debris (provide the quality and quantity of the generated debris) and waste (consists the types and amount of wastes).

2.1.1. General information

The general information included information regarding HHs head name, gender, address, caste and ethnicity. The total sample size surveyed this study were 17,814 HHs (4896 in Gorkha and 12,918 in Sindhupalchok). Among the total, 21.8% (3889 HHs) of household heads were female headed, 78.2% (13,923) were male headed and 0.0% (2 HHs) were third gender headed (Table 1).

Among the overall surveyed households, Janjati HH heads were the dominant. 44.6% HH heads were Janjati (excluding Newar and Thakali) followed by Brahmin-Chhetri-Newar-Thakali (42.8), Dalit (10.1%) and others (2.5%).

2.1.2. Debris

In this study, debris is defined as demolished parts of a damaged building or house by the earthquake. It may be in the form of stone, wood, mud, etc. The total amount of debris of an earthquake affected house is calculated from the sum of debris of stone, wood and mud. Since, majority of the damaged house type were SMM (Stone Masonry with Mud Mortar), brick quantity from the demolished houses were not consideration in study. Quantity of debris was obtained based on visual estimation or as per beneficiary's response (in case of debris already reused or disposed). For more accuracy during visual estimation, measuring tape was used to calculate approximate area (length × breadth) and height of debris. The quantity of debris generated depends upon the size of demolished house. Debris quantity was calculated in cubic meter (m^3).

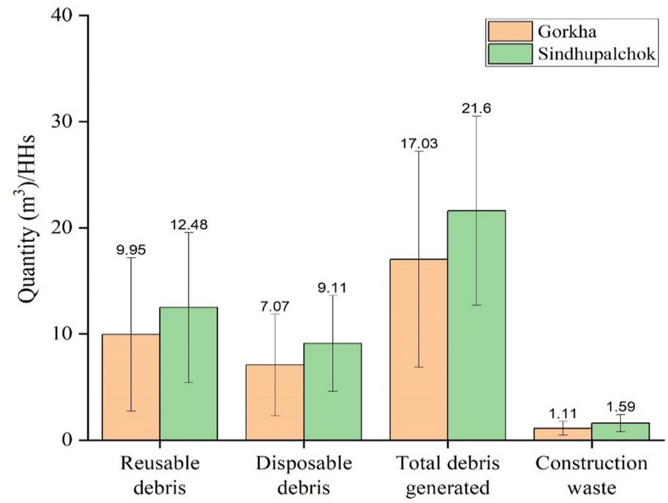

Fig. 2. Comparison of reusable, disposable, and total debris along with amount of constructed waste generated during post-earthquake reconstruction in two district of Nepal. Error bar ± SD. The number above the error bar is the mean of the respective variables.

Based on the use of debris, it is categorized as reusable and disposable debris. The debris used only for reconstruction of new earthquake resilient house is considered as reusable debris. The remaining debris is categorized as disposable debris. The disposable debris are mostly dumped or used in construction of temporary shelter, shed, filling pits, etc.

2.1.3. Waste

Here, waste is defined as the remaining and wastage of construction materials during and after the reconstruction of house. Quantification of construction waste were also obtained based on afore mentioned visual estimation method. Waste types were also recorded. Construction waste includes cumulative volume of plastics, cement bags, scarp metals, plaster, cement, wood, stone, bricks, sand, aggregate and CGI sheets remaining after reconstruction. The waste also includes loss of construction material during transportation from storage to construction sites. Waste generated was calculated in cubic meter.

2.2. Analysis

Simple statistics were used to determine the amount of debris and waste in two districts and at administrative levels. To evaluate the differences in quantity of debris generated, debris reused, debris disposed, and waste generated, a Z- test were used. Z-test is performed to find to determine if two population means are different when the sample size is more than 30 [29].

Table 1
Household head survey status in Gorkha and Sindhupalchok districts.

Name of district	Gorkha	Sindhupalchok	Total (Overall)
Number of wards	18	91	109
Number of household sampled	4896	12,918	17,814
Household head			
1. Gender			
Male headed	75.2% (3681 HHs)	79.3% (10,242 HHs)	78.2% (13,923 HHs)
Female headed	24.8% (1215 HHs)	20.7% (2674 HHs)	21.8% (3889 HHs)
Third Gender headed	–	0.0% (2 HHs)	0.0% (2 HHs)
2. Caste and ethnicity			
Brahmin-Chhetri-Newar-Thakali	32.4% (1584 HHs)	46.8% (6043 HHs)	42.8% (7627 HHs)
Janjati	49.3% (2415 HHs)	42.8% (5534 HHs)	44.6% (7949 HHs)
Dalit	16.4% (801 HHs)	7.7% (995 HHs)	10.1% (1796 HHs)
Others	2.0% (96 HHs)	2.7% (346 HHs)	2.5% (442 HHs)

Table 2
Quantification of debris and waste generated in Gorkha and Sindhupalchok district of Nepal.

	Gorkha (n = 4896)			Sindhupalchok (n = 12,918)			z-test for equality of means	
	Mean	SD	σ^2	Mean	SD	σ^2	Z - score	p
Reusable debris	9.95	7.21	51.91	12.48	7.07	50.11	−21.04	< 0.001
Disposable debris	7.07	4.77	22.79	9.11	4.51	20.42	−25.86	< 0.001
Total debris generated	17.03	10.15	103.11	21.60	8.92	79.63	−27.70	< 0.001
Total waste	1.11	0.64	0.41	1.59	0.80	0.65	−41.20	< 0.001

SD Standard Deviation, σ^2 variance, p level of significance, Z-score measurements to describe the value's relationship to the mean between two groups.

All the analysis were performed in R [25]. Graphical representation was done in Origin Pro 16 (OriginaLab, Northampton, Massachusetts, USA) whereas the maps were generated from Arc GIS 10.3 (ESRI Inc., Redlands, California, USA).

3. Results

In an average, each individual HH used 57.96% of total debris that were generated from the demolished house during the reconstruction. Most of the houses demolished in the study area were made of low strength stone masonry with mud mortar. A Z-test was conducted to compare the mean of quantity of debris and waste generated by the individual household in two districts. There was a significant difference between the total amounts of debris generated in two districts - Gorkha (m = 17.03 m^3/HHs; Standard deviation (SD) = ± 10.15) and Sindhupalchok (m = 21.61 m^3/HHs; SD ± 8.92). Similarly, significant differences were noticed in quantity of debris disposed by the households in Gorkha (m = 7.07 m^3/HHs; SD ± 4.77) and Sindhupalchok (m = 9.11 m^3/HHs; SD ± 4.51). On the other hand, the result showed significant differences between the amount of debris reused in Gorkha (m = 9.95 m^3/HHs; SD ± 7.21) and Sindhupalchok (m = 12.48 m^3/HHs; SD ± 7.07) districts of Nepal. Moreover, there was a significant difference in amount of waste generated at the construction sites in Gorkha (m = 1.11 m^3/HHs; SD ± 0.64) and Sindhupalchok (m = 1.59 m^3/HHs; SD ± 0.65) (Fig. 2 and Table 2).

In Gorkha, the highest quantity of debris was generated by Ajirkot GP (21.30 m^3/HH) and the least by Siranchok GP (11.40 m^3/HH). Likewise, in Sindhupalchok, the highest quantity of debris was produced by Jugal GP (33.10 m^3/HH) and the least by Chautara Sangachokgadi NP (19.60 m^3/HH) (Fig. 3). The demolished houses in Ajirkot GP and Jugal GP were comparatively larger in size resulting more debris generated as compared to other GP or NP of Gorkha and Sindhupalchok districts respectively.

In Gorkha, the highest amount of construction waste was generated by HHs of Barpak Sulikot GP (1.20 m^3/HH) and lowest by HHs of Siranchok GP (Fig. 3). Likewise, in Sindhupalchok the highest quantity of construction waste was generated in Lisankhu Pakhar GP (2.10 m^3/HH) and lowest by HHs of Sunkoshi GP (0.40m^3/HH) (see Annex I).

The major types of construction wastes include polythene, sacs, scarp metals, stones, cement and its mortar, effluents, electric wires, PVEC pipes, etc. Usually, the effluents are drained to nearby area. Open defecation by HHs and construction workers were not noticed.

The amount of debris and waste generated by an individual HH showed a significant differences in quantity of debris generated, reusable debris, disposable debris, and the amount of waste generated at the construction sites in administrative region of both studied district of Nepal. On an average, highest amount of debris were generated in GP (20.75 m^3/HHs; SD ± 10.79) than NP (19.94 m^3/HHs; SD ± 7.99). A significant difference was noticed in the amount of debris generated in two administrative areas. Similar pattern were noticed in amount of debris that are disposable in the areas. On the other hand, the amount of reusable debris in GP (11.89 m^3/HHs; SD ± 7.79) is marginally higher than NP (11.69 m^3/HHs; SD ± 6.56), but no significant differences were noticed (p = 0.052). However, the amount of waste generated in NP (1.53 m^3/HHs; SD ± 0.75) was relative higher than GP (1.39m^3/HHs; SD ± 0.81) and shower higher significant differences (Fig. 4 and Table 3).

We compared the mean amount of debris and wastes generated in GP of Gorkha (n = 4491) and Sindhupalchok (n = 4431). The result showed that

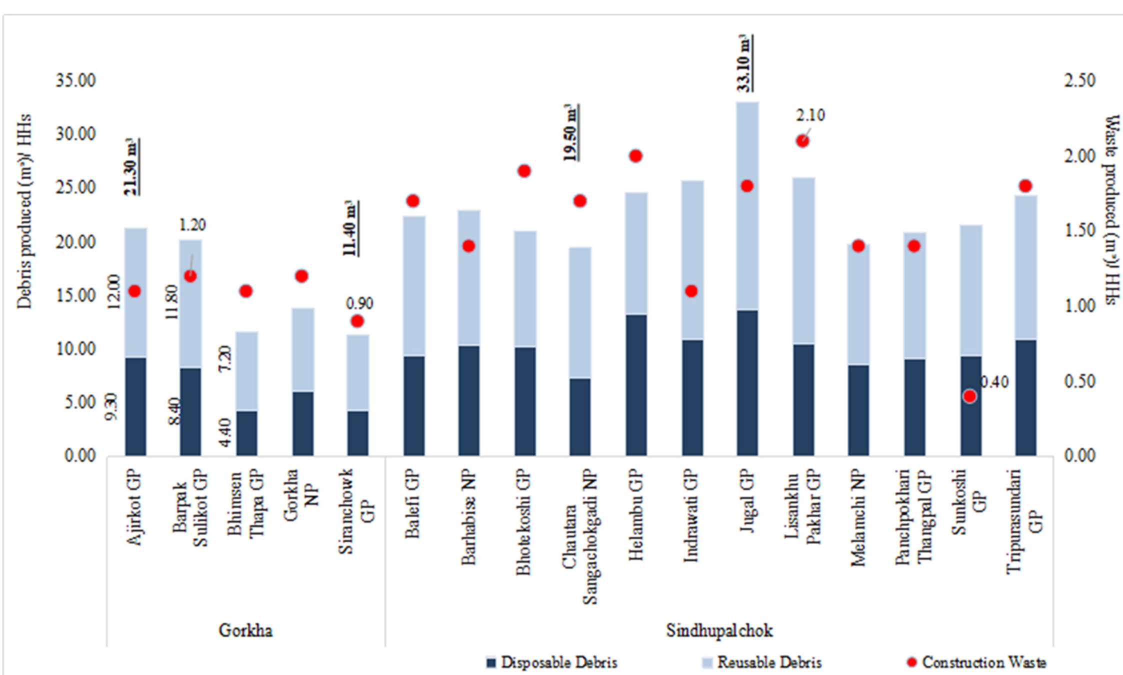

Fig. 3. Average quantity of debris and waste produced per HH at GPs and NPs (overall) (Underlined and bold values represent amount of debris generated (sum of reusable and disposable debris).

Annex I

Quantity of debris and waste generated in each wards of Gorkha and Sindhupalchok districts.

Ward	Reusable debris (m^3/HH)	Disposable debris (m^3/HH)	Construction waste (m^3/HH)
Gorkha			
Ajirkot GP			
3(Hansapur)	14	9.7	1
4(Simjung)	11.7	8.9	1.2
5(Muchhok)	10.3	9.4	1.1
Barpak Sulikot GP			
1(Barpak)	16.8	9.6	1.2
2(Barpak)	14.8	9.2	1.2
3(Swara)	10.7	8.8	1.2
4(Saurpani)	12.7	8.4	1.1
5(Takumajh Lakuribot)	13.1	10.6	1.4
6(Takukot)	10.2	9.9	1.2
7(Panchkhuwa Deurali)	7	7.6	1.2
8(Pandrung)	9.2	3.2	1
Bhimsen Thapa GP			
1(Masel)	7.3	4.2	1.1
5(Baguwa)	7.1	4.5	1.2
Gorkha NP			
1(Taple)	7.6	6.5	1.2
2(Taple)	8	5.7	1.2
Siranchowk GP			
1(Kerabari)	7.9	7.3	0.9
7(Shreenathkot)	7.4	2.4	0.8
8(Jaubari)	6.1	3.2	1.1
Sindhupalchok			
Balefi GP			
1(Jalbire)	16.8	12.3	1.9
2(Fulpingkot)	13.9	9.4	1.7
3(Fulpingkot)	14.8	8.8	1.7
4(Fulpingdanda)	14.1	8.9	1.6
5(Fulpingdanda)	14.5	9	1.6
6(Mankha)	10	9.2	1.7
7(Mankha)	9.3	9	1.7
8(Mankha)	10.6	9.1	2
Barhabise NP			
1(Ghorthali)	12.7	13.2	1.4
2(Karthali)	12.1	9.6	1.5
3(Barhabise)	11.5	10.9	1.7
4(Barhabise)	10.4	10.8	1.6
5(Gati)	12.9	9.3	1.6
6(Gati)	13.5	9.4	1.5
7(Ghumthang)	14.5	12.9	1.1
8(Maneswnara)	14.2	8.7	1.2
9(Ramche)	12	9.2	1.2
Bhotekoshi GP			
1(Listikot)	12.6	13.5	2
2(Tatopani)	8.2	9.2	2.1
3(Tatopani)	8.1	6	2.1
4(Fulpingkatti)	12.9	13.4	2
5(Marming)	12.3	9.3	1.4
Chautara Sangachokgadi NP			
1(Syaule Bazar)	11	6.6	1.9
2(Batase)	11.1	6.2	2.1
3(Batase)	11.4	6.1	1.6
4(Kubhinde)	12.8	7.8	1.8
5(Chautara)	13.9	7	1.8
6(Pipaldanda)	13.7	8.9	1.6
7(Sanusiruwari)	13.8	9.4	1.9
8(Irkhu)	13.9	9.8	1.8
9(Kadambas)	14.4	8.5	1.9
10(Sangachok)	10.3	6.3	1.4
11(Sangachok)	10.4	6.3	1.4
12(Sangachok)	10.4	6.2	1.4
13(Thulo Sirubari)	11.6	7.6	1.6
14(Thulo Sirubari)	10.9	7.4	1.5
Helambu GP			
1(Helambu)	9.6	11.8	2.4
2(Kiwool)	11.4	15.1	2.2

Annex I (*continued*)

Ward	Reusable debris (m^3/HH)	Disposable debris (m^3/HH)	Construction waste (m^3/HH)
3(Palchok)	12.5	18.2	2.1
4(Mahankal)	11.4	13.3	2.2
5(Mahankal)	11	13.5	2.3
6(Ichhock)	10.5	10.1	1.3
7(Ichhock)	13	11	1.4
Indrawati GP			
1(Simpalkavre)	10.7	9.6	1.7
2(Kunchok)	10.9	10.4	1.4
3(Kunchok)	11.2	10.2	1.5
4(Nawalpur)	14.1	10.8	1.1
5(Bandegaun)	17.7	8.5	1
6(Bandegaun)	15.3	10.2	1
7(Sipapokhare)	28.2	12.7	1.1
8(Sipapokhare)	27.8	13.1	1.1
9(Bhotasipa)	15.8	9.6	1.5
10(Bhotasipa)	9.9	9.6	1.4
11(Bhimtar)	7.9	13.4	0.5
12(Bhimtar)	8.4	13.5	0.4
Jugal GP			
1(Selang)	19.3	11.5	1
2(Golche)	18.9	10.6	2.3
3(Gumba)	20.4	13	2
4(Pangtang)	14.4	15.2	2.2
5(Baramchi)	18.2	15.9	1.6
6(Hagam)	21.9	14.2	1.9
7(Hagam)	22.3	16.1	1.6
Lisankhu Pakhar GP			
1(Thulo Dhading)	16.1	11.8	2.2
2(Lisankhu)	11	10.1	2.3
3(Lisankhu)	9.4	8.7	1.8
4(Attarpur)	16.9	11.8	2.3
5(Jethal)	18.4	10.4	2.2
6(Petku)	19.9	10.7	1.7
7(Thulopakhar)	16.1	10.5	2.2
Melamchi NP			
1(Bhotechaur)	10.1	11.6	1.4
2(Bhotechaur)	9.5	10.8	1.7
3(Haibung)	8.8	10	1.6
4(Thakani)	11.6	8	1.7
5(Sindhukot)	10.9	8.1	1.6
6(Talamarang)	12.3	7.2	1.2
7(Dubachour)	13.5	8.6	1.6
8(Dubachour)	14.9	8.5	1.6
9(Jyamire)	12.5	5.9	1.3
10(Shikharpur)	12	6.1	1.2
11(Melamchi)	9.6	8.9	1.4
12(Bansbari)	9.3	8.9	1.2
13(Fatakshila)	10.2	8.8	1.4
Panchpokhari Thangpal GP			
2(Baruwa)	11.7	9.2	1.4
Sunkoshi GP			
6(Thumpakhar)	12.4	9.4	0.4
7(Pangretar)	12.1	9.4	0.4
Tripurasundari GP			
1(Ghorthali)	15	10.4	1
2(Chokati)	15.3	11.9	1.2
3(Dhuskun)	13.2	10.1	2.1
4(Piskar)	17.1	12.9	3.1
5(Tauthali)	10.7	10.7	1.5
6(Tekanpur)	9.1	10	1.8

the highest amount of debris were generated in GP of Sindhupalchok (m = 24.21, SD ± 10.11) than in Gorkha (m = 17.32, SD ± 10.27). Similar trends were found in the amount of reusable and deposited debris. The average amount of wastes generated in GP of Sindhupalchok were also higher than GP of Gorkha district (Fig. 5a).

Similarly, the average amount of debris generated in NP of Gorkha district (n = 405, m = 13.83 m^3/HHs, SD ± 8.13) was significantly lower than Sindhupalchok (n = 8487, m = 20.24 m^3/HHs, SD ± 7.89). Resuable debris, disposable debris and amount of waste also follows the similar

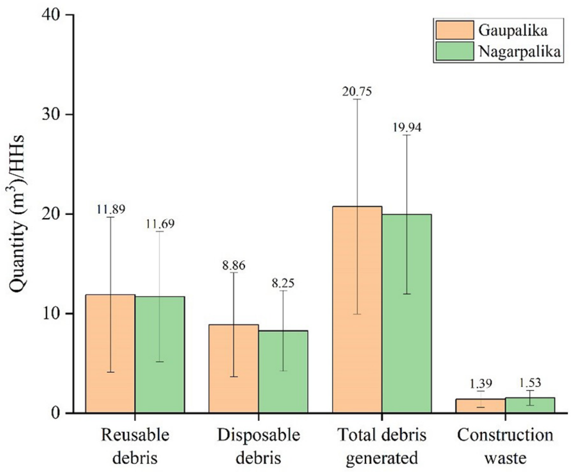

Fig. 4. Comparison of reusable, disposable and total debris along with amount of construction waste generated during post-earthquake reconstruction in GPs and NPs of Gorkha and Sindhupalchok districts. Error bar ± SD. The number above the error bar is the mean of the respective variables.

trends (Fig. 5b). On the other hand, GP of both Gorkha and Sindhupalchok showed higher amount of debris and waste nagarpalika of respective districts (Fig. 5 c and d).

Table 3
Quantification of debris and waste generated in GP and NP of Gorkha and Sindhupalchok districts.

	Gaupalika (n = 8922)			Nagarpalika (n = 8892)			z-test for equality of means	
	Mean	SD	σ^2	Mean	SD	σ^2	Z - score	p
Reusable debris	11.89	7.79	36.13	11.69	6.56	42.91	1.93	0.052
Disposable debris	8.86	5.22	27.12	8.25	4.05	16.49	8.43	< 0.001
Total debris generated	20.75	10.79	115.79	19.94	7.99	64.33	5.61	< 0.001
Total waste	1.39	0.81	0.38	1.53	0.75	0.57	−9.54	< 0.001

SD Standard Deviation, σ^2 variance, p level of significance, *Z*-score measurements to describe the value's relationship to the mean between two groups.

Assigned debris and waste disposal site was not observed in the study area, due to which beneficiaries were self-responsible for debris and waste management. Some houses were partially demolished and were used as store house or cattle shed whereas a small number of houses were yet to dismantle.

Optimum utilization of debris helps to reduce the adverse impact on natural environment. Wood, stone, mud, etc. from demolished houses were mostly reused. Usually, woods were reused in form of wooden band, door/window panels, furniture and form-work whereas stone were used for wall construction, foundation, soling, and gravel making. Mud was mostly utilized for land/road filling.

4. Discussion

Large amounts of debris may be generated after seismic events and could constitute serious environmental and logistic problems [12]. The result showed more than 50% of debris generated from the demolished houses were used during housing reconstruction after earthquake, especially in rural areas. The results of Sarkar [27] also support our findings. Disposal and reuse of the debris are main objectives of post-earthquake reconstruction process [27]. Debris management, for developing countries, is the actual challenge because of the limited technical and financial capacities [16]. During post-earthquake reconstruction and recovery in developed countries during Marmara Earthquake (1999) in Turkey [4], Kobo earthquake (1995) in Japan [9] modern available technologies were used for debris management. However, in Nepal, applications of technologies for debris management were not reported [26]. The study areas are located in remote localities of Nepal. Lack of facilities (for example road accessibility, use of technology) is one of major factors that determines post-earthquake activities. In Gorkha and Sindhupalchok districts, beneficiaries were self-responsible for debris and waste management. UNDP [31] reported that the earthquake of 2010 in Haiti led to the accumulation of around 10 million m^3 of debris (approximately 33.33 m^3/HH), where, the management of debris was the most challenging issue. However, our findings show comparatively less quantity of debris generated from demolished houses (20.34 m^3/HHs). The quantity of debris generated per HH mostly depends on the size and types of the house. Similarly, the amount of debris generated in Sindhupalchok is higher than that of Gorkha. Size of demolished house in Sindhupalchok might be larger than Gorkha. Sindhupalchok has many small towns, the houses were constructed with thick wall structure made up of stone and mud mortar. To adapt with the cold environment in rural high hills in Sindhupalchok, houses were constructed with locally available materials. Therefore, the amount debris generated were higher in Sindhupalchok. The advantage of using locally available materials (like wood, stone, mud etc.) is cost effective and environment friendly that can further be reused after demolition. Murredi and Ali [20] stressed that recovery comprises removal of debris and assessment of debris is immediate challenges for reconstruction after disaster ultimately contributes to environmental management. A large number of people used debris materials for housing reconstruction in Nepal [5] which ultimately contributed to reducing the environmental degradation. Similar to our findings, previous studies have also suggested the reuse of debris material for reconstruction have both economic and environmental advancement ([2,26]. Moreover, our study also agrees with previous findings where it was suggested to promote recycle of the debris by reusing the materials for reconstruction or reclamation of landfill site [8,27].

The commencement of reconstruction could only be feasible with the clearance of debris at the initial stage that further provides the open area and salvage materials to the beneficiaries. A study indicated that disaster debris management starts immediately after the disaster and continues for long time during reconstruction [24]. Various factors determine the effectiveness of management process, most of which are associated with environmental, economic and social impacts [3]. The management or removal of debris requires both time and money, so there is a need of proper debris management plan. As suggested by Dugar et al. [8], the best management practices of debris are the recycle, reused and reduce strategies. Similar techniques were adopted by the individual household in the study sites. However, the mechanisms of management process is not promising in Nepal due to lack of technical and financial resources [8]. After demolition of the houses by an earthquake, management of the debris poses difficulties mainly due to lack of proper management sites. Our studies showed that individuals household were responsible for the management of their own debris due to lack of management sites, thus, allocation of proper debris management sites at local levels will be commendable for the better management practice. Similar findings were reported in previous studies conducted in Iran [3] and Nepal [8].

Estimation of total volume of debris to manage disaster waste provides necessary information on management of hazardable debris, application of technologies, and dispose in land fill area [16], but such scenarios were not reported in the study areas. According to our findings, the amount of debris and waste varies from district to district, and between GP and NP (Fig. 5). This might be due to ward level mason training and awareness programs by government and support organizations. Therefore, the issue of the debris and waste management is mostly site specific. PDNA [23] in its initial reports pointed out that the demolished houses were built from low strength masonry were cleared first compared to the concrete structure. Our study also reported the same findings where the low strength structures were removed first followed by concrete structures. Similar to debris management practice, the individual households were also responsible for waste

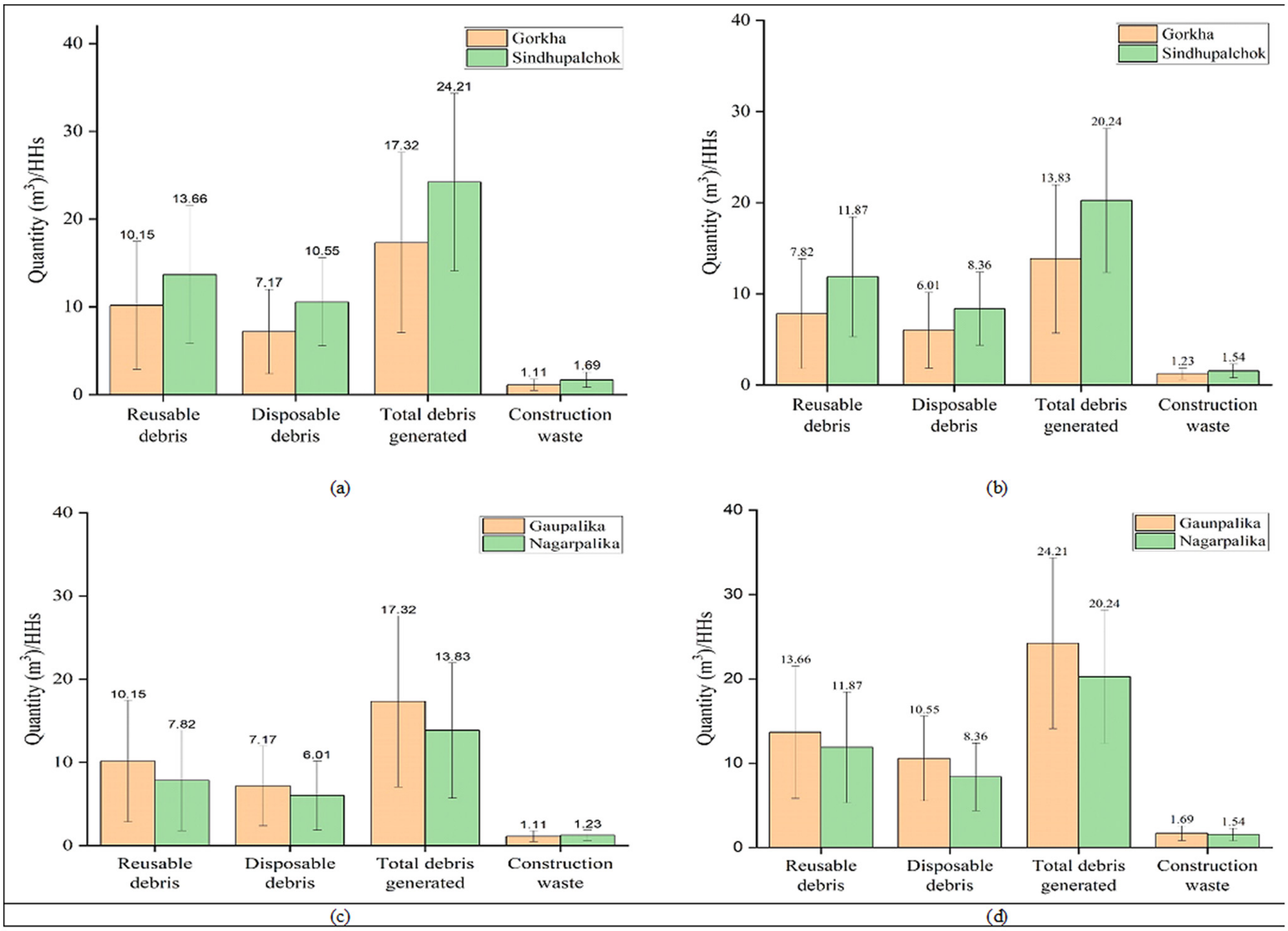

Fig. 5. Comparisons between mean of amount of debris generated, reused, disposed and amount of wastes generated in (a) GP of Gorkha and Sindhupalchok districts, (b) NP of Gorkha and Sindhupalchok districts, (c) GP and NP of Gorkha, and (d) GP and NP of Sindhupalchok. Error bar ± SD. The number above the error bar is the mean of the respective variables.

management. The individual houses treated their waste either by incineration, land filling or compositing but as the cumulative volume is less, the impact on environment might be negligible, Giusti [13] also reported similar practices in waste management that is effective on protection of environment. Hirayama [14] pointed out that not only the household level and local level government are enough but the need of central government intervention to manage the debris is observed for emergency debris removal and treatment immediately after disaster.

However, it is recommended to adopt the safety measures to reduce potential health hazards during debris or waste management.

5. Conclusions and recommendations

The volume of reusable debris during housing reconstruction were significantly high. Most of the generated debris were local materials like stone/rubble, wood, mud, roofing and other vegetative debris. Despite of lack of specific policy and guidelines relevant to debris and waste management, overall status of reuse of debris in the study areas were satisfactory; more than 50% debris have been reused or recycled for housing reconstruction. It is noteworthy that, optimization of debris can reduce the adverse impacts in the environment. Therefore, problems associated with debris and waste management have to be considered with priority during reconstruction period after disaster. The study recommends to establish the debris and waste management strategy and guideline and to prepare debris and waste management plan at community level by local administrative based on those national debris and waste management strategy and guidelines by implementing agency.

Declaration of competing interest

None.

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