Appropriate management of earthquake generated waste: Lessons from the 2016 earthquake in Ecuador

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Abstract
The earthquake that hit Ecuador on April 16th, 2016, generated immense devastation to the province of Manabi and created large volumes of debris and waste. This study aims to analyze the lack of a pre-disaster plan that affected the 2016 earthquake waste management. Without an acceptable method, the maker-decisions that faced proximate and fundamental problems fell into turmoil which consequences the disposal of debris confined in makeshift and a low rate of recovery of recycling materials. Data was collected through surveys addresses to total medium and small-sized scrap businesses (n=22) in Portoviejo city in October 2019. In addition, statistical information from public and private agencies was obtained.

The results of this study showed limitations in the 2016 earthquake waste management process such as lack of landfill areas, lack of temporary and final disposal sites and organizational limitations in the recycling process and material recovery. In addition, 2016 earthquake generated approximately 7,561,219.81 m^3 of debris in Manabí, of which 6.9% was in Portoviejo. In the first month post-earthquake, 13,500,000 kilograms of ordinary and hazardous waste in Portoviejo city were collected, of which 20% was reused or recycled.

Keywords: Disaster waste management, Earthquake, Ecuador, Pre-disaster planning, Recycling.

Introduction

Humans have confronted natural disasters throughout history which have detrimental effects on the population, communities and economy. An earthquake occurred in Ecuador's north-eastern Pacific coast on the 16th of April 2016 at a magnitude of 7.8 on Richter's scale and its aftershocks severely damaged six neighbouring provinces: Esmeraldas, Guayas, Manabí, Los Ríos, Santa Elena and Santo Domingo de Los Tsáchilas. Manabí, being the epicentre with a high population density, suffered the worst, particularly in its main cities Portoviejo, Manta and Pedernales. The earthquake resulted in hundreds of human deaths and had devastating effects on healthcare and educational facilities[33] and key infrastructures such as buildings, highways and bridges. Several airports ceased operations, telecommunication services shut down and power system outages affected homes and industries[36].

The earthquake also generated a considerable volume of waste including rubble from damaged houses and buildings, charred materials, concrete and asphalt[9]. National agencies and Provincial Governments cleared debris on emergency access roads to eliminate threats to lives, public health and safety. Temporary roads were built when access to affected areas was vital; however, the cleaning was insufficient.[33]

According to Lorca et al[26], effective waste management must be deployed in two phases: pre and post-disaster. The former focuses on disaster waste management (DWM) strategies to reduce risks if a disaster event occurs. The latter phase focuses on clearing debris from evacuation routes. In addition, responsibilities and administrative procedures are assigned for managing collection and operations related to debris reduction, separation, recycling and disposal.

While such post-disaster waste management was undertaken in the 2016 earthquake, no protocol was present in place to surmount it which explains the unprepared response to the earthquake impact. A month after the earthquake, the protocol proposed did not include clauses related to waste transport, provisional storage sites, strategies for separation and treatment of disaster waste, or disposal or recycling options.

Therefore, this study aimed to determine waste management efficiency in the 2016 earthquake, using Portoviejo, the capital city of Manabí, as a case study. We hypothesise that a lack of DWM planning in Ecuador magnified adverse effects in the earthquake's aftermath. Additionally, we investigated waste management practices developed for the 2016 earthquake in Portoviejo.

Material and Methods

Geographic location of the study area: This study was performed in Portoviejo city, located in Manabí province, Ecuador (Figure 1).

Data collection: First, secondary data were collected by reviewing comprehensive literature encompassing the approved protocol (2016) and the national disaster response plan (2018). Second, semi-structured interviews were held with municipality officials to identify post-earthquake strategies. Third, key documents related to the 2016 earthquake in Ecuador were analysed. These included both published and unpublished documents by Government and non-government organisations. Finally, a questionnaire for collecting information on waste management and recycled waste originating from the 2016 earthquake was prepared.

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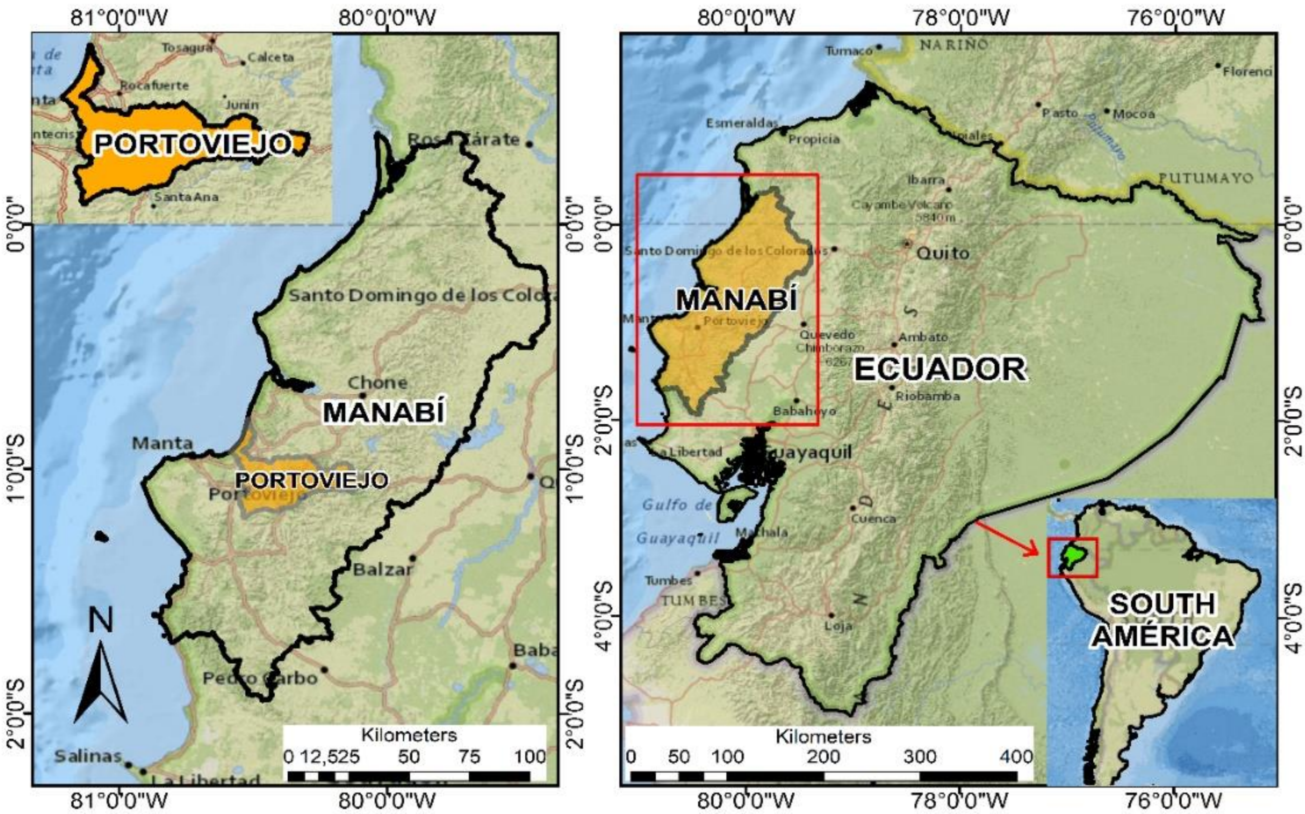

Figure 1: The geographic location of the study area in Portoviejo city, Manabí province, Ecuador [Source: National Geographic, Environmental Systems Research Institute (ESRI), Garmin, HERE, UN Environment Programme World Conservation Monitoring Centre (UNEP-WCMC), United States Geological Survey (USGS), National Aeronautics and Space Administration (NASA), European Space Agency (ESA), Natural Resources Canada (NRCAN.), The General Bathymetric Chart of the Oceans (GEBCO), National Oceanic and Atmospheric Administration (NOAA), Increment P Corporation]

Table 1
Data on the 2016 earthquake waste management and government agencies

Data	**Organization**
Technical Report 2016. Quantity and costs of demolition and removal debris post-earthquake 2016, Phase I.	Ministry of Transportation and Public Works (MTPW)
Technical Report 2017. Quantity and costs of demolition and removal debris post-earthquake 2016, Phase II.	
MTOP 2016 Accountability Report	
Location sites disposal debris approved by MAE	Ministry of Environment of Ecuador (MEE)
Status Report 60 Status Report 63 Status Report 65 Status Report 69 Status Report 71	Risk Management Undersecretaries (RMU)
Household registration for housing reconstruction 2016-2017	Ministry of Urban Development and Housing (MUDH)

The questionnaire-interview in the Decentralised Autonomous Government (DAG) of Portoviejo city, sampling 15 respondents, was pertinent to gather information about the quantity of damaged buildings, demolition costs, pre-existing waste management systems, emergency waste management plans, disaster funding sources, cost of emergency waste collection, transportation, handling and disposal, options of reuse and recycling of disaster waste as well as temporary and permanent waste disposal sites.

We tried to obtain qualitative data from a census conducted for small-and medium-sized scrap dealers (n=22) to identify the level of reuse and recycling of construction and demolition (C and D) materials.

Moreover, we gathered information on the number of recovered materials by inserting four technical information sections: 1) purchase and sale of recovered material, 2) operational costs of recovering recyclable material, 3) reuse of recovered material and 4) recyclable waste management and protocols in case of a disaster.

The results that were surveyed allowed us to infer the recycling potential of different materials and subsequently calculate the total quantity of each material recycled or reused. Furthermore, we reviewed several documents as well as various articles and official technical reports for both fact-checking and supplementing data (Table 1).

Results

Before undertaking a focal analysis for Portoviejo city, some general facts for Manabí province must be presented. Manabí province was the most impacted by the 2016 earthquake. During this process, many buildings were partially or completely ruined structurally. The collapse of most buildings was linked with the type of soil on which they were built.[33,41]

The damage was greater in concrete-multi-storey buildings erected on soft sediment areas than those constructed of wood, or a combination of wood and brick, even when there was no adherence to building codes. In this regard, Penna et al[30] demonstrated that modern masonry buildings built with seismic codes and suitable quality materials achieved good seismic performance in the area affected by the 2012 Emilia earthquake in Italy. The MUDH assessed 66,281 buildings affected by the earthquake, of which only 19,273 were considered safe while 25,986 were declared unsafe and needed major repairs[27]. In contrast, 22,436 buildings were qualified for demolition (Table 2).

The management of disaster waste is a crucial task for post-disaster recovery. The 2016 earthquake weakened many buildings and houses. Subsequently, estimating the required waste-storage capacity, cost and clean-up time were highly improbable. Debris was often disposed of at unofficial sites during the emergency; the total quantity dumped at unauthorised sites in Manabí province is still unknown. Guerrero Miranda and Luque Gonzàlez[20] claim that the debris management after the earthquake was chaotic because the most critical processes for its management were by the criteria of technicians of the local authorities and relevant ministries and there was no unified system for such leadership. Once the disaster occurred, municipalities identified specific sites for dumping rubble.[34]

The management of the massive demolition of faulty buildings in Manabí was challenging for authorities, given the insufficient technical and financial resources[1]. Moreover, waste management was not a top priority in most cantons before the earthquake and DWM plans were non-existent. Consequently, an effective recycling programme was not available at the time. The Ministry of Environment of Ecuador (MEE) partnered with Manabi municipalities to assemble plans for managing debris compliance with environmental regulations.

Additionally, sites were designated to dispose of both ordinary and hazardous waste. A plan to decrease ordinary waste, especially plastic water bottles from shelters and highly populated areas, was also implemented. Ordinary waste was transferred from disaster zones to avoid contamination. Transfers were coordinated so that vehicles returning from humanitarian aid deliveries could transfer plastic bottles and cartons to appropriate sites for elimination. In contrast, hazardous waste was sent to regular disposal sites in each municipal demarcation.

On 26th April 2016, the Committee for the Reconstruction and Productive Reactivation of Employment was created and its functions were assigned accordingly to local entities. With the United Nations Development Programme (UNDP) support, the committee scrutinised demolition and debris removal protocols.

Meanwhile, technical specialists from the MEE identified sites to dispose of demolished waste. Rubble and waste were removed from damaged buildings and roads and disposed of at municipal landfills and makeshift sites. Decimated waste was not sorted during this process.

With UNDP guidance, local authorities implemented an emergency job programme to start the reconstruction process. With the help of 30 families, the UNDP reconstruction of a rural coastal community began in Manabí, prioritising debris management and the remaking of infrastructure to restart local economies.

Table 2
Building status in Manabí post-earthquake 2016

Building status	Total
Fully damaged (collapsed)	22,436
Partially damage	25,986
Undamaged	19,273
Total	67,695

Source: MUDH[27]

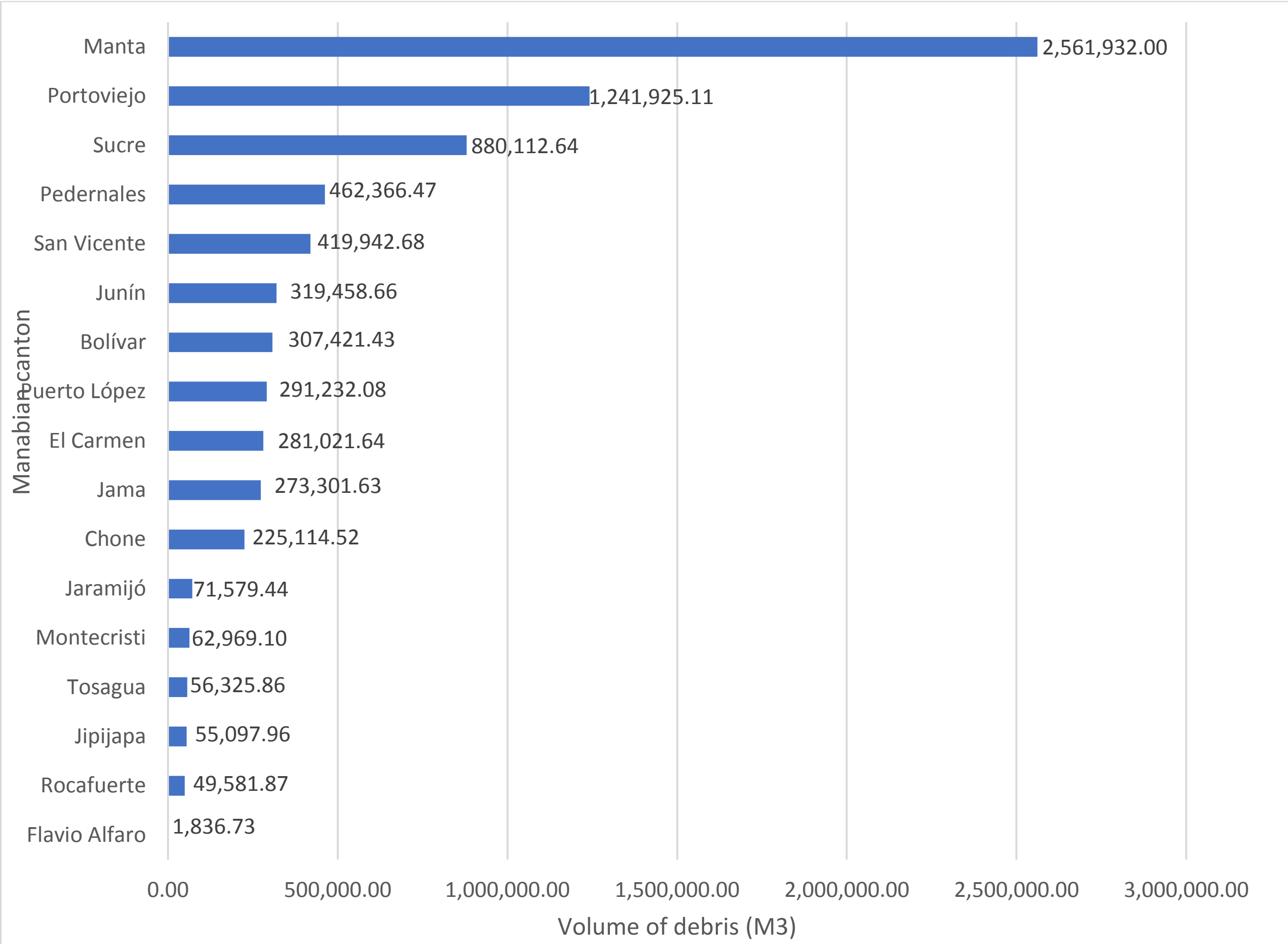

Figure 2: Building-waste generated by the 2016 earthquake per canton in Manabí, Ecuador

However, the UNDP only deployed recyclers with protective equipment at the La Solita landfill of Portoviejo[5]. The UNDP coordinated its activities with the Ministry of Transportation and Public Works (MTPW), MUDH and Cantonal governments. The damage caused to buildings by the 2016 earthquake was so detrimental that more than 140,000 people became homeless overnight. The demolition and clearance of these buildings generated vast amounts of waste (Figure 2). Furthermore, the MTPW reported that 11,472 homes and buildings were annihilated throughout Manabí province.[15,16,29]

Figure 2 shows that the Manabian cantons that generated the most debris were Manta (33.9%), Portoviejo (16.42%), Sucre (11.6%) and Pedernales (6.12%). Most damaged buildings in Manabí were old and built partially or entirely of bricks. Other building materials found in the debris were stone, wood, metal, cement, aluminium, steel and soil. No data are available on the amount of each material generated by post-earthquake demolition.

Portoviejo city case: On 16th April 2016, Portoviejo, the home of a significant percentage of Manabí's population, business and services, witnessed the surge of a natural disaster which interrupted its ordinary life and economic activities. Portoviejo hosts buildings of reinforced concrete frames with masonry infills, steel buildings and houses of traditional construction such as brick[23,40]. Notably, the seismic resilience of wooden houses was higher than that of concrete. However, traditional buildings were affected by a long-standing lack of regular maintenance.

Several landmark buildings were struck significantly. The primary causes of building collapse in Portoviejo were: 1) addition of new stories above pre-existing ones without structural reinforcement, 2) serious structural flaws in buildings such as stiff slabs with slender columns, short columns, deficient detailing of slab-to-column connections, unreinforced masonry infills, unconfined column failures and concentrated masses on upper floors[2,30,31], 3) the pattern between buildings[41] and 4) structural characteristics that led to the construction of ground floors with a height of 5 m with a mezzanine.

The Portoviejo DAG estimated that 1,196 buildings collapsed, or their structures tilted by the 2016 earthquake. In some cases, following the demolition of damaged buildings, housing proprietors and contractors could rescue reusable building materials. A clear picture of the types of materials from the earthquake in Portoviejo (1,241,925.1 kg) is shown in table 3.

Table 3
Percentage of each type of building material found in earthquake debris

Material	Percentage
Masonry	60
Concrete	15
Earth (mud)	10
Metal	10
Wood	5

Source: Analysis results based on municipality officers interview data, 2020

Table 4
Volume and percentage of each component of the recovered waste after the earthquake in Portoviejo city

Material	Kg/month	Percentage
General rubbish	1,627,030	60.01
Cardboard	496,605	18.32
Paper	135,265	4.99
Polyethylene terephthalate (PET Plastic)	149,640	5.52
Home plastic waste	67,420	2.49
High-density polyethylene (HDPE)	23,885	0.88
Polyvinyl chloride (PVC)	8,470	0.31
Low-density polyethylene (PEBD)	13,770	0.51
Bronze	7,036	0.26
Copper	19,705	0.73
Aluminium*	43,532	1.61
Calamine	520	0.02
Aerosol recycling material	205	0.01
Car batteries	35,395	1.31
Steel	4,162	0.15
Copper bronze radiators	9,069	0.33
Copper aluminium radiators	8,809	0.32
Lead recycling material	4,208	0.16
Thermoplastic polymers (from shoes and boots)	5,950	0.22
Glass**	50,409	1.85
Total	2,711,085	100.00

*Aluminium waste is composed of sheets, casts, cans, gutters/sidings, wires, rims and radiators.
**Glass detritus included clear white glass and coloured glass scraps.

Prior to the 2016 earthquake, waste was usually disposed of in a single open dump. Afterwards, the solid waste continued to be dumped in the municipal landfill under emergency conditions. No procedures or controls were devised for this type of dumping until March 2017; however, the municipal authority constructed a new landfill cell with a capacity of 240,000 m^3 to prolong the lifespan of the existing dump[13]. Therefore, all disaster waste went to the pre-existing municipal waste dump. According to the municipal GAD, the most substantial hurdle during the earthquake emergency was interference by informal recyclers during the collection process. However, authorities ordered their collections later. Brown and Milke[7] determined that DWM was only efficient when the activities retrieving materials are envisaged.

Reuse and recycling of earthquake-related waste: A relatively small fraction of the waste was recycled and reused in the cleaning-up phase, providing socio-economic benefits via job creation. Technical personnel from the MTPW office, or its contractors, determined the amount of debris generated, managed the collection thereof in temporary storage sites and made specific disposal or recycling arrangements. Despite efforts of the local government, MEE and MTPW, no records were kept in the volume of each type of waste generated, carried, disposed of, retrieved, or reused. However, some data were gathered from collection and scrap centres on the materials (Table 4).

The waste materials recycled in the post-earthquake period included general rubbish (60%), cardboard (18.32%), paper (4.99%), polyethylene terephthalate (PET Plastic) (5.52%), plastic home waste (2.49%), aluminium (1.61%) and glass (1.86%) (Table 4). Recovery of disaster-related waste was accomplished in four ways: 1) collection at the Portoviejo municipal dump, 2) gathering by informal recyclers from curb side set outs and accumulated PET plastic on streets, 3) collection by municipal employees of solid waste and 4) gathering by informal recyclers from disaster debris at temporary disposal landfill sites and unauthorised sites.

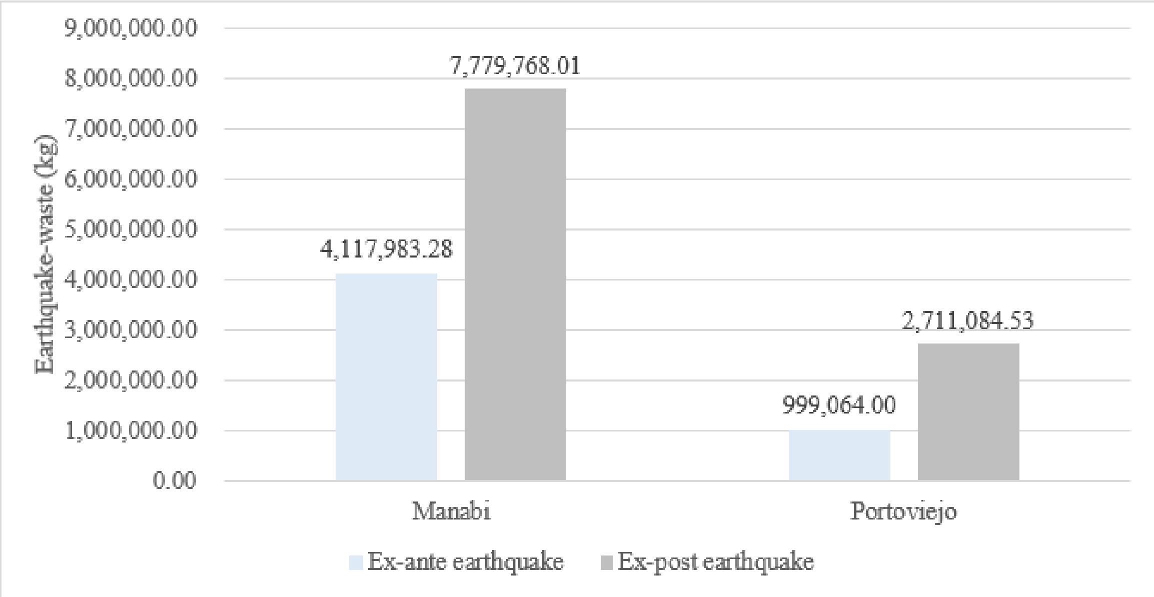

Figure 3: Growing recovered 2016 earthquake-waste scale in Manabi province and Portoviejo city (kg)

Recyclers recovered a portion of ordinary waste in the municipal dump: cardboard, paper, PET plastic, home plastics, high-density polyethylene, low-density polyethylene and aluminium, as well as construction and demolition waste at the temporary disposal landfill sites. Many retrieved materials were sold to small junk shops in Portoviejo city. A few subsidiary recycling centres in Manabí province gathered material, then processed at industrial plants in Quito or Guayaquil. The remaining unrecovered waste was crushed and compacted in each landfill. Concrete was not recycled in Portoviejo but was reused as a backfilling material in discrete quantities or discarded. Building materials such as bricks, stone debris and wood were not reused. In Portoviejo, recycled waste amounted to 2,711,084 kg, representing 34.85% of the total post-earthquake material recycled in Manabí province (Figure 3).

Although waste volume was higher in Manabí province than that in Portoviejo, the latter was nearly three-fold that of the normally generated waste (Figure 3). Among the essential materials retrieved from Portoviejo were scrap metal (37%), cardboard (54%) and recycled paper (51%). The reuse of home appliances, scrap and building materials post-disaster in Portoviejo was 0.2% lower than that in the pre- earthquake period (0.7%), due to the severe damage to certain materials. The benefit of recycling disaster waste lies in its value for use in reconstruction while also providing income to recyclers and their families during the economic recovery period. Therefore, the clause on reuse and recycling must be included in the DWM plan to promote reuse and recycling as much as possible.[4]

Discussion

The DWM scheme implemented throughout the 2016 earthquake was inadequate. Without a plan, participants involved had to learn as they went along but provided more accessible ways to solve proximate problems. For example, under normal conditions, the official glass recycling rates in Germany in 2016 reached 85.5%[38], while in the study case, in post-disaster 2016, recycled glass rated only 1.85% of total material recovered. To increase the rate of material recycling Brown and Milke[7] posited strengthening a disaster waste recycling, programme pre-disaster whereas Crowley[11] appreciates that ex-ante planning benefits disaster management. In other words, the arrangements to effectively manage waste must be in the pre-crisis stage.[25]

Although the disposal of earthquake waste in the Cantons of Manabí province included a few ad hoc sites, illegal dumping of debris continued in various sensitive areas such as the banks of the Portoviejo River. This type of illegal dumping also occurred in the Aceh province of Indonesia after the 2004 tsunami, in which approximately 400,000 m^3 of waste was dumped into rice fields, fishponds and other open areas[42]. Furthermore, after the 2010 earthquake in Haiti, illegal dumping of debris took place on the Rivière Grise[12] and only one site was approved for the disposal of 15 to 19 million m^3 of debris in the entire country due to lack of funds. After the 2016 earthquake in Ecuador, 21 disposal disaster waste sites were designated by the Government. Dumping certainly is not the best practice for sustainable waste management; however, this post-earthquake approach is much more definite in restoring normality as soon as possible.[3]

After an earthquake, cleaning up debris is essential for restoring livelihood. In Ecuador, the reconstruction phase began in 2017, after most damaged buildings had been demolished and its total cost amounted to 3 billion USD[29], which represented approximately 3% of Ecuador's 2016 GDP. The central government spent 92,134,703 USD on the demolition and removal of debris in Manabí, of which 15,133,061 USD (16.43%) was spent on debris removal in

Portoviejo[37]. Furthermore, operating costs for municipal waste management in Portoviejo ranged from 7,049,562.75 USD to 8,291,193 USD. After the earthquake in 2016, a clean-up of debris was accomplished in 11 months.

In developing countries, waste collection and disposal are impromptu tasks[32]. After natural disaster outbreaks, waste management increases management difficulties[19]. United States counties with debris management plans for disasters are efficient in such endeavours[7]. Unfortunately, in 2016 in Ecuador, earthquake disposal of debris occurred at makeshift sites and the status of affected buildings was determined unprofessionally by the responsible technicians. The absence of a DWM plan is a case in point. Otherwise, this would have allowed us to get across rough phases inexpensively and speedily.[7]

In Ecuador, seven types of disaster waste were recovered and recycled—general rubbish, cardboard, PET plastic, paper, home plastic waste, glass and aluminium. The 2016 earthquake generated a volume of scrap concrete that was 15% lower than that of masonry. Therefore, no concrete material was recycled due to insignificant volumes. Improving C and D materials must be a cornerstone of the desirable waste management of natural disasters in the future[17]. In addition, authorities missed the opportunity to recycle building waste. However, a portion of the C and D waste could have been crushed and sized for use as aggregates in low-resistance concrete[22]. Likewise, demolished concrete could be recycled into coarse aggregates for use in structural concrete.[22]

Earthquakes in Mexico (1985, 2003), El Salvador (2000), Peru (2007), Haiti (2010), Costa Rica (2012) and Ecuador (2016) provide examples of downplaying engineering guidelines regarding the earthquake resistance of buildings. For example, approximately 80% of all schools in Port-au-Prince, Haiti, collapsed during the 2010 earthquake[6] and a similar percentage of schools disintegrated in the 2016 Ecuador earthquake. The February 2010 earthquake in Chile was 1.0 Mw stronger than the Ecuador earthquake and killed 340 people[10]. Notably, 663 people were killed in Ecuador primarily due to collapsed buildings.[35]

The amount of waste produced in similar disasters had been higher in other locations than in Manabí; however, the DWM strategy indicated that Ecuador did not deliver with an appropriate protocol. For instance, after the 2011 Great East Japan and 2016 Kumamoto earthquakes, debris was collected and transferred to temporary sites for sorting and recycling, with final disposal at designated landfill sites. After the 1995 Japan earthquake, debris clearance and final removal were conducted primarily in coastal areas[21]. Despite the MEE's quest to find adequate sites for waste disposal after the 2016 earthquake in Ecuador, waste continued to be dumped in unauthorised and impromptu areas and significant gaps remain in DWM. Reuse and recycling including specialised normativity are not simple procedures and guidelines for operative processes should be applied[3]. Separating materials into the appropriate categories is crucial. Residential and disaster debris must be classified. Municipal solid waste and disaster debris should not intermingled[8].

However, in an emergency scenario after an earthquake, authorities must deal with abnormal quantities of debris and waste. Under these circumstances, applying extraordinary waste management methods is necessary. In Ecuador, emergency management was entrusted to the Risk Management Undersecretaries (RMU). The RMU promulgated the National Disaster Response Plan in 2018.

A specific protocol for an appropriate DWM response has not yet been designed. In this regard, the most relevant standard guidelines have been produced by the Federal Emergency Management Agency in the United States[18], the Ministry of Environment in Japan (2011) and the United Nations Office for the Coordination of Humanitarian Affairs[39]. Therefore, the development of local DWM plans should use the international experience.

This study identified some limitations in the 2016 earthquake waste management process such as lack of landfill areas, unavailability of financing resources (funding mechanisms), lack of temporary and final disposal sites and organizational limitations in the recycling process and material recovery. The foresight of waste management plans, resources, robust legislation and clear goals to manage waste effectively and efficiently is recommended[14]. The precarious implementation of prevailing regulations, poor local expertise and capacity standards, inadequate funds and poor coordination are the main challenges in the post-disaster phase[24]. The high rate of recovery/recycling combined with the shortest possible collection time is a crucial factor for correct emergency waste management irrespective of the selected strategy.[19]

Resources available for operational financing dictate the choice of DWM options. Nevertheless, basic information on the typologies of flows and codes for individual waste (e.g. European Waste Catalogue) from developed countries is essential in future emergency planning. In addition, temporary debris storage sites on the entire management chain are a key data source for future emergency planning[19]. Finally, a DWM guide must be created on public and private property demolition of structures, environmental and safety concerns, waste clearance and removal operations, recycling methods, disposal operations, waste management staff responsibilities, contracted services and other related clauses. This guide will become a tool to operate the National Disaster Response Plan, approved in 2018 by the RMU.

Conclusion

Many countries worldwide are grappling with predictions and the threat of earthquakes. The improvement of poor planning and short-sighted government policies, that lead to significant loss of life and increase the destructive effects of such phenomena, is important. In Ecuador, for instance, poor planning and governmental failures exacerbated the harm caused by the 2016 earthquake.

In the aftermath of the earthquake, poor DWM led to technically inadequate landfills that made waste disposal in Portoviejo quite problematic. Currently, recycling is still a marginal economic activity in Manabí and elsewhere. However, recognising that the work of recyclers is necessary for effective waste management is crucial. In almost all instances, small recyclers lack the equipment and space to store the volume of scrap materials required to increase the fraction of recycled materials. For this reason, landfilling is a necessary waste management option. When managing earthquake-related waste, assistance from recyclers is crucial, as separating recyclable materials can be arduous if mixed with waste generated from a disaster. Given the vital role of informal recyclers in post-earthquake clean-up in Ecuador, policymakers should consider formal agreements with recyclers to conform to an inclusive value chain for recycling. Furthermore, protocols to evaluate relative risks of disaster waste processing are also needed.

Although construction codes in the Portoviejo Municipal DAG are mandatory, enforcement has not been consistent. Accordingly, a set of minimum requirements for building design, construction and operation is necessary to protect public health and safety. If correct regulations were in place, more lives could have been saved, reducing the scope of destruction. As data on the quantities of specific materials recovered for recycling is lacking, a registry of recovered materials in landfills and other sites should be created, maintained and permanently updated. This process ensures that recycling becomes an essential part of any embedded DWM culture.

Although the response to the 2016 earthquake was relatively effective, planning for emergency waste management during natural disasters is essential. Beyond operational planning, a strategy for critical points in the decision-making process is required. Although one reason for resistance to planning is the perceived low probability of large-scale disasters, learning from experience improves managing disaster waste. During an earthquake, planning personnel must determine the quantity of the waste generated, gather it in temporary storage sites and select and arrange appropriate disposal or recycling options based on a scheme created in non-disaster times. However, Ecuador currently has few guidelines for selecting management options for these disaster cases. Lessons from the 2016 earthquake event are still waiting to be learnt.

Indeed, the lack of a blueprint during the first 45 days post-earthquake pushed national and local authorities to follow a pragmatic management approach. This study suggests fixing an adaptable protocol suitable for disaster waste management in Ecuador, considering the positive choices such as the high recycling rate in earthquake scenarios and the viability of pre-treatment on temporal disposal sites. Therefore, further research highlighting waste management planning is needed.

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