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Study of Debris Generated by the Earthquake with Special Reference to Gurkha Earthquake 2015 in Nepal

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Abstract

This study was carried out during the period from May to August 2018. Literatures from various sources were collected and the conclusion was drawn. The study found that the types of debris depends on the types of disaster. There are various types of formulae identified by different writers, which are used to calculate the volume of the debris generated by the disasters. The debris generated by the Gorkha earthquake 2015 in Nepal was not managed properly though there is huge quantity of debris to be managed. Similarly, there is no strategic plan, no appropriate technology, no pre–disaster debris management planning. The debris was cleared from the public places but it could not be managed properly due to various difficulties such as public awareness, technology know how and lack of resources. The economic value of the debris was not considered by the government agencies. Furthermore, there is lack of co-ordination between stakeholders, lack of supporting organizations in this sector, the support was only focused on search and rescue for survival but not on debris management, and no proper mechanism for community mobilization for disaster debris management.

Keywords: Debris management strategy; Gorkha earthquake 2015; 3R principles; unit estimate of debris; public awareness; composition of earthquake debris.

1. Introduction

Debris can be defined simply as materials both from natural and man-made which is generated through any catastrophe. According to the Federal Emergency Management Agency (FEMA) Disaster debris defined as "Anymaterial, including trees, branches, personal property and building materials on public or private property that is directly deposited by disaster." Disaster generates large volume of debris.

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Quantity of such debris depend on the nature and severity of the disaster. From the review of the past disaster the accumulated debris quantity from the single event cross the quantity equivalent of five to fifteen times of annual waste generated volume of the same affected community [1]. Disaster debris management plan is not in high priority as compared to emergency plan for people's safety and well-being in post disaster management [2]. However, such disaster waste can adversely affect both response and recovery activities in disaster-affected area. Moreover, this disaster debris waste may create many hazardous problems such as epidemic diseases, contamination of drinking water, clogging of surface runoff etc [3].

Nepal is at high risk of natural disasters- particularly seismic activity, landslides and flooding. The country is ranked 11th position in the world as most at risk of a significant earthquake according to the study report of UNDP/BCPR, 2004 [4]. With a dense population and its location in a high-risk seismic zone, the Kathmandu Valley is particularly susceptible to an earthquake's potentially devastating impact on both population and infrastructures. Moreover, the growth rate of population in Kathmandu Valley is of 4% per year, it is one of the fastest growing metropolitan areas in South Asia [5]. Unplanned urbanization and weak implementation of building code Kathmandu valley is vulnerable to disaster. We have the history on earthquake disaster according to National Strategy for Disaster Risk Management in Nepal (2008), there have been 876 deaths, 6,840 injuries and over 55,000 buildings damaged in 22 earthquakes incidents in the last 3 decades in the country [6]. In the occurrence of an earthquake equivalent and more than 8 magnitudes in Kathmandu valley, will loss 100,000 people and 200,000 will severely injured, 1.8 million displaced and 60-80% of buildings could be damaged and around 55 to 65 million tons of debris accumulated from this destruction [7].

A devastating earthquake measuring in 7.8 Richter scale hit Nepal on 25 April 2015 at 11:56 AM (Local Time). Its epicenter was in Barpak, Gorkha some 77 kilometers northwest from the Kathmandu [8]. The earthquake was preceded by a major aftershock of 7.3 magnitude on 12th May 2015 [9]. Statistics of Nepal police up to 22nd June 2015 shows the data that 8660 people had lost their lives and 21,952 were injured [10]. Apart from of loss and injury of life it caused extensive damage to residential and ancient buildings in both urban and pastoral areas as well. It is estimated that the total value of disaster effect (damages and losses) was US $ 7 billion. 76% of this was due to physical infrastructure and asset and remaining 24% loss was due to higher cost of production of goods and services. 491,620 private building were completely damaged whereas 269,653 were partially damaged [12]. Nevertheless, 7,532 schools and 1,100 health services were also damaged. There was huge amount of debris accumulated in earthquake affected 31 districts. In Kathmandu valley it was expected that around 3.9 million tones debris was accumulated after the demolition of damage building [12]. This is the volume of debris equivalent to 11 years of waste generated by the valley [12]

Based on the construction practices and materials used, debris from destroyed or damaged building by a major earthquake would consists mainly of brick, stone, concrete blocks, tiles, cement concrete, steel bars, CGI sheets, wooden joist, beams, doors and window frames, steel pipes and tanks, UPVC pipes and tanks, electrical wires and cables, broken glass pieces and furniture and fixture [7].

Debris management was not considered a staid issue, relative to the emergency plans regarding people's safety and well-being. The lesson learned is that, in order to protect people, planning should be based on a systems approach, whereby every component is functional in itself and is coordinated into a cohesive working response. It was found that nearly about four months after Gorkha earthquake the debris were still not cleared in many parts of the country. This situation reflects the lack of preparedness and technical capacity of government towards the disaster debris management. Due to large volume and limited accessibility, segregation, collection and management seems complex and directly impact in response and recovery activities [12].

Not only the local bodies such as Village Development Committee, Metropolitan city, Municipality but

Government of Nepal was also not able to address the accumulated debris management after Gorkha Earthquake. Pedestrian face the problem for walking, moreover many of the affected area was blocked by the debris and faced difficult to reach the emergency response services on time. There was exit solid waste management Act 2011 in Nepal with the main focusing for management the municipal waste and cannot address the disaster waste. It was also realized that there were no institutional plan and policy to handle the waste generated in temporary shelter and debris accumulated,. It was also realized to build capacity on disaster related waste from household level to the community as well as government level. Reuse, reduce and recycle (3R) principle and its link with business chain should be in priority to enhance capacity of related sectors so that it should be balance of the ecosystem. Activities handled by different sectors need to be followed by monitoring, evaluation and feedback regularly. Nevertheless, a short-term, mid-term and long-term polices and strategies should be formulated for the effective disaster waste management situation in Nepal [13]

Nepal occupies the 800 km-long central segment of the Himalayan seismic belt and is one of the most earthquake-prone countries in the world [14]. The Himalaya region has a long history of frequent strong earthquakes and has been shaken by four great earthquakes (Mw = 8.7, 1897; Mw = 8.1, 1905; Mw = 8.4, 1934; and Mw = 8.7, 1950) in the past two centuries Historically, Nepal has experienced six earthquakes (1255, 1408, 1505, 1833, 1934 and 2015) with magnitudes exceeding 7.5 since 1255 [15].

1.1 Debris generated by disaster

Earthquake, floods, tidal waves, landslide, typhoons, volcanic eruptions etc. are the main disaster, which occurred usually as ecological disruptions and breaks the adjustment capacity of the affected community [16]. Harmful wastes such as solvents, pesticides, asbestos, oil and solvents, failure of post-disaster unsafe structure and indirect vectors are accountable for public healthiness risk. Sometimes disaster waste blocked the access and make difficult to reach the affected community. Railways, highway and often airport may have crammed and the relief and reconstruction activities will be difficult. Chemical and heavy metal from disaster waste sometimes contaminate the agriculture land, waterways and community too [17]. The most important response works such as medical care, transportation of victims or relief items, firefighting, provision of shelter, food, clothing, and water supplies were delays in foremost disaster during the last era because of transportation because of debris-blocked roads. On the other hand, the issue of debris management has not given a high priority as compared to emergency plan regarding people’s safety and well-being [2]. Debris clearance in a post-disaster scenario is a complex and demanding task not only because of high volume and limited accessibility but also because of the miscellaneous nature of debris. Hence, articulating a debris removal strategy is very important in a condition that discusses how each type of debris should be segregated, collected and managed. The main challenges for debris management are inadequate resource, lack of capacities of both local and national institutions. Lack of vulnerability and risk assessment, environmental baseline data, technology know-how, communication, and coordination etc. On the other hand, handling large volume of debris, ensuring capability of property owners to return to an area and assist with cleanup, separation of hazardous and nonhazardous waste and managing contaminated waste are also challenging for debris management. Similarly, the establishment of permanent recycling infrastructure, lack of funds to acquire the required technology and equipment are another challenge for disaster debris management [19]. The Historical volume of debris generated by the respective disaster is presented in table (Table-1).

Table 1: Historical recorded volume of debris generated by disaster.

Year	**Event**	**Debris quantity**	**Data Source**
2011	Japan tsunami	70 - 180 million tons	**[20]**
2010	Haiti earthquake	23 - 60 million tons	**[21]**
2009	L'Aquila, Italy earthquake	1.5 -3 million tons	**[22]**
2008	Sichuan, China earthquake	20 million tons	**[23]**
2005	Hurricane Katrina Louisiana USA	76 million cubic meters	**[24]**
2004	Hurricanes Florida, USA	3 million cubic meters	**[25]**
2004	Indian Ocean Tsunami	10 million cubic meters	**[26]**
2004	Hurricane Charley, USA	2 million cubic meters	**[27]**

Source [20, 21, 22, 23, 24, 25, 26 &27]

1.2 Types of debris

The types of debris depend on the types of disaster and its severity hitting the area and the nature of the affected community [28]. Therefore, collecting the information about the waste materials that produce by any disaster can help in making the work more efficient, and can be directed for each kind of the waste to transport correctly in recycling point [29]. Preparing enough information about the components of the disaster waste can help on saving time and money on the collection side, and the quick removal of the debris will allow the life to go back to normal quickly which will help the stability to come back to the area, and it also helps to move the economic wheel in the region [30]. Debris comprehensively classified as recyclable materials, non-recyclable materials and hazardous waste [31]. It can be also classified as the damaged building, sediment, green waste, personal property, ash, and charred wood [29].

1.2.1 Earthquakes

Generally, earthquakes are results of the interaction between two tectonic plates at the fault. The strength of the earthquake depends on the type of friction occurring between the plates, and the elasticity of the surrounding area [32]. Nevertheless, the main strikes of the earthquake are not the only reason of damage, but the aftershocks will cause damage as well. However, bigger earthquakes generate more aftershocks [33]. Another important debris generator to consider is the secondary disaster that happens after the earthquake, and it might cause the major damage, such as heavy raining [34]. The massive amount of earthquake debris comes from destroyed buildings especially in the countries where buildings are not designed as earthquake resistance techniques. This debris can vary from few tones to hundreds of tones. Additionally, the hazardous wastes resulting from the earthquakes are usually different chemicals that are used in the inhabited areas like pesticides and fuels that might leak [35]. On the other hand, there is the debris resulted from the landslide and different collapses, where the amount of this debris depends on the size of the affected area [36]. When a secondary catastrophe occurs after the earthquake, like heavy rain, it can cause a debris flow. In the debris flow, all different types of debris as soil, rocks, and buildings remain can accumulate to make a massive mud-rock. This flow can make more damage to the infrastructure, transportations, and building than the earthquake itself [34] Waste from the collapsed building and other structure and accumulate which make difficult in shorting out the hazardous waste. Road and bridge may have collapsed and difficult for transportation. The quantity of earthquake disaster waste is commonly huge in quantity compared to another disaster [17].

1.2.2 Floods

When heavy rainfall exceeds certain limits, it can turn into a catastrophic flood, where this rain might be seasonal or annual. When floods occur in a certain area, the water carries the different objects. It meets on its way, and with these object. It can hit buildings, people, and vehicles etc. causing significant damage [37]. Beyond that, when floods happen after another catastrophe, like an earthquake, for example, the water will carry all the debris resulted from the other catastrophe. The debris, in this case, will contain mud and rocks as well as cars and building remains [34]. On the other hand, trees and other vegetation will be also carried by the flood. This mix of water and debris will form what looks like a huge rock that will cause more damage, and hold more debris on its way as it moves with a speed of approximately 10 meters per second [37]. Common waste produce by flooding are mud, clay, and gravel. Access to transportation and waterway may be blocked. Waste from the effective community may be damage building materials and household use. The probability of mixing of hazardous materials into mud clay and gravel is high. Removal of that debris required for search and rescue operation [37].

1.2.3 Tsunami

The damage of the tsunami strike comes from the high rise of the tsunami wave due to earthquake epicenter in sea and then the hard landing on the affected area, where the damage caused by the wave attack depends on the length, the height, the depth of the wave, and the debris carried by this wave [38]. The debris resulting from a tsunami consists mainly of marine sediments like sand and mud, and rubble parts of the residential areas like wood and metal. Also, it can contain oils and hazardous chemicals. Dead animals' bodies and other livings like trees and vegetation will also exist in the debris [42]. The hazardous materials might not be very dangerous but it still needs to be handled carefully, where handling the falling buildings will be one of the most challenging parts especially from the humanitarian perspective [43]. However, the main load of debris consists of vehicles, destroyed homes, boats, and other objects that can be carried by the waves for hundreds of kilometers for more than an hour time depending on the severity of the tsunami [38]. Tsunami swipe out the all infrastructure and spread the debris over large area. Debris is often being mixed with soils, trees, bushes, and other loose objects such as vehicles. This makes waste difficult handle and segregate [17].

1.2.4 Hurricane/ Typhon/ cyclone

The hurricane is a tropical cyclone consists mainly of very heavy rain and wind that can reach the speed of nearly 300 kilometers per hour. It is usually formed at the depth of 50 meters under the sea, where the temperature is 27^{o} Celsius at least. Whereas warm water, high humidity, and the lack of wind, feed the hurricane strength and make it lasts for longer periods [44]. Common waste is from the damaged building, trees, bushes etc. Waste is spread over the open land, streets, and marketplaces. This would include roofing materials, small items and dust carried by the wind. Ships, boats electrical, and telephone grids may be damaged and become waste [17]. Hurricane debris can pile up to reach almost 5000 Kg of waste [44]. One of the most problematic wastes is sand and salt of the sea, as the beaches and can be totally removed by the storm. Additionally, the other materials carried by the hurricane can cause more damage to the buildings and the infrastructures. These materials can be uprooted trees, houses, ceilings, boats, etc. [44]. Trees and other vegetation form a large part of the degradable debris, considering that broken branches, fallen leaves, uprooted trees, and other vegetation can make 70% of the hurricane debris in some areas or more [45].

1.3 Earthquake and debris

Earthquake is one of the major natural disasters, which can create a huge volume of debris and solid waste. The volume of such debris and solid waste depend on the nature of the built environment and the intensity of earthquake disaster [1]. The main challenge is to address the earthquake debris due to lack of preparedness and the composition of the generated debris. Sometimes the volume of debris due to the earthquake may have crossed the volume of many times annual waste produced by the same affected community. The emergency response and recovery activities are always affected by those waste and debris. Due to the road blockaded by the Great Hanshin-Awaji earthquake in Japan in 1995, there was a delay in emergency services and lifeline support reaching. There was found public and environmental health hazard was reckonable due to unmanaged debris in a review of the 2004 Indian Ocean tsunami waste management response report [1]. Due to Tohoku earthquake and tsunami waste quantity was exceed over 23 million tons in 2011 [39]. Similarly, in 2011 there was 8 million tons of debris due to Christchurch earthquake [47], The debris was estimated 23-60 million tons of in Haiti in 2010 earthquake [29], 20 million tons was accumulated in China after Sichuan earthquake in 2008 [49]. there was 10 million cubic meters debris was generated in Indonesia only due to Indian Ocean Tsunami in 2004 [50]. Due to Marmara earthquake in Turkey in 1999 there was 13 million tons debris was accumulated [51] where as 15 million tons debris was generated by the Great Hanshin-Awaji Earthquake in 1995 in Kobe of Japan [52] . Not only can these large waste volumes crush existing solid waste management facilities and personnel, it could also affect both the response and long-term recovery of an earthquake-affected area. In developing countries, the issue of waste management is mainly focused on municipal waste. Policies of those countries regarding the waste management cannot address the disaster waste as well as construction and demolition waste. Thus, unavailability of relevant policy framework, coordination among relevant government levels and departments, stakeholder's involvement and lack of financial and technical capacities are the main challenge for disaster waste management in developing countries. On the other hand, replication of lesson learned and adopt latest technologies from developed countries are the possible opportunities for developing countries regarding disaster waste management [53].

2. Composition of Earthquake debris

It is already mention that the types of debris produced by an earthquake depend on the types of built environment of the affected community and the intensity of disaster impact [54]. However, the types of typical debris due to the earthquake are classified as construction and demolition waste, Hazardous waste, municipal solid waste, putrescible waste white goods, and vehicle waste and special waste. Building materials fall under the construction and demolition (C&D) waste, fuels, oil, and batteries fall under hazardous waste. Similarly, household garbage, personal belongings fall under municipal waste whereas refrigerators and air condition and vehicle waste fall under white goods. Likewise, archeological important waste falls under special waste [12]. In some case silt material is injected due to liquefaction during the earthquake, sometimes rock falls also occur and in case the diverse nature of waste accumulated in tsunami during the earthquake [47].The devastating earthquake known as Chi-Chi earthquake measured 7.3 Richter scale struck Taiwan on 21 September 1999 which create more than 20 million cubic meters of demolition waste. Inert material such as concrete, brick pottery, and fines was collected and stored in a temporary site and recycled which significantly help to reduce the site clearing cost. Pauli, Tali, and Taichung were the three different area chosen for the investigation of the composition of the demolition waste. A shovel-type excavator driven into each waste dump hill took the sample of waste. Sample materials classified into inert materials and impurities. Inert materials were further classified into composite materials such as concrete, brick, and pottery and fine whereas impurities composite materials as metal, glass, wood, paper, plastic, and rubber [11]. The composition of inert materials in Pauli, tali, and Taichung were 96.48%, 97.35%, and 78.61% respectively whereas impurities were 3.52%, 3.55% and 21.39% respectively [11] The composition of the demolition waste from Puli and Tali was inert materials because they were mountainous area and major sources were earth block buildings, reinforced brick building, and light steel house. The content of concrete in tali (51.02%) is higher than that from the Puli site (33.66%). The major sources were reinforced brick and concrete buildings since the city of Tali is a developed urban area. On the other hand, the content of inert material and impurities is 78.61% and 21.39%, respectively [11], for the demolition waste from the Taichung site. It is obvious that the impurity content in the waste from the Taichung site is higher than those from the other sites, as the sources of the waste from the Taichung site were not only demolished buildings but also demolished interiors and excavated earthworks [11]. Third largest city of Sri Lanka called Galle was severely affected by Indian Ocean tsunami in 2004. European Union funded project COMA (The Construction Waste Management) for the period of (2005-2009). COMA tried to find out the justifiable way for C&D waste management. The result of the study says that more than 50% of the waste contains brick, cobac, and normal clay brick, On the other hand, the study found that about 14.2% of C&D waste might contain different hazardous materials [49].

2.1 Estimating the amount of debris

Estimating of actual amount of debris is challenging and difficult task but it is important to identify the real volume of debris to plan effective management process. By knowing the real information, it would easy for preparing different handling process facilities to address the accumulated debris quantities [18] Pre-disaster debris estimation is very useful in both disaster response planning and implementing activities for it, which can be carried out by using GIS/hazard maps. Japan has good experience regarding on this matter. Hirayama and his colleagues estimated the debris volume/weight per house or per unit floor area [31]. Different method can be used to estimate the quantity volume/ or weigh of debris for both pre and post- disaster event. This estimate can be done to predict the quantity of total waste or in broken down into different items such as timber, concrete, metal etc. [47] These methods are briefly explained here.

2.1.1 Unit estimate

In this method, quantity of debris is calculated from a single type of property and its level of damage. For example, for residential areas, it is needed to divide the affected properties into the level of damage (full demolition, partial repair and minor repairs). Each level can then be divided further based on the kind of structure of the material goods, its age and size. For each category, it can then be estimated, using local evidence and experience, the quantity and composition of the waste. The total waste will be the sum of the number of houses in each category (N) multiplied by the quantity of waste (W, in mass or volume as needed), as shown in formula. If desired, this technique could be further developed by not only estimating the total quantity of debris but for each sub-category estimating the composition of the waste such as quantity of concrete, brick, timber etc. [55]. According to him, the quantity of debris is calculated by using the formula:

W $=\sum_{i=0}^{n} W_n N_n$ (Total quantity of waste = W, number of house = N) [55]

2.1.2 Volume estimate

This method is useful for differential shape of the building. In this method, the quantity of debris is anticipated that the weight of debris in a commercial building is one-third of the volume of the erected building. This is thumb rule and bit rough technique. This approximation technique is useful for fully demolition building, where the volume of building is known. The building can be further classified according to construction type [47]. According to C. Brown, the formula for the calculation of debris is: Total waste (in tons) = $\frac{1}{3} Building\ volume\ (m^3)$ [47].

2.1.3 Area estimate

This area estimate method is based on the individual damage area i.e. floor area of building and impacted land area. In building waste is calculated according to unit floor area of the building and total quantity is multiplied by total damage building thus volume of debris is according to the damage level and types of building. It is useful in a spread type of damage area where an aerial image can be used to determine the damage condition such as tsunami influenced area etc. For each area, unit debris quantity per m^2 is applied [47] But the total quantity is calculated using the formula: Total waste (W) = $\sum_{i=0}^{n} W_n A_n$

(n= number of building and A= floor area of building) [47].

2.2 Debris Management Strategy

Debris removal can be categorized as public property debris removal, private property debris removal and private property demolition. Public property debris removal is simple and does not required any permission from the property owner whereas more documentation and approval as well as involvement of different stakeholder require for private property debris removal and demolition work [51]. The disaster waste management practice at the beginning of history has been managing as a logistical exercise. Clearing and removing the debris and through bit away was understanding the debris management which causes the impact of the environment in long-term. In 1703, in L'Aquila city was severely damaged by the earthquake. The debris from it was deposited in an area behind the Basilise, and now it forms the Botanic Gardens, which need remediation due to poorly compacted fill. Modern disaster waste manager should have to take strategy to increase awareness towards environmental, social and economic impact for meaningful disaster waste management considering the increase of volume and diversity nature of disaster waste for better-integrated ways [1]. Emergency clearance, debris removal, 3R (reduce, reuse and recycle) and disposal of debris are the common four step for post-earthquake debris management strategy. Nevertheless, the pre-disaster planning will be better for identify the likely debris quantity and types from typical disaster and also help to identify the related stockholders regarding the debris management. It also helps to prepare post disaster strategy [12]. Debris removal activities usually carried out in manly two phases. Initial debris clearance activities are for life and safety threats whereas debris removal is done in the recovery phase [28]. Strategic management, funding mechanism, operational management, environmental and human health risk management, and legislation and regulation are the main six elements of disaster waste management. The disaster debris management will start immediately after the disaster and continue until the end of reconstruction. Effective debris waste management has mainly two-phase pre and post disaster phase. In pre disaster phase, protective disaster waste-management strategies should be introduced and focus on speedy recovery after disaster whereas post disaster waste management focuses on policy related issue and cleanup operation [56]. Debris management strategy is based on the preparing post-disaster management plan has gone through certain phase and reflect through a cycle. This post- disaster waste management plan is interconnected with general disaster management plan. Debris exist during disaster impact. Collection, transportation, reusing, recycling and landfilling or disposing of works is parallel with relief and response phase. Construction and demolition waste can be used during reconstruction phase. Similarly, pre-disaster activities are building code and zoning vulnerability analysis in mitigation phase and the preparedness plans, emergency training warning system, evacuations plan, public education is carried out in preparedness phase [18].

2.2.1 Estimating

Always volume of debris depend on the area that is affect by the disaster. In addition, it depends on the power and type of disaster hitting this area. Commonly, the debris bulk by different disasters incident do not elucidate the way of calculating [1] Through the assessing of debris quantity, it should be seen the require resource. Then it is estimated the carrying time, storage capacity of presence site and then quantity and types of debris. It would help to recover the overall allowance efficacy [2]. Estimation the bulk of debris can be done using geospatial exploration that uses different techniques to calculate the bulk like the amount of debris producers, like the number of buildings etc. and these producers vary according to the nature of the area [18]. Calculating the volume of debris is the evidence about the bulk of debris estimated from earlier experiences in the same country, or from different countries. Essentially, this method can give a sign about the amount of generated debris [29]. One post-disaster way to compute the waste bulk is by measuring the number of load trucks used to transport the debris, and the space it occupies in landfills. Determining the quantity of waste generated from one unit of measurement is another method to calculate the volume of disaster waste (the unit may be a house of a floor of house). Finally, GIS/hazard maps can also be used to estimate waste volume [1].

2.2.2 Collecting

Collection of debris is depending on the amount of debris generated, types of debris, and the urgency of site clearance, disaster site characteristics, debris recycling possibilities, and geographic complications. The collecting equipment is mainly for collecting, segmenting and lifting. Common equipment is bulldozers, front-end loaders, cables cranes, cutting torches, hand tools (shovels, picks, hammers, handcarts etc.) [2]. Collection of debris can be divide into two stages. The first stage is the emergency collecting, and that is important to save people's lives immediately after the disaster hit. The second stage is about collecting the rest of the waste, and it continues until the points where collecting waste go to the routine process [57]. Generally, the municipality of each area is responsible for collecting the waste in its region. Nevertheless, governments in some cases might require from the private owners to collect the debris by themselves if there is no potential risk of doing that. In addition, the army might participate to help with the physical work, and private contracting companies can provide their services to make the work more efficient [1].

2.2.3 Transporting

For efficient logistical work, the planner should consider the distance between the affected area and the sites where the debris will be taken. Therefore, the temporary storages or the separation sites should not be too far to save fuel and avoid unnecessary environmental impacts and financial cost [29]. Hauling time i.e. time required traveling between the debris clearance area and disposal site is the key efficiency for debris transportation. Transportation network i.e. primary route to secondary feeder roads to residential street should be fixed and clearance of such rout is needed firstly [2].

2.2.3 Handling

Handling disasters debris is usually achieve in two main ways, either by recycling or composting, where composting is considered as a practical solution for the mixed waste that is hard to separate [29]. There are many issues regarding the debris handling in the community such as time and process the materials, unavailability of specialized processing equipment, inability to physically separate the materials, lack of desire to offset raw material used in rebuild and unavailability of markets to absorb large quantities of material. However, every debris management plan should include a strategy for reuse, recycle including mulchingor composting. Reuse and recycle strategy will reduce the handling cost and provide valuable material resources. From many past disaster waste management experience there are many benefit from the recycling of debris such as reduction of landfill space used, reduction the quantity of raw materials used in re-building, generation of revenue from recycled debris, reduction in transportation for raw materials and debris and job creation (for developing countries in particular) [31]. Developed countries usually trend to recycle the maximum of the debris they have, especially the debris of the building that can be used for rebuilding the area whereas developed countries tend to send this debris to landfills, although landfills in most cases do not have enough capacity to take all the debris. Additionally, the composting of the debris in landfills can cause some serious environmental impacts, due to the gases released in the composting process, or by contaminating the groundwater in the landfill area [57]. It was noticeable that most of the disasters debris comes mainly from the destroyed and demolished buildings. In developed countries, this debris is usually recycled and used to cut the use of raw materials for rebuilding the affected area. On the other hand, the materials classified for burning can be used to provide energy, while in some cases it might be necessary to handle these wastes by open burning in case of dangerous hazard removal [1].

2.2.4 Stakeholders

Involvement of different stakeholders in disaster debris management is important to achieve the goal of disaster waste management [18]. In general, disaster-affected community, informal waste sector e.g. scavengers, waste pickers or recyclers, the informal waste management service companies and their employees, private sectors and non-government waste organizations and local authorities are the key stakeholders for disaster waste management [17] Moreover, construction industries, volunteers, welfare organization, civil engineers and architecture are the related stakeholders too [35]. Effective communication between different stakeholders regarding the key issues is vital to increase awareness and empowering public participation in debris management. Thus the strong pre and post disaster communication should be needed between different stakeholders to succeed their participation [1]. Nevertheless, there also exists local communities such as NGO's and CBO's and hence the numbers and types of such stakeholders may vary from country to country and from case to case [35].

2.3 Case Studies

There are many cases of earthquake debris management around the world which might be the lesson learned for upcoming similar cases. United Nation Environment Program (UNEP) head office is located in Nairobi, Kenya and one of its offices known as the International Environment Technology Center (IETC) [53] located in Osaka, Japan, which supports the environmentally sound technologies under the Rio 1992 Agenda 21. IETC provides inclusive support through recommended service, guidelines, the collection of technologies, and training for disaster waste management and grnerates policy, financing, technical, institutional and stakeholder aspect too. Disaster waste management project supported by European Union in Indonesia after Asian tsunami 2004, was the first major project of IETC [53]. Not only this, but UNEP was also involved in post-disaster debris management following 2005, Pakistan earthquake, Cyclone Nargis in Myanmar and the Wenchuan Earthquake in China in 2008, an earthquake in Haiti 2010 as well as the tsunami 2011 in Japan [58].

2.3.1 Pacific coast Japan tsunami

In Pacific coast of Japan a devastating earthquake happened on 11 March 2011. Its epicenter was approximately 70 km east of Japan's Oshika Penisula, while its hypocentre was 35 km underwater. With a magnitude of Mw 9.0 [59] this was the strongest earthquake ever to hit Japan. This is one of the greatest earthquake in the world among five since 1900 recorded data [59]. Due to this devastating tsunami 15,824 people lost their life, 3,155 were missing whereas 26,992 were injured. Similarly, 129,225 houses were completely collapsed, 254,204 were half collapsed and 69177 were partially damaged. Total 210 US billion was loosed by Japan due to this disaster. Over 23-million-ton, debris accumulated in the affected area [59]. For Miyagi the total volume was 16 million tons, Iwate faces 4.5 million tons and Fukusima was 2.8 million tons. It was planned that the debris from residential and commercial areas should be removed and brought to the temporary storage sites by the end of August. At the date of June 21, Natori, Miyagi Prefecture, had removed 80 percent of its debris, Rikuzentakata, Iwate Prefecture, removed 27 % whereas Kamaishi had able to remove only 13 percent. Japan itself has good experience on earthquake debris management, as it was able to recycle 50.1 percent of debris after Hanshin quake but face bit challenge on tsunami debris management [60]. Immediate after tsunami 2011 in Japan UNEP formed an international team of senior experts. A member of Japan's Task Force on Debris Management and UNEP officials joined them, which is the largest post disaster debris management team in the history of Japan. UNEP's international expert mission was conducted in two phases for debris management. In the preparatory phase team is focused on collection all relevant background information. Studied satellite images and government documents. Team was also examine the available logistic during the preliminary visit. In the second phase, the team was involved in detailed coordination with government authorities, meeting with the city officials for dealing with debris management. Also visited the storage areas as well as availabel treatment, recycling, re-use and disposal facilities. In the second phase, team was able to closeout meeting with experts and city officials where experiences were exchanged in a structured manner [59].

2.3.2 Ancient city Ray

An ancient city Ray familiar as best civilization sites in the world southern urban part of Tehran province. In this city 49, 72 and 82% of building were rigorously damaged with magnitude of 4.5, 6 and 7 Richter scale of earthquake [61]. Hazards United States tool as a geographic information system-based natural hazard analysis tool was used to review the incident. 93, 197 and 331 thousand cubic meter of debris would be produced at 4.5, 6 and 7.5 Richter earthquake respectively. Best route from the affected areas to the temporary disposal location were identified by using Arc-GIS tool. This tool was also used to allocate the required number of heavy equipment and manpower for debris disposal. It was success to manage debris with the shortest time as well as with the shortest network of street distance. This practice was highlighted that the debris management is an intimate part of post-accident recovery process but not only a logistic activity [61].

2.3.3 Haiti earthquake 2010

On January 12, 2010, a magnitude 7 Richter scale earthquake occurred within 15 miles of Port au Prince, Haiti. The resulting damage was severe as many neighborhoods were destroyed. The Haitian government lost almost all of its ministries, and many hospitals and other infrastructure facilities were destroyed. Numerous aftershocks of magnitude 4 or 5 have only increased the damage. Around 230,000 lost, 1,000,000 people made homeless and around 250,000 residences destroyed [62]. The debris created from the earthquake is estimated to be around 23-60 million ton [29]. United Nations Development Programmed (UNDP) start a combined labor-intensive Cash for Work programmed (LI/CFW) in partnership with the World Food Programme (WFP) and the Government of Haiti. Planning, demolition, and removal, transportation, and reuse, recycling and disposal are the key activities followed by UNDP for debris management in Haiti with the partnership of government, I/NGO, local communities [40]. Global Community partner for Good (CHF) International also launched a CLEARS program in Haiti to response in debris management in Port-au-Prince, Petit Goava, and Gonaives. St. Marc and Cap Haitien. CHF firstly removed debris at a temporary site close to the airport with the close coordination with local mayors. Debris transported from the temporary site to a permanent site identified by the Government of Haiti in coordination with USAID and the US Army Corps of Engineers. Sun Mountain carried Environment assessments for those permanent locations to ensure the minimal negative environmental impact due to debris dump. CLEARS program was meet the 2035 cubic meters of debris per day in the partnership with Caterpillar for heavy equipment. Majority of the debris in an open place was done by the heavy equipment whereas smaller spaces such as drainage canals and narrow streets manual labor with hand tools such as shovels, hammers, and wheelbarrows which would be picked up by smaller loader to be loaded onto a dump truck for disposal [64].

2.3.4 Indonesia tsunami

Northern area of Sumatra in Indonesia struck by a powerful earthquake of magnitude 9 on 26 December 2004. A number of aftershocks also occurred, some of magnitude 7.1 [67]. These earthquakes triggered tsunamis that affected Indonesia and neighboring countries in Asia (including India, Malaysia, Maldives, Sri Lanka, and Thailand) and the east shores of Africa (including Somalia and Yemen), trigged severe damage to the coastal areas and small islands. Around 250,000 people were lost but the final death is still not known. Millions had homeless and the cities about 50 km from the edge of the ocean were severely damage [65]. More than 1,080,000 cubic meters of tsunami waste was cleared (this is, however, less than half of the debris actually generated from the tsunami). In addition, more than 90,000 cubic meters of municipal waste cleared [66]. For Banda Aceh alone, more than 457,860 cubic meters of waste cleared. Timber recovered and stockpiled for future use is 12,954 cubic meters, while about 1,223 cubic meters has been processed for reuse and recycling. It found that 60-70 percent of the waste generated from residential sources, and the remaining from non-residential sources [67].

2.3.5 Sichuan earthquake

On 12 May 2008, an 8.0 Richter Scale magnitude earthquake struck the Sichuan Province of China. The earthquake affected about 70 million people [41], overwhelming lives, livelihoods, and lands. Some 15 million people evacuated from their homes. As of December 2008, the death toll had reached more than 100,000 people with over 374,643 injured and 17,923 missing. Around 20 million ton of debris accumulated during this earthquake. Upon request from the national Government, UNEP, involve managing debris and conducted different training and debris management activities as well [41].

2.3.6 Canterbury earthquake

In September 2010 and February 2011, The Canterbury region of New Zealand suffered a massive earthquake. 1400 commercial, as well as 7500 residential properties demolished [68]. Approximately 4 million tons of debris was accumulated through demolition whereas more than one million tons from repairs. The Government of New Zealand appointed Canterbury Earthquake Recovery Authority (CERA). CERA led and coordinated the recovery effort and led on construction and demolition waste management. For construction and demolition waste management CERA introduced the “Pick and go” strategy which directed debris straight into the end-user market and found very effective. It had found many limitations such as lack of pre-event planning; poor coordination between local authority and contractors during the recovery, incomplete policies and acts, and insufficient capacity in construction and demolition waste facilities to process waste [68].

3. Earthquake scenario in Nepal

Nepal is one of the most vulnerable country in the world in terms of natural disaster. Due to active tectonic process earthquake is one of the major disaster of Nepal. Fragile topography, unplanned urban settlement, high Himalaya and weak government organization are the major barriers against the addressing towards disaster [69]. Himalaya was formed due to a collision between the Indian and Eurasian plate for 50 million years at the rate of 35-38 mm/year towards N-NE [46]. Nepal suffers many frequent earthquakes in history and has shaken by four great earthquakes (Mw = 8.7, 1897; Mw = 8.1, 1905; Mw = 8.4, 1934; and Mw = 8.7, 1950) in the past two centuries [14]. Moreover, it has experienced five earthquakes (1255, 1408, 1505, 1833 and 1934) with magnitudes exceeding 7.5 since 1255 [15]. The vulnerability to the earthquake in Nepal is very high due to the fast growing of urbanization, poor construction practice, and lack of awareness and preparedness [71]. Kathmandu valley consists of three districts namely Kathmandu, Lalitpur, and Bhaktapur, situated in the middle of Nepal. Due to the composition of lacustrine sediment, the valley has high earthquake wave amplification capacity, almost recorded earthquake occurred not in Nepal only including the border of India, and Tibet affected Kathmandu valley severely [70]. Nevertheless, this valley is ranked first for seismic hazard in the 2001, studyfollowed by Istanbul, Turkey; Delhi, India; Quito, Ecuador; Manila, Philippines; and Islamabad/Rawalpindi, Pakistan [71]. Structural framework and paleo-seismologic studies suggest that east and west of the Kathmandu valley is situated at the transition between 2 seismo-tectonic segments of Himalaya and may be adversely affected by the earthquake in a short time interval so post-disaster management is a crucial issue [72]. On the other hand, Kathmandu valley is one of the fast-growing metropolitan areas in South Asia with the four percent per year. Due to the haphazard and uncontrolled growth of built-up area valley is losing its open space which making most vulnerable cities in the world. The situation is more critical because of unplanned urban development and limited implementation of the building code [7]. In 1934 AD earthquake, Kathmandu valley was severely affected as one-quarter of all building was destroyed including many of the temples in Bhaktapur. Nevertheless, the valley was suffered three of similar size quake in the 19th century: in 1810, 1833 and 1866AD and suggested that earthquakes of this size occur approximately every 75 years [73].

3.1 Gorkha earthquake 2015

In 25th April 2015 at 11:56 NST Nepal struck by a devastating earthquake measuring 7.8 Richter scale with its epicenter in Barpak, Gorkha district around 80 kilometers northwest from capital city Kathmandu -28.2500 latitude and 84.1160 longitudes [74]. Nevertheless, this catastrophic earthquake was followed by more than 550 aftershocks with magnitude greater than 4 within 45 days with four aftershocks had a magnitude greater than 6 including one of major with 7.3 magnitudes on 12 may having an epicenter in Chilankha, Dolakha [75]. 31 district among 75 were directly affect by this earthquake. 14 district within 31 were severely affected whereas remaining 17 were bit less effect. Death toll rate from 31 district was 8046 from 134656600 population and number of injured were 17633 [76]. It caused severe damages to the residential and historical buildings. Around 4,91,620 buildings were fully damaged, 2,69,653 houses were partially damaged, 7,532 school buildings were collapsed whereas around 1,100 health service were destroyed by this earthquake. The total economic loosed value was estimated USD 7 billion and 76% of this loose value represented by the destroyed infrastructure and 24% loosed represent the cost of services and produced goods. This earthquake was the most devastating earthquake in the history of Nepal in eight decades and around one-third of the population of Nepal were directly impacted [12].

3.2 Debris generated by Gorkha earthquake 2015

After Gorkha earthquake, it was estimated that about 18.85 cubic meter of debris accumulated in 31 affected district and about more than 3.9 million tones debris was expected from the earthquake-damaged buildings in Kathmandu valley alone after their demolition. This expected quantity is equivalent to 11 years of waste generated by the valley. Moreover, Solid Waste Management Technical Support Center/ Minister of Urban Development (SWMTSC/MOUD) report shows that there was 3.176 million liters of paints and 33 kg of lead found from the damaged house after Gorkha earthquake. Such materials including battery, mercury is hazardous to health including environment and safety consideration [12]. This serious case of debris seems an alarming issue. Neither the government institution is working on disaster waste nor any clear rules and responsibility exits regarding on disaster waste management in Nepal. Moreover, we have least knowledge and technology for scientifically manage the disaster waste so that it will be environment friendly and socially acceptable. However, this task comes under the ministry of home affairs and solid waste technical support center (SWMTSC). SWMTC is not accomplished in handling the large volume of debris generated due to the limited financial resource, inadequate equipment, and untrained human resource. Immediate after the earthquake the Ministry of Home Affairs (MOHA) was the lead for disaster waste management with rescue army, armed police force, and general police force. On the other hand, the local representative from NGO’s, INGO's, rescue army from India, China, USA, Israel etc. were also participated. This work was parallel with relief and rescue activities. Debris from the demolition of the building during those work collected and storage up on the roadside, lowland areas, private land and riverside etc. [77] But it was found that the dumping of debris was done without any proper segregation. Its effect was not only obstructing to the pedestrians but also increase the air pollution level caused respiratory disease and contamination of water resource [69].UNDP took an incentive for debris management in Nepal after the Gorkha earthquake. A team having 80 Nepali civil engineers worked as UN Volunteers successes to manage debris of 3,000 houses in Sindhupalchwok manually, an estimated

225,000 cubic meter of debris from those private houses was cleared with the coordination with the local community. UNDP replicated this practice in other affected area as well as in public building too [78] But the people of Kathmandu, Lalitpur, and Bhaktapur pay a lot of amount to the contractor to clear the debris of the destroyed buildings which was transported and dumped in nearby suitable place without segregation [79]. Residential building of Nepal generated a large volume of waste per unit area (ton/m^2) compare with Japan and China but the unit area volume in case of the public reinforced concrete building is similar. Different types of building generate different quantities of building waste. During the Gorkha Earthquake, it ranged from 1.9 to 3.23 ton/m^2 in weight and 0.89 to 1.57 m^3/m^2 in volume in Kathmandu Valley [80]. Eight percentage of debris consists of construction materials: bricks, concrete, wood, tin, broken furniture, wires, electronic equipment and another scrap in Kathmandu Valley could be recycled with or without government help. Some people sorted the debris for reusing such as brick, sal wood, CGI sheet due to economic necessity in the absence of government plan after Gorkha Earthquake [81]. The Kathmandu metropolitan city (KMC) used some open space for debris dump and little bit debris such as bricks and other materials from damage structures used to fill potholes and road section. Rubble from damage historical, cultural sites and government building transported in Tundikhel [82]. The core settlement of Kathmandu valley consists the mix of old market centers, traditional private houses, public houses as well as world heritage cultural places and infrastructure that hold the history of originated back to pre Lichachbi period whereas peri-urban settlement consists modern RCC frame structure buildings [9]. The building types in Kathmandu valley are adobe, which was constructed in sun-dried bricks (earthen) with mud mortar, fried brick in mortar , stone in mud mortar , brick in cement mortar , stone in cement mortar , RCC frame structure etc. [83] During the Gorkha earthquake, Kathmandu valley also severely affected. RCC buildings along the ring road found in tilted but most of the damage occurred in masonry building. RCC building around the Gongabu, Sitapaila, Balkhu area were rigorously damaged. Buildings in Sankhu, Khokana and core settlement of Bhaktapur were also seriously damaged [84]. There were 5104 number of buildings in Kathmandu, 3278 number of buildings in Lalitpur, 5950 number of building in Bhaktpur and 788 number of buildings in Thimi were damage from the valley core sector. Likewise 150 number of building in Gongabu from peri-urban sector were damage whereas 25 number of buildings in Gattekulo from densely settled sector were damage. Similarly, 812 number of buildings in Khokana, 503 number of buildings in Panga, 1420 number of buildings in Sankhu and 989 number of buildings in Bugmati were damage from the historical town sector [83]. After the earthquake 2015, A team under the Federal of Contractor Association of Nepal (FCAN) was formed to study the real situation of debris management in historical settlement Taukhel (Machhegaun) of the Chagunarayan municipality as a pilot study. This team consists of the writers, construction management specialists, environmental specialists, and youth Community for Nepalese Contractors (YCNC). In this location, 98 buildings out of 120 were completely destroyed by the earthquake. According to the study, two million Nepali rupees required for debris management in that location. Modality was prepared including five conditions which cover the formation of local disaster management and reconstruction committee, the maximum involvement of local community, monitoring team including local political representative, site selection for debris disposal and 50% of total budget should be from the local level for debris management. 5058 m^3 of debris from the 98 building was managed within 18 days starting from 2072/02/10 and expenditure was only 65% of estimated cost. Initiation of the local community is vital for the debris management, a huge volume of debris can manage with an available small machine with low cost technology. Reusing and recycling of debris are the key factors for debris management. This is the main lesson learned from this pilot study project [12]. It is estimated that around 80-90% of disaster debris could be recovered in Kathmandu valley, because of the difficulties in separation of different waste. This seem a bit more difficult. After separation bricks, wood/timber, and metals could be reused and recycled which covered only a few quantities of whole debris. Per unit waste quantity of residential buildings is higher as compared to the public buildings of the same type because residential buildings consists of smaller rooms. The unit generation rates of different materials in different types of building from the case study of Vyas municipality; headquarter of Tanahu district. It is assumed that 96% of the building types in the Kathmandu valley are represented in this study. It helps to identify the amount of debris of each building including types of debris. The unit generation rates expressed in volume or weight for each building is highly based on its roof and structure type as well as the number of stories. Unit generation rates of debris in terms of volume and weight of different type of buildings with different structural conditions of the same study area is presentedin table (Table-2). These data are very useful to calculate the debris of individual building as well as the whole debris quantity form damage building of required area [80].

Table 2: Quantity of building waste per unit area for different building

S.N.	Building types and stories	Symbol	Building utility type	Building waste per unit		Building waste per unit area	
				Quantity	Quantity	Quantity	Quantity
1	Reinforced concrete; 2 storied	RC 2S	Public	2.01	0.92	1.39	0.64
1a	Reinforced concrete; 2 storied first floor	RC 2S (1F)	Public	2.83	1.28	1.60	0.73
1b	Reinforced concrete; 2 storied 2nd floor	RC 2S (2F)	Public	1.18	0.55	1.18	0.55
2	Reinforced concrete and masonry; 2 storied	RC-M 2S	Public	2.04	0.98	1.45	0.70
3	Reinforced concrete; 1 storied	RC 1S	Public	3.05	1.27	1.18	0.56
4	Reinforced concrete and masonry; 1 storied	RC-M 1S	public	3.04	1.32	1.25	0.62
5	Masonry-CGI sheet roofed (C/S joint); 1 storied	M-C	Public	1.9	0.89	1.39	0.64
6	Reinforced concrete; 2 storied	RC1 2S	Residential	2.97	1.36	2.23	1.03
6a	Reinforced concrete; 2 storied first floor	RC1 2S (1F)	Residential	4.24	1.92	2.74	1.25
6b	Reinforced concrete; 2 storied 2nd floor	RC1 2S (2F)	Residential	1.73	0.82	1.73	0.82
7	Reinforced concrete and masonry; 2 storied	RC-M1 2S	Residential	3.23	1.57	2.34	1.13
8	Reinforced concrete ; 2 storied	RC2 2S	Residential	2.88	1.33	2.23	1.15
8a	Reinforced concrete; 2 storied first floor	RC2 2S (1F)	Residential	4.22	1.93	2.87	1.31
8b	Reinforced concrete; 2 storied 2nd floor	RC2 2S (2F)	Residential	1.62	0.76	1.62	0.76
9	Reinforced concrete and masonry; 2 storied	RC-M2 2S	Residential	2.93	1.43	2.39	1.15
10	Masonry – CGI sheet roofed (C/S joint); 1 storied	M-C1	Residential	2.57	1.22	1.95	0.93
11	Masonry – CGI sheet roofed (C/S joint); 1 storied	M-C2	Residential	2.80	1.33	2.04	0.97
12	Masonry-tile roofed (mud joint); 2 story	M-T(M) 2S	Residential	2.49	1.29	1.84	0.97
12a	Masonry-tile roofed (mud joint); 2 story 1st floor	M-T(M)2S (1F)	Residential	3.49	1.78	2.19	1.13
12b	Masonry-tile roofed (mud joint); 2 story 2nd floor	M-T(M)2S (2F)	Residential	1.52	0.83	1.50	0.80
13	Masonry-CGI sheet roofed (mud joint); 2 story	M-C (M) 2S	Residential	2.45	1.28	1.80	0.95
13a	Masonry-CGI sheet roofed (mud joint); 2 story 1st floor	M-C (M) 2S (1F)	Residential	3.41	1.75	2.11	1.1
13b	Masonry-CGI sheet roofed (mud joint); 2 story 2nd floor	M-C (M) 2S (2F)	Residential	1.52	0.83	1.50	0.80

Source: [80]

Where, 2S-2 stored, 1S-1 storied, 1F- first floor, 2F-second floor, RC-reinforced concrete, RC-M-reinforced concrete and masonry, M-C-masonry and CGI roofed, M-T(M)-masonry and tile roofed (joint in mud mortar), M-C(M)-masonry and CGI roofed (joint in mud mortar)

Unit generation rates in Nepal were projected and found bit more as compared to China in all types of building but it is less than Japan in RC public buildings. More quantity of bricks were used in Nepal, whereas more proportion of concrete and reinforcement is used in Japan and China [80].

In case of Nepal, earthquake debris management has many challenges but more opportunity too. Debris clearance and transport, special waste stream, financial constraint, environmental, Health and safety consideration lack of rules and regulations pertaining to disaster waste management are the major challenges. On the other hand, debris management based on 3R (Reduce, Reuse and Recycle) concept for construction and demolition debris and community initiatives are the opportunity. Debris management based on the 3R concept is one of the best opportunity on it. Recycling, reusing and reducing of disaster waste have major benefits. Construction and demolition debris have all three recycling, reusing and reducing option. Residual debris after this process can be disposed of. Metal and white goods, vegetation, automobiles have both recycling and reduction options, whereas electronic waste has recycling option only. Due to high volume, limited accessibility and diverse nature of deposited debris it is difficult to clearance. Materials from heritage buildings and monuments are the special waste stream. Handling and retaining during repairing of such materials is another major challenge. Availability and mechanism of funding distribution for demolition and debris management are financial constraints for debris management [12].

3.2 Legal framework and available guidelines in Nepal

The Solid Waste Management Rules 2013, The Solid Waste Management Act 2011 and the National Policy on Solid Waste Management 1996 are the relevant rules regarding the debris management but the government has lacked proper guidelines and framework to deal with the the earthquake debris management [84]. The Constitution of Nepal 2015 has a clear provision to formulate sustainable development policy and law to minimize environment decline due to industrial and physical development. It also instructs to form environmental sustainable development policy and law and the implementation of policy related to pre-information, preparedness, relief, and rehabilitation to reduce risk caused by natural disaster. It cannot be found any provision of waste management until seventh National plan, 1991. Waste management was mainstreamed with environment management in Eight National plan 1991 and continued until Thirteen National Plan 2016 [13]. Solid Waste Management Act was formulated in 2011 and focus on solid waste management from source separation to final disposal. This act helps to build capacities of local bodies regarding solid waste management and give the mandate to charge the service fee and punishment to wrongdoers. The draft policy for National Solid Waste Management 1996 predict the participation of the private sector and the public to minimize the waste but did not mention the disaster waste management. This national plan mentions the role of SWMTSC for hazard flow mapping of debris flow during hydrological, metrological hazards and water induced disaster prevention but include the debris management from another disaster. It includes many action plan on disaster reduction except disaster waste management. After the Gorkha earthquake, Nepal Government did rapid emergency rescue based on natural calamity (relief) Act 1982. The act has the clear provision of central, regional, district and local level committee. Afterward, the Earthquake damaged buildings structure demolition (removal) Guidelines 2015 was formulated. But the guidelines have a lack of proper management of disaster waste generated from the demolition of buildings [84]. For proper coordination and implementation of disaster preparedness and response activities an act of National Disaster Response Framework (NDRF), 2013 was formulated. This act is able to explain the role and responsibilities of different stakeholders in disaster risk management and gives the clear role of debris management and animal carcasses management for local bodies but still not clear on role and responsibility on disaster waste management to other stakeholders. Thus, the Disaster Waste management policy, strategy and action plan were formulated under the relevant available policy [13]. United Nations Office for the Coordination of Humanitarian Affairs Environmental Emergencies section, developed disaster waste management guidelines for developing countries [17]. Well known plan for disaster waste management are existed in developed countries such as United States Environmental Protection Agency (USEPA) formulate “Planning for National Disaster Debris” in 2008, Federal and Emergency Management Agency Japan Society of Material Cycle and Waste Management (JSMCWM) etc. [28]. Kathmandu Valley Post- Earthquake Debris Management Strategic Plan, 2014 also estimated the types and volume of debris to be generated in the event of the earthquake of intensity VII-VIII-IX. It was forecast that in the event of earthquake of intensity of VIII in Kathmandu valley there would be accumulated 4,354 million brick waste, 1,046,000 m^3 of sand waste, 2,112,000 m^3 of aggregate waste, 345,000 m^3 of steel waste, 1,278,000 m^3 of timber waste, 4,321,000 m^2 of CGI sheet and other waste would be 211,000 m^3 [7]. Kathmandu Valley Post- Earthquake Debris Management Strategic Plan 2014 has also suggested the open space for such debris management. Bagmati corridor, Oxygenation Park, Balkumari Gwarko, Satdobato and Ekantakuna along Ring Road and Shankha park are the major suggested open space for earthquake debris management [84].

4. Conclusions

Each disaster either manmade or natural generates debris and volume of such debris depends on the built up area and the severity of the disaster. Accumulated disaster debris effects on early response and relief phase to recovery and reconstruction phase if not properly managed. Moreover, this disaster debris waste may create many hazardous problems such as epidemic diseases, contamination of drinking water, clogging of surface runoff etc. Earthquake is one of the major natural disaster, which creates huge amount of debris. Nepal has suffered many devastating earthquake in history, Gorkha Earthquake 2015 is one of them. Due to this earthquake 31 district of Nepal were directly impacted and large amount of debris were accumulated in each affected areas. Due to the lack of proper management strategy, poor coordination among related stakeholders and lack of technology and enough resources, management of such accumulated debris was not managed properly. Earthquake debris has many challenge and opportunities too. 3R (Reduce, Reuse and Recycle) is the key factors for earthquake debris management. Estimating, collecting, transporting, handling and stakeholders are the major component for debris management strategy. Moreover, community mobilization and awareness can play significant role for earthquake debris management in Nepal and similar countries around the world.

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