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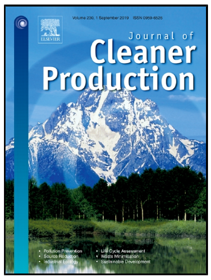


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**A systematic review of recent developments in disaster waste management**

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**Abstract:** Disaster waste management received increasing attention in recent year, but there was no review updating the evolving development after the study of Brown et al. (2011a). To explore how the topics in disaster waste management evolved in recent years and to analyze whether the gaps identified by Brown et al. (2011a) are covered, 82 papers published from 2011 to 2019 were selected from the Scopus database based on the defined process and criteria, to systematically examine the disaster waste management research from nine aspects of planning, waste, waste treatment options, environment, economics, social considerations, organizational aspects, legal frameworks and funding. The results suggested that there were no obvious changes or developments in the field of disaster waste management, although a few research gaps have been addressed, such as waste separation, waste quantities, case studies of incineration and waste to energy, direct economic effects, social considerations as well as application of GIS technology. Except for the comparative studies, future directions were suggested by the gaps that persist since Brown et al. (2011a) and the new gaps that were identified in this review.

**Keywords:** Waste management; disaster context; systematic review

## Contents

## 1. Introduction

Based on the International Disaster Databases (EM-DAT), the total number of natural or man-made disasters has dramatically increased in recent years. As clarified by Brown et al. (2011a), disasters not only caused economic, environmental and social losses, but produced a large amount of waste. For instance, more than 100 million tons of solid waste were produced in hurricane Katrina (Lorca et al., 2017). The Wenchuan earthquake, the Great East Japan earthquake and Canterbury earthquake respectively generated solid waste of more than 380, 27.99 and 8 million tons (Xiao et al., 2012; Domingo and Luo, 2017; Sasao, 2016). Such gigantic amounts of wastes challenge the effectiveness of response and recovery actions (Brown et al., 2011a), which are summarized as the following aspects:

(1) Compared with the municipal waste in "peace time", waste volumes generated in disaster contexts are 5-15 times, and those quantities are difficult to be properly managed by traditional managerial strategies/approaches.

(2) For emergency organizations, road blockage caused by disaster waste poses challenge to access affected area within a short time. Moreover, it may cause other unexpected losses (e.g. affected populations and economic losses);

(3) Waste exposed in affected areas may induce infections, and further threaten public safety and health. In addition to that, poor clearance of disaster waste aggravates the psychological burden (e.g. emotional stress) of victims. In this sense, it has a negative impact on the effectiveness of psychological recovery. Consequently, it is critical to investigate these issues with respect to disaster waste management (DWM).

With respect to DWM, related studies are strongly scattered across different disciplines, methods (e.g. qualitative and quantitative) and fields (e.g. environment science, disaster operations management and management science). Therefore, a clear picture of DWM research is vacant because little prior research focuses on aggregating these literatures systematically. Although, a few earlier literature reviews covered a large number of studies (e.g. Ekici et al., 2009, Brown et al., 2011a), there was no research using the clearly defined processes and criteria to systematically review the relevant literature. As Cook et al. (1997) portrayed it, systematic review synthesized in a transparent and reproducible way are helpful in improving the decision-making and practice of academics and practitioners by the identification of contradictory evidence. This method is a key tool to develop the evidence base, and it is also widely applied in the field of management (Nurmala et al., 2017; Anaya-Arenas et al., 2014).

On the other hand, the need and challenge of DWM research were highlighted by four editorials (Milke, 2011; Periathamby et al., 2012; Taebi and van de Poel, 2015; Denot, 2016). Moreover, DWM was identified as a critical research gap in the field of disaster operations management (Altay and Green, 2006; Galindo and Batta, 2013; Gupta et al., 2016), and was suggested for more attention. Inspired by such recommendations and suggestions, an increasing number of researchers discussed the topic of DWM from several aspects in recent year.

However, since Brown et al. (2011a) presented a comprehensive review before 2010, there is no updated work to summarize the recent studies. Consequently, the purpose of this paper was to *develop an updated systematic literature review using the categories adopted by Brown et al. (2011a) and to present a new "blueprint" of DWM research based on the comparative analysis with the study of Brown et al. (2011a).*

To achieve this goal, an interdisciplinary and systematic review of 82 key papers in a time frame since Brown et al. (2011a) to date (between 2011 and 2019) was conducted, and the inclusion and exclusion criteria of key papers were discussed in subsection 2.3. The methods used were:

Firstly, according to Altay and Green (2006), Gaindo and Batta (2013) and Gupta et al. (2016), descriptive analysis was used from the selected classification scheme, in terms of *chronology of development*, *publication*, *authors' affiliation*, *type of disaster* and *cross tabulation between topic and contribution*.

Secondly, to make a clear contrast with Brown et al. (2011a), the structure of the thematic analysis used was based upon their study. In detail, the content of this DWM research systematically reviewed *planning*, *waste*, *waste treatment options*, *environment*, *economics*, *social considerations*, *organizational aspects*, *legal framework* and *funding*.

Thirdly, compared with research gaps identified by Brown et al. (2011a), the changes and developments of DWM research were summarized in this review.

Fourthly, recommendations for future directions were detailed.

Three contributions were made by the authors of this paper. Firstly, an updated literature review was analyzed here, which tracked recent developments of DWM research. Secondly, an interdisciplinary and systematic review was conducted to present a clear picture of DWM research, which provided basic guidance for both disaster managers and academics. Thirdly, the potential research directions were provided based on the gaps that persist since Brown et al. (2011a) and pertaining to the new gaps which were identified in this review. This provides the foundation for future research.

The remainder of this paper was structured as follows: Section 2 introduced the research methodology. Then, based on Tranfield et al. (2003), descriptive analysis and thematic analysis were presented in Section 3 and Section 4. Particularly, based upon the structure of Brown et al. (2011a), the recent literatures were analyzed from planning, waste, waste treatment options, environment, economic, social considerations, organizational aspects, legal frameworks and funding. Based on the results of comparative studies, the research gaps and future directions were detailed in Section 5. Finally, conclusions and limitations of this paper were included in Section 6

## 2. The Research Methodology

A systematic literature review was employed to analyze the papers covering the DWM research published from 2011 to 2019. Specially, the study of Brown et al. (2011a) provided the benchmark to structure this paper's content. Other sources (not related to DWM) were taken into account, to guide and improve the form and structure of this paper (Abidi et al., 2014; Reim et al., 2015; Annarelli et al., 2016; Calabrese et al., 2018; Altay and Green, 2006; Gupta et al., 2016; Galindo and Batta, 2013).

By definition, a systematic review should present a clear picture of a specific research question in a transparent and reproducible manner (Cook et al., 1997). To improve the validity and reliability, a list of specific steps should be carefully carried out (Leseure et al., 2004). Following the methodology proposed by Tranfield et al. (2003), four main steps (planning, searching, screening and extraction/synthesis/reporting) were used and detailed in the following subsections.

### 2.1 Planning

At the beginning of this review, a review panel (researchers majoring in waste management, disaster management, environment science) was constructed to discuss the research question and the needs of this review. After a detailed discussion, the following research questions (RQs) were defined.

*RQ1. What is the current status of the research on DWM?*

*RQ2. Were the gaps identified by Brown et al. (2011a) covered or not?*

*RQ3. What challenges should be overcome in the future?*

**2.2 Searching**

The inspiration of this paper came from a well-cited work of Brown et al. (2011a) who offered a review of DWM article, published between 1990-2010. To update the status of DWM, the time between 2011 to 2019 (until March 2019) was used for the literature search. The database of Scopus was used as search engine. Scopus is the largest multidisciplinary abstract and citation database of peer-reviewed literature (Geraldi et al., 2011), and both major and minor publishers (e.g. Elsevier, Emerald, Springer and Wiley) are covered in this database. Moreover, Scopus is regarded as one of the most complete databases when it comes to global research, and it is widely used by authors conducting a multidisciplinary systematic literature review (Reim et al., 2015; Calabrese et al., 2018).

Then, a structured keyword's search was conducted to identify the literature and to avoid the unbiased research. In this paper, waste management was the central topic, disaster was the context. Thus, the keywords should be detailed from two aspects, a. waste management, b. the context.

On the one hand, keywords with a focus upon waste management are chosen from Brown et al. (2011a). They emphasized that the term "*debris*" and "*waste*" were widely used by researchers interested in DWM research. In general, the term "debris" describes the largely inert building and vegetative materials, but the latter refers to the entire waste matrix (e.g. vegetative waste, construction and demolition (C&D) waste, toxic chemical and post-disaster municipal waste). Besides, the meaning of word which is similar to "waste" and "debris" were also taken into consideration, such as "*wastage*", "*rubbish*", "*garbage*", "*flotsam*", "*litter*", "*trash*".

On the other hand, inspired by the study of Altay and Green (2006) and Gupta et al. (2016), the disaster context was described by the term "*disaster*", "*natural hazards*", "*emergency crisis*" and "*catastrophe*". Additionally, according to Gupta et al. (2016), DWM was closely associated with humanitarian logistics. Therefore, the term "*humanitarian*" was also used as a search word.

Based on the search process used, 1764 papers were identified as potentially relevant. Table. 1 displays the results of searching based on the selected keywords.

**Table. 1 The results of searching with different keywords for relevant papers for this literature review**

| Keywords | *Disaster* | *Catastrophe* | *Natural hazards* | *Emergency crisis* | *Humanitarian* | Total |
|---|---|---|---|---|---|---|
| *Waste* | 565 | 34 | 309 | 39 | 40 | 987 |
| *Debris* | 403 | 19 | 149 | 4 | 9 | 584 |
| *Wastage* | 22 | 3 | 6 | 1 | 1 | 33 |
| *Rubbish* | 2 | 2 | 5 | 1 | 0 | 10 |
| *Flotsam* | 4 | 0 | 2 | 0 | 0 | 6 |
| *Litter* | 37 | 4 | 36 | 0 | 1 | 78 |
| *Trash* | 11 | 2 | 6 | 4 | 2 | 25 |
| *Garbage* | 16 | 1 | 18 | 2 | 4 | 41 |
| **Total** | | | | | | 1764 |

### 2.3 Screening

To guarantee the fidelity and completeness of this review, the related papers were carefully reviewed by four researchers according to the inclusion and exclusion criteria (Table. 2), although, some subjectivity was inevitably involved in manual scrutiny of the papers, engaging four researchers helped to improve the objectivity of the screening process (Galindo and Batta, 2013).

As Table. 2 Presented, inclusion and exclusion criteria used for selecting papers under five categories: *document type*, *language*, *availability of full text*, *subject* and *disaster contexts*. According to the criteria, the process of screening was:

During the first screening, given that DWM is still an emerging topic (Gupta et al., 2016; Galindo and Batta, 2013) and a few meaningful research gaps mentioned by Brown et al. (2011a) were only discussed in conference papers, the journal and conference papers published in English were selected. Although the use of conference papers is uncommon in systematic literature reviews, due to the quality of papers (Reim et al., 2015), there were some conference papers considered into a systematic review. (Boehm and Thomas, 2013; Calabrese et al., 2018).

To further identify and select the most suitable papers, another two criteria about subject and disaster were analyzed. In terms of subject, the selected research concentrated on investigating the waste/debris management in disaster contexts. Usually, the effects of disaster on waste/debris management was emphasized in their studies. In contrast, some researches who addressed a specific technology, unsuitable waste management results in disasters and peace-time waste management were excluded. Regarding disaster contexts, it was difficult to judge whether an event was a disaster (Galindo and Batta, 2013). For example, can an airplane crash or a fire in a factory be considered as a disaster? To solve this challenge, the principle proposed by Galindo and Batta (2013) was adopted and detailed in Table. 2.

**Table. 2 The following inclusion and exclusion criteria were used for selecting relevant papers for in-depth analysis**

| Aspect | Inclusion criteria | Exclusion criteria |
|---|---|---|
| *Document type* | Journal paper and conference paper. | Book chapter, editorial and comment. |
| *Language* | All papers in English. | Other languages, such as Chinese and Japanese. |
| *Availability of full text* | Available | Not available |
| *Subject* | 1. The Central topic was waste management | 1. Central topic is a specific technology, such as microbial biotechnology, architecture design, geotechnical engineering and material technology (especially construction materials). |
| | 2. Focus on the effects of a disaster on waste management. | 2. Focus on a disaster resulted from unsuitable waste management. |
| | 3. Select key words with a focus upon debris management. | 3. Keywords is management of debris-flow. |
| | 4. Concentrate on waste generated from disasters, especially municipal waste in disaster contexts was included. | 4. Peace-time waste management. |
| *Disaster contexts* | The focus of the papers on disruptive community disruptions which can seldom be solved by using local resources. Therefore, external resources are needed such as in giant earthquakes. (Galindo and Batta, 2013) | The event did not seriously disrupt the community, and was easy to be solved by local resources, did not require participation of non-local agencies, such as airplane crash and resultant contaminated drinking water. (Galindo and Batta, 2013) |

After the review process was completed, 74 papers were selected for further analysis. According to Reim et al. (2015), the literature selected by keywords can be used as a secondary source of literature analysis. This led the authors select eight additional papers that contributed to DWM research. Therefore, 82 papers were selected for this systematic literature review, based on the searching and screening process. Fig. 1 outlined the process of locating, studying and evaluating papers.

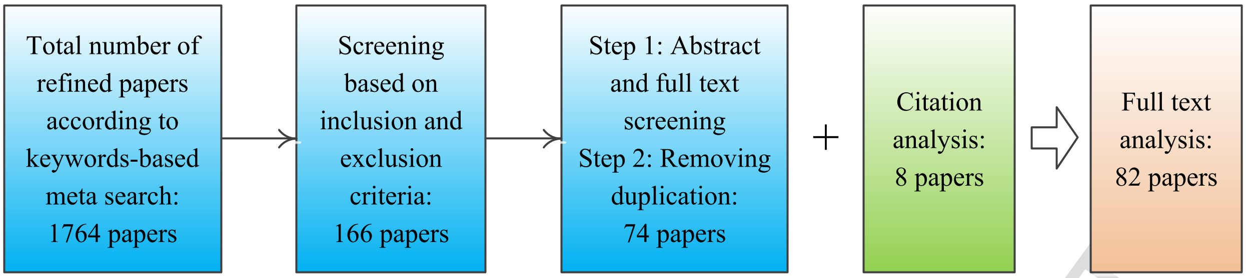


**Fig. 1 Process of locating, studying and evaluating the papers**

### 2.4 Extraction, synthesis and reporting

A good systematic review relies on a clear reporting of the selected papers. In general, a two-stage report including descriptive analysis and thematic analysis is necessary (Tranfield et al., 2003). Some authors refer to descriptive analysis as meta-analysis and statistical analysis, which provides a brief overview of a specific topic. Inspired by the well-cited studies of Altay and Green (2006) and Galindo and Batta (2013), papers subject to 'descriptive analysis' were analyzed from five aspects: a. chronology of developments, b. publication (e.g. journal paper and conference paper), c. authors' affiliation (e.g. developed country and developing country), d. type of disaster (e.g. general, earthquake, tsunami, hurricane, landslide, flood, bushfire, thunderstorm and man-made disaster), e. cross tabulation among contributions (e.g. theory, model and application) and topics (e.g. outline of DWM, plans/strategies of DWM, location of DWM site, identification of disaster waste as well as quantities of disaster waste).

Because the authors of this review article focused on updating the work of Brown et al. (2011a). Therefore, the thematic analyses were analyzed from: "planning", "waste", "waste management options", "environment", "economics", "social consideration", "organizational aspects", "legal frameworks" and "funding".

## 3. Results of the descriptive analysis of the selected papers

In this section, 82 papers were classified from five aspects: a. the chronology of developments, b. the mainstream journals in which they were published, c. the major authors' affiliations, d. the most mentioned disaster types, e. the important topics as well as their contributions in the field of DWM.

### 3.1 The chronology of developments in the DWM

To document the trends in the number of papers published on DWM, the analysis method used by Gupta et al. (2016) of the number of papers published each year, and by the method used by Sanders and Manfredo (2006), which was based upon two-year moving averages.

Table 3 presented the moving average beginning in 2012. The number of papers showed a continuously upward trend from 2013 and reached the highest point at 18 in 2016. The two-year moving average in 2017 was 16.5 (the highest compared with the previous year), which was due to the papers published in 2016 (eighteen) and 2017 (fifteen). Although the slightly downward trend was showed from 2017, the number of papers published still indicates that there is a growing attention to the DWM research (Compared with papers published before 2015).

**Table 3**. **The number of selected papers reviewed by year**

| Year | Number | Two-year moving average |
|---|---|---|
| 2011 | 5 | - |
| 2012 | 7 | 6 |
| 2013 | 3 | 5 |
| 2014 | 4 | 3.5 |
| 2015 | 10 | 7 |
| 2016 | 18 | 14 |
| 2017 | 15 | 16.5 |
| 2018 | 12 | 13.5 |
| 2019 | 8 | 10 |
| **Total** | 82 | - |

### 3.2 Publication

Motivated by Annarelli et al. (2016), the targeted papers were reviewed by publication, to identify the mainstream journals and their research fields. Table 4 reported the list of journals and conferences. In regard to journals, the top three journals with the number of papers included: Waste Management (eleven), the International Journal of Disaster Risk Reduction (nine), Resources, Conservation and Recycling (four). Additionally, Natural Hazards, Socio-Economic Planning Sciences, the Journal of Material Cycles and Waste Management, the Journal of Cleaner Production and Sustainability, each published, three of the selected papers.

Based upon these results, those observations were made: (1) Clearly main-stream of waste management researchers invested a special attention to DWM. Many papers were published in Waste Management, which was influenced by the editorials published in that journal in 2011 and 2016 (Milke, 2011; Denot, 2016). (2) Although nine papers published in the International Journal of Disaster Risk Reduction, DWM research received limited attention from the academics concentrating on disaster management, which may have resulted from the special attention to disaster response issues and strategies (Gupta et al., 2016). Regarding the subject areas covered by each journal, these observations were made: (1) It was clear that DWM research was closely linked to the environmentally-related areas, such as environmental sciences and environmental studies. (2) Given that earthquakes generated a large quantity of C&D wastes, the related issues were widely discussed in the area of Engineering. (3) Remarkably, in the field of Operations Research and Management Science, DWM was treated as a reverse logistics system to investigate the traditional problem of logistic management (e.g. location of temporary storage site, allocation of resources and inventory management of processing site).

**Table 4. The number of papers selected for in-depth analysis for this review article according to journals and conferences**

| Journal and conference | Subject area | Number |
|---|---|---|
| *Waste Management* | Engineering, Environmental; Environmental Sciences | 11 |
| *International Journal of Disaster Risk Reduction* | Geosciences, Multidisciplinary; Meteorology & Atmospheric Sciences; Water Resources | 9 |
| *Resources Conservation and Recycling* | Engineering, Environmental; Environmental Sciences | 4 |
| *Natural Hazards* | Geosciences, Multidisciplinary; Meteorology & Atmospheric Sciences; Water Resources | 3 |
| *Socio-Economic Planning Sciences* | Economics; Management; Operations Research & Management Science | 3 |
| *Journal of Material Cycles and Waste Management* | Environmental Sciences | 3 |
| *Journal of Cleaner Production* | Engineering, Environmental; Environmental Sciences; Green & Sustainable Science & Technology | 3 |
| *Sustainability* | Environmental Sciences; Environmental Studies; Green & Sustainable Science & Technology | 3 |
| *Disaster Prevention and Management* | Environmental Studies; Management; Public, Environmental & Occupational Health | 2 |
| *Waste Management and Research* | Engineering, Environmental; Environmental Sciences | 2 |
| *Landscape and Urban Planning* | Ecology; Environmental Studies; Geography; Geography, Physical; Urban Studies | 1 |
| *Biosecurity and Bioterrorism - Biodefense Strategy Practice and Science* | International Relations; Public, Environmental & Occupational Health | 1 |
| *Australian Journal of Emergency Management* | - | 1 |
| *Operations Management Research* | Management | 1 |
| *Journal of Civil Engineering and Management* | Engineering, Civil | 1 |
| *International Journal of Applied Earth Observation and Geoinformation* | Remote Sensing | 1 |
| *Environmental Science and Technology* | Engineering, Environmental; Environmental Sciences | 1 |
| *Natural Hazards and Earth System Sciences* | Geosciences, Multidisciplinary; Meteorology & Atmospheric Sciences; Water Resources | 1 |
| *International Journal of Emergency Management* | - | 1 |
| *Transportation Research Part B - Methodological* | Economics; Engineering, Civil; Operations Research & Management Science; Transportation; Transportation Science & Technology | 1 |
| *Disasters* | Planning & Development | 1 |
| *International Journal of Urban Sciences* | - | 1 |
| *Operations Research* | Management; Operations Research & Management Science | 1 |
| *Expert Systems with Application* | Computer Science, Artificial Intelligence; Engineering, Electrical & Electronic; Operations Research & Management Science | 1 |
| *Engineering Construction and Architectural Management* | - | 1 |
| *Jurnal Teknologi* | Engineering, Civil; Engineering, Industrial; Management | 1 |
| *Science of the Total Environment* | Environmental Sciences | 1 |
| *Memoirs of the Faculty of Engineering* | - | 1 |
| *EURO Journal on Computational Optimization* | - | 1 |
| *International Journal of Environmental Science and Technology* | Environmental Sciences | 1 |

**(Continued)**

| Journal and conference | Subject area | Number |
|---|---|---|
| *ISPRS Journal of Photogrammetry and Remote Sensing* | Geography, Physical; Geosciences, Multidisciplinary; Imaging Science & Photographic Technology; Remote Sensing | 1 |
| *Clean Technologies and Environmental Policy* | Engineering, Environmental; Environmental Sciences; Green & Sustainable Science & Technology | 1 |
| *Plos One* | Multidisciplinary Sciences | 1 |
| *Journal of Environmental Science and Technology* | - | 1 |
| *Renewable and Sustainable Energy Reviews* | Energy & Fuels; Green & Sustainable Science & Technology | 1 |
| *Geomatics Natural Hazards and Risk* | Geosciences, Multidisciplinary; Meteorology & Atmospheric Sciences; Water Resources | 1 |
| *Production and Operations Management* | Engineering, Manufacturing; Operations Research & Management Science | 1 |
| *Global Journal of Environmental Science and Management* | - | 1 |
| *Journal of Environmental Management* | Environmental Sciences | 1 |
| *Spatial Information Research* | - | 1 |
| *Risk Analysis* | Mathematics, Interdisciplinary Applications; Public, Environmental & Occupational Health; Social Sciences, Mathematical Methods | 1 |
| *Computer-Aided Civil and Infrastructure Engineering* | Computer Science, Interdisciplinary Applications; Construction & Building Technology; Engineering, Civil; Transportation Science & Technology | 1 |
| *Transportmetrica A - Transport Science* | Transportation; Transportation Science & Technology | 1 |
| *International Journal of Urban and Regional Research* | Geography; Planning & Development; Urban Studies | 1 |
| *Conference* | - | 5 |
| | | Total: 82 |

### 3.3 Authors' affiliation

Brown et al. (2011a) argued that DWM research was seldom performed by scholars from developing countries. To analyze whether that tendency persisted or not, the number of papers reviewed by country of the academic's affiliation was shown in Table 5.

**Table 5. The number of papers according to the developed and developing country affiliations of the authors.**

| Affiliation | Country | Number | Affiliation | Country | Number |
|---|---|---|---|---|---|
| *Kyoto University* | Japan | 4 | *Rochester Institute of Technology* | USA | 1 |
| *Kobe University* | Japan | 4 | *Dogus University* | Turkey | 1 |
| *The University of Melbourne* | Australia | 4 | *UNEP International Environmental Technology Centre* | Japan | 1 |
| *University of Moratuwa* | Sri Lanka | 3 | *Pacific Northwest National Laboratory* | USA | 1 |
| *Universiti Teknologi Mara* | Malaysia | 3 | *Universidade Federal do Rio de Janeiro* | Brazil | 1 |
| *Middle East Technical University* | Turkey | 2 | *Muroran Institute of Technology* | Japan | 1 |
| *Islamic Azad University* | Iran | 2 | *Pontificia Universidad Católica del Perú* | Perú | 1 |
| *University of Canterbury* | New Zealand | 2 | *Chulalongkorn University* | Thailand | 1 |
| *Radford University* | USA | 2 | *University of Engineering and Technology Lahore* | Pakistan | 1 |
| *Hanyang University* | South Korea | 2 | *Toyo University* | Japan | 1 |
| *Western Carolina University* | USA | 2 | *National University of Singapore* | Singapore | 1 |
| *Shanghai Maritime University* | China | 2 | *Università Politecnica of Marche* | Italy | 1 |
| *University of Florida* | USA | 2 | *International Solid Waste Association Austria* | USA | 1 |
| *Kyushu University* | Japan | 2 | *Seoul National University* | South Korea | 1 |
| *University of Bologna* | Italy | 2 | *Iwate University* | Japan | 1 |
| *Okumura Corporation* | Japan | 1 | *Hokkaido University of Education* | Japan | 1 |
| *Pontificia Universidad Católica de Chile* | Chile | 1 | *Academy of Military Medical Sciences* | China | 1 |
| *Indian Inst Management Rohtak* | India | 1 | *Programme of Biomedical Science* | Malaysia | 1 |
| *Universite du Quebec a Montreal* | Canada | 1 | *Taean Environmental Health Center* | South Korea | 1 |
| *University of Waikato* | New Zealand | 1 | *Tokyo Metropolitan University* | Japan | 1 |
| *University of Padova* | Italy | 1 | *Northern Illinois University* | USA | 1 |
| *University of Hawaii at Manoa* | USA | 1 | *Tongji University* | China | 1 |
| *Purdue University* | USA | 1 | *University of Brescia* | Italy | 1 |
| *Shanghai Jiao Tong University* | China | 1 | *Harvard University* | USA | 1 |
| *National Geospatial-Intelligence Agency* | USA | 1 | *Shenzhen University* | China | 1 |
| *Bilkent University* | Turkey | 1 | *University of Paris Est – Marne la Vallee* | France | 1 |
| *Yeditepe University* | Turkey | 1 | *Korea Environment Institute* | South Korea | 1 |
| *Resilient Organisations* | New Zealand | 1 | *Kyungpook National University* | South Korea | 1 |
| *Tohoku University* | Japan | 1 | *Louisiana State University* | USA | 1 |
| *Massey University* | New Zealand | 1 | | | |
| | | | | | Total: 82 |

It was found that twenty-six papers (31.7%) were published by academics from developing countries, and 68.3% of the papers were published by scholars from developed countries, with the criteria of developing/developed countries according to the Human Development Reports (United Nations, 2018). These results showed a shift from those reported by Brown et al. (2011a), although the authors from developed countries still published a higher percentage of the papers than the authors from developing countries.

### 3.4 Disaster type mentioned in the selected papers

Disaster waste closely depend upon the type of disaster (Brown et al, 2011a). After careful scanning, the authors of this review found that a few authors discussed waste management in various disaster contexts (Tabata et al., 2017; Wakabayashi et al., 2017; Asari et al., 2013; Koyama et al., 2016; Pramudita and Taniguchi, 2014). Therefore, the total number of papers reviewed by disaster type was 89. From Table 6, some observations were made: (1) About 37% papers (Thirty-three) analyzed DWM in the context of earthquakes, which may result from easy identification and quantification of C&D wastes. (2) Apart from earthquakes, other disaster types were not deeply discussed, especially in the context of man-made disasters. (3) General studies indicate that many of the paper's author (twenty-two) paid no attention to different disaster contexts. However, the DWM research is still in its early stage. Too many generalizations are less likely to guide the practical and future research in any particular situations. A similar viewpoint was also suggested to focus on the specific disaster contexts (Brown et al., 2011a; Gupta et al., 2016).

**Table 6. The number of papers reviewed by disaster type**

| Type | Literature | Number |
|---|---|---|
| *General* | Brown and Milke (2016), Takeda et al. (2015), Trivedi et al. (2015), Brown et al. (2011a), Grzeda. et al (2014), Yusof et al. (2016), Crowley and Flachsbart (2018), Kim and Hong (2017), Crowley (2017), Francesco et al. (2018), Regattieri et al. (2018), Boonmee et al. (2018), Otsuka and Katsumi (2015), Wang et al. (2019), Ozdamar et al. (2014), Lesperance et al. (2011), Zawawi et al. (2018), Yoo et al. (2017), Zawawi et al. (2015), Maryono et al. (2015), Caniato et al. (2016), Regattieri et al. (2016) and Baek et al. (2016); | 23 |
| *Earthquake* | Sasao (2016), Asari. et al (2013), Tabata. et al (2017; 2016), Xiao et al. (2012), García-Torres et al. (2018), Berktas et al. (2016), Çelik et al. (2015), Sahin et al. (2016), Domingo and Luo (2017), Karunasena and Amaratunga (2016; 2015), Shibata et al. (2012), Kawamoto and Kim (2016, 2019), Faleschini et al. (2017), Onan et al. (2015), Wakabayashi et al. (2017), Askarizadeh et al. (2016), Saffarzadeh et al. (2017), Hu and Sheu (2013), Raila and Anderson (2017), Poudel et al. (2018), Cheng et al. (2018a), Karunasena et al. (2012), Pham et al. (2014), Askarizadeh et al. (2017), Sakai et al. (2019), Pramudita and Taniguchi (2014), Memon (2015), Zhang et al. (2016), Hooper (2019) and Koyama et al. (2016); | 33 |
| *Tsunami* | Asari et al. (2013), Prasetya et al. (2012), Tabata et al. (2017), Wakabayashi et al. (2017), Pereira-Portugal and Lee (2016) and Koyama et al. (2016); | 6 |
| *Hurricane/Typhoon* | Fetter and Rakes (2011; 2012), Habib. et al (2017; 2019), Kim et al. (2018), Lorca et al. (2017), Fetter and Rakes (2013), Hu et al. (2019), Jiang and Friedland (2016), Thompson et al. (2011) and Szantoi et al. (2012); | 11 |
| *Landslide* | Tabata et al. (2017) and Wakabayashi et al. (2017); | 2 |
| *Flood* | Leader et al. (2018), Pramudita and Taniguchi (2014), Phonphoton and Pharino (2019), Saat et al. (2016), Tabata et al. (2018), Kim and Kim (2017) and Beraud et al. (2012); | 7 |
| *Bushfire* | Cheng and Thompson (2016), Cheng et al. (2019) and Brown et al. (2011b); | 3 |
| *Thunderstorm* | Cheng et al. (2018b); | 1 |
| *Man-made disaster* | Aoki (2018), Noh et al. (2015) and Zhang et al. (2017). | 3 |
| | | Total: 89 |

### 3.5 Cross tabulation between topic and contribution

Once a researcher investigates the detail of DWM, a clear question/topic is necessary. Moreover, they need to design a suitable artifact (e.g. theoretical framework, mathematical model and application) as their contribution to analyze a detailed question (Altay and Green, 2006; Galindo and Batta, 2013). Therefore, cross tabulation between topics and contributions was analyzed by the authors of this literature review. Particularly, given that the input data was abstracted from the potential and occurred disasters (Anaya-Arenas et al., 2014), the time phases of the disasters were divided into two categories (e.g. pre-disaster and post-disaster), although the time phases are ambiguous and difficult to be defined (Anaya-Arenas et al., 2014; Gupta et al., 2016). From Table 7, the following results were found: (1) Only one paper addressed the development of DWM in 2011

(Brown et al., 2011a). After that, there was no literature review to analyze the evolving status. (2) Over 40 percentage of studies (thirty-six) were implemented within a theoretical framework. In detail, strategies, plans and policies of DWM were highlighted in the pre-disaster research. Usually, after a disaster, case studies were used to summarize the experiences of DWM and to discuss the organizational issues. (3) Mathematical models (e.g. mathematical programming and graph theory) were widely adopted to optimize the performance of the DWM system in the post-disaster period. However, similar methods were rarely used in pre-disaster research. (4) Post-disaster research received special attention (69 papers, 84.4%), while only 12 papers (14.6%) focused upon pre-disaster waste management. The same proportions were also documented by Crowley (2017). (5) It should be noted that new technologies (e.g. high-resolution aerial imagery and 3D spatial information) is used to estimate the volume of disaster waste (Szantoi et al., 2012; Yoo et al., 2017).

**Table 7. The number of papers reviewed by cross analysis between contribution and topic**

| Item | Topic | Theory | Model | Application | Number | Total |
|---|---|---|---|---|---|---|
| - | Outline of DWM | Brown et al. (2011a); | - | - | 1 | 1 |
| *Pre-disaster* | Strategies, plans and policies of DWM | Crowley and Flachsbart (2018), Yusof et al. (2016) and Zawawi et al. (2015, 2018); | - | - | 4 | 12 |
| | Factors that impact the success of a DWM plan | Trivedi et al. (2015) and Crowley (2017); | - | - | 2 | |
| | Location of DWM site | - | - | Grzeda et al. (2014); | 1 | |
| | Quantities of disaster debris | - | Tabata et al. (2016); | - | 1 | |
| | Capacity building for DWM | Karunasena and Amaratunga (2015, 2016); | - | - | 2 | |
| | DWM and its effect | - | Wakabayashi et al. (2017); | - | 1 | |
| | Integrated issues | - | - | Askarizadeh et al. (2016); | 1 | |
| *Post-disaster* | Identification/separation of disaster debris | Shibata et al. (2012); | - | Jiang and Friedland (2016), Pham et al. (2014) and Zhang et al. (2016); | 4 | 34 |
| | Estimation of disaster debris | Tabata et al. (2018); | Poudel et al. (2018); | Koyama et al. (2016), Szantoi et al. (2012), Thompson et al. (2011), Garcia-Torres et al. (2017), Yoo et al. (2017) and Benjamin et al. (2011); | 8 | |
| | Dispersal of disaster debris | - | - | Prasetya et al. (2012); | 1 | |
| | DWM and its effect | Phonphotopn and Pharino (2019), Aoki (2018), Raila and Anderson (2017), Noh et al. (2015), Caniato et al. (2016), Beraud et al. (2012) and Baek et al. (2016); | Cheng et al. (2018a; 2018b) and Tabata et al. (2017); | Faleschini et al. (2017); | 11 | |
| | Treatment (option) of disaster waste | Brown and Milke (2016); | Sasao (2016); | Portugal-Pereira and Lee (2016), Regattieri et al. (2016, 2018) and Leader et al. (2018); | 6 | |
| | Allocation of resources (e.g. facility) | - | Fetter and Rakes (2011, 2013); | - | 2 | |
| | Location of facility, temporary storage site and processing site | - | Wang et al. (2019); | Cheng and Thompson (2016); | 2 | |

**(Continued)**

| **Item** | **Topic** | **Theory** | **Model** | **Application** | **Number** | **Total** |
|---|---|---|---|---|---|---|
| *Post-disaster* | Route planning of debris clearance | - | Çelik et al. (2015), Cheng et al. (2019), Takeda et al. (2014), Berktas et al. (2016), Pramudita and Taniguchi (2014), Hu et al. (2019) and Sahin et al. (2016); | - | 7 | 35 |
| | Organizations of DWM | Kawamoto and Kim (2016; 2019), Saat et al. (2016), Maryono et al. (2015) and Hooper (2019); | - | - | 5 | |
| | Experience of DWM (case study) | Sakai et al. (2018), Karunasena et al (2012), Domingo and Luo (2017), Memon (2015), Lesperance et al. (2011), Kim and Kim (2017), Saffarzadeh et al. (2017), Francesco et al. (2018), Zhang et al. (2017) and Brown et al. (2011b); | - | - | 10 | |
| | Integrated issues | Xiao et al. (2012) and Asari et al. (2013); | Lorca et al. (2017), Hu and Sheu (2013), Onan et al. (2015), Habib and Sarkar (2017), Boonmee et al. (2018) and Habib et al. (2019), Fetter and Rakes (2012), Kim et al. (2018) and Ozdamar et al. (2014); | Otsuka and Katsumi (2015) and Askarizadeh et al. (2017); | 13 | |
| **Total** | - | 36 | 26 | 20 | 82 | |

## 4. Results of the thematic analysis

Since 2011, there were no reviews to update the development of DWM research and to analyze whether the research gaps identified by Brown et al. (2011a) are addressed or not. Therefore, building upon their work, the structure of the thematic analysis was organized from nine aspects: *planning*, *waste*, *waste treatment options*, *environment*, *economics*, *social considerations*, *organizational aspects*, *legal frameworks* and *funding*, to compare our findings with theirs. Especially, their research gaps were listed in front of each subsection. The comparison between research gaps and the recent studies were discussed at the end of this section.

### 4.1 Planning

**Research gaps**: (1) The existing plans focused on technical interventions but ignored the guidance on decision making in different disaster contexts; (2) There were no guidance documents that could be readily applied to other developed countries, especially regarding the establishment of effective organizational, financial and legal structures for DWM; (3) Plans of DWM seldom existed in developing countries.

Based on the documents with regard to "Planning for disaster debris" and "Planning for natural disaster debris" (USEPA, 1995; USEPA, 2008), planning generally are associated with the overview, events and assumptions, debris collection strategy, roles and responsibilities, debris management sites and contracted debris operation (Corwley and Flachsbart, 2018). As Crowley (2017) noted, pre-disaster plans contributed to rapid waste clean-up. However, the lack of enforced plan was commonly identified as a capacity gap in DWM practice, in developed countries (Sakai et al., 2019; Domingo and Hao, 2017) and developing countries (Karunasena et al., 2012; Zawawi et al., 2018).

To analyze the reason why such a conflicting situation commonly existed, Brown et al. (2011b) did an interview with disaster managers. They analyzed three possible reasons as: the perceived difficulty in planning for the unknown, the low probability of such large-scale disasters and the success of DWM practice (implemented without a plan). Similarly, Maryono et al. (2015) identified the top four factors which impacted the intentions of preparing for DWM, such as awareness of the difficulty with regard to running a program of reduction, reuse and recycling, awareness of cooperation with other stakeholders, concerns about previous experience as well as awareness of the insufficiency of facility.

**Conclusion:** In recent year, the planning of DWM is still limited in both developed and developing countries, and there is no obvious development in planning for DWM. Thus, research gaps identified by Brown et al. (2011a) is not well covered. Moreover, planning for DWM seems not received by disaster managers in practice, but the reason why the situation exist is not clear.

### 4.2 Waste

**Research gaps**: (1) The nature of disaster waste was widely investigated from the perspective of disaster type. However, other viewpoints (e.g. the nature of the built environment being impacted, the level of hazards and ability to recycle) were rarely discussed; (2) The method to measure, calculated and estimated the waste quantities was not explicitly stated, although lots of authors reported the data of waste quantities; (3) Although a few estimation methods may be transferred between contexts, actual waste quantities were less likely to be transferred. In other words, the general method to estimate waste in different disaster contexts was absent; (4) Compared with the estimation method retrospectively quantified disaster waste following disaster events, the evaluation models for predicting the quantities of waste were limited.

#### 4.2.1 Waste composition and separation

Given that the nature of disasters is closely associated with disaster contexts, the type of disaster is widely adopted for separating waste at the early stage of DWM research. For example, C&D waste received an increasing attention by researchers interested in earthquake waste management (Domingo and Luo, 2017; Karunasena et al., 2012), while vegetative waste or green waste was widely discussed in the case of hurricane waste management (Lorca et al., 2017; Thompson et al., 2011). The large number of studies concentrated on waste which was directly caused by the disasters, especially earthquake caused waste.

However, the indirect impact of disasters on waste management was rarely reported in the papers, although the corresponding waste management is also of great significant. For example, waste related to evacuation shelters (e.g. plastic packaging waste of food and water) was highlighted as an important issue in the Great East Japan Earthquake (Asari et al., 2013). Besides, electronic waste received a special attention because of the high risk of health and environmental consequences, although the proportion of electronic waste is very small (Leader et al., 2018). Moreover, in the period of humanitarian aid, healthcare waste was treated as a separate category due to the hygiene concerns (Caniato et al., 2016).

Although the nature of disaster waste was well identified by disaster type, the nature of the building environment was also called for future research (Brown et al., 2011a). Due to differences of geographical location (e.g. internal and coastal area) and urbanization level (e.g. industrial and urban), significant differences were observed in the types and quantities of disaster waste, and, also, in the management approach (Francesco et al., 2018). Therefore, it is necessary to analyze the nature of disaster waste from different perspectives. After a widely reading of papers, the method of waste separation was concluded from two viewpoints regarding affected area and level of hazards.

**Affected areas.**

Given the main differences of population densities, building structures (e.g. masonry and masonry-frame structures are typical in rural area, but concrete-frame structures are common in urban area) and lifestyles, Hu and Sheu (2013) and Xiao et al. (2012) respectively investigated the urban- and rural- generated waste in Wenchuan earthquake, and they suggested the considerable different solutions for Chinese DWM practice. Tabata et al. (2017) identified two types of waste (e.g. costal- and inland- generated waste) and discussed the diverse solutions to reduce the negative impact of environment and economy.

**Level of hazards**.

Given that exposures to hazardous wastes results in high risk of public health, managing such materials is of great significant, especially in disaster contexts (Zhang et al., 2017; Kim and Hong, 2017). For example, (1) Wood is widely used for construction, and it is often treated by hazardous materials (e.g. lead, arsenic and creosote) to protect wood from fungi and termite attack (Dubey et al., 2007; Baek et al., 2016). Unfortunately, once a disaster occurs, the damage to such wood will lead to a negative impact on ecological sustainability. To achieve the safe management of such a hazardous material, Kim and Hong (2017) analyzed the solutions in term of quantification of waste volumes, technologies and policies for safe management or disposal of the waste. (2) Zhang et al. (2017) noted that the frequency of the occurrence of man-made disasters (e.g. nuclear events and hazardous materials spill) pose significant challenges to human beings. They critically investigated the effectiveness of environmental management systems which are based on the case of the Tianjin warehouse explosion. The explosion occurred on 12 August 2015 resulted in 165 dead and more than 800 injured people. Fortunately, the environment was well monitored and controlled by sound management of toxic chemical and post-disaster solid waste.

Similarly, Lesperance et al. (2011) argued that the recent DWM plan did not address the management of waste containing chemical, biological and radiological materials. They identified numerous challenges in properly managing the related wastes (e.g. anthrax waste). (3) Humanitarian aid and health care are inextricably linked (Raila and Anderson, 2017), and the frequent exposure of health-care waste poses potential public health risks and aggravates the psychological burden of victims. However, health-care waste management is a big challenge for low- and middle- income countries owing to obsolete technology and shortage of funds (Caniato et al., 2016). To reduce the potential risk of public health and to minimize the negative impacts on climate change, Caniato et al. (2016), Raila and Anderson (2017) and Zhang et al. (2017) discussed the related policies, estimated the waste volumes and designed the DWM system.

**4.2.2 Waste quantities**

Risk prevention and reconstruction planning depend on the development of methodologies with respect to waste quantities (Garcia-Torres et al., 2017). Moreover, under- and over- estimation of waste volumes would result in a high level of costs during the period of DWM (Lorca et al., 2017). Therefore, accurate prediction/estimation of waste volumes is helpful in performance improvement and cost reduction. Based upon the review of relevant papers on waste quantification, two types of methods are used: a. mathematical model, b. technology-based analysis tool, to estimate the waste volumes.

The mathematical models use mathematical notation and logic to describe the relationships among types of disasters, severity of the disasters (e.g. magnitudes of earthquake and strength of hurricane), type of wastes (e.g. buildings and trees) and characteristic of disaster waste (e.g. density of buildings/trees/population, tree height, location of buildings/forests and age of buildings), and then to use the inventory data, so as to estimate the waste volumes (Pham et al., 2014; Askarizadeh et al., 2017; Askarizadeh et al., 2016; Poudel et al., 2018; Thompson et al., 2011; Garcia-Torres et al., 2017). Such a method can be used not only to estimate the data of waste volumes in the aftermath of a disasters, but also to predict the potential waste generation in the period of pre-disaster (Tabata et al., 2016; Tabata et al., 2018).

A second type of approach to estimate the quantities of diverse types of wastes associated with disasters are automatic detections and estimations of waste volumes analyzed by high-resolution satellite and aerial imagery (Pham et al., 2014; Jiang and Friedland, 2016; Koyama et al., 2016;

Szantoi et al., 2012; Saffarzadeh et al., 2017). This method provided an quick evaluation of damages, especially in a large areas and the collapsed infrastructure which may not be detected at ground level (Pham et al., 2014). However, the accuracy of aerial imagery weakened by the difficulty of distinguishing the shadow between collapsed buildings/trees and other urban features (e.g. fences). Additionally, the shadows of standing trees and unaffected buildings could also be inaccurately assessed as damage due to their shapes and colors (Pham et al., 2014; Szantoi et al., 2012). Moreover, when the method was used to estimate tree debris, it was hard to identify the downed branches and the small diameter trees which also contributed to total waste quantities (Szantoi et al., 2012).

**4.2.3 Waste management systems**

Given that systems for management of disaster wastes are always difficult, time-consuming and expensive, the modeling of DWM systems is of urgently needed (Cheng et al., 2018). As Lorca et al. (2017) noted, DWM operation are regarded as humanitarian logistics activities. The system of DWM could be described as a reverse logistics system according to Hu and Sheu (2013) who explored the traditional problem of logistic management (e.g. location of temporary storage site/processing site, transportation and route planning, as well as allocation of resources), which provides quantitative decision-support tools for DWM practice from a reverse logistical perspective. In general, such systems were formulated by a mathematical programming model which included objective functions, constraints and decision variables (Hu and Sheu, 2013; Habib et al., 2019; Fetter and Rakes, 2012).

Firstly, the selection of temporary storage sites and processing sites is the main location problem in the period of DWM (Wang et al., 2019; Cheng and Thompson, 2016). In detail, the decision variable is whether to establish a waste processing site in location, a or b or c. Certainly, allocation of facilitates must be simultaneously considered in making the waste processing location decision (Habib and Sarkar, 2017). That decision must also be used in allocating human resources and vehicles, storage of the wastes as well as processing of them.

Decisions also need to be made about if the wastes are to be incinerated, landfilled, or recycled (Boonmee et al., 2018). Generally, the support models are designed to help to achieve the goal of cost minimization, and they are also limited to constraints based on the actual disaster contexts. Cheng and Thompson (2016) summarized 55 constraints from the perspectives of environmental, social-cultural and economic-engineering with special foci upon: distance from surface water, land use, distance from residential areas, land slopes and roads, which are the top five criteria considered in previous research.

Secondly, given the distributed characteristics among the affected areas, temporary storage sites, processing sites and markets, an effective routes planning contributes to implementation of disaster operations management (Sahin et al., 2016; Takeda et al., 2015; Pramudita and Taniguchi, 2014). Route planning refers to performing analyses about which routes to use for transportation, to collect and to transport wastes from certain areas in the shortest time. Thus, minimization of travel and waiting time are integral to planning the routes. Also, the total time will be affected by the priority of critical nodes (e.g. school and hospital), the busy degree of roads (e.g. daytime and nighttime), the incomplete information of roads and road blockages (Berktas et al., 2016; Hu et al., 2019; Celik et al., 2015; Sahin et al., 2016). Particularly, the potential damage to roads was considered into the design of route planning, which addresses the gap with respect to the ignorance of stochastic behavior in disaster operations management.

Although many researchers investigated the optimized DWM system in a certain disaster context, uncertainties and risks were not well considered in the design of waste management system. To deal with this problem, uncertainties and risks influence the reliability of DWM systems which must be tested by the relationships between system capacity and waste generation (Cheng et al., 2018a; Cheng et al., 2018b). Additionally, several authors emphasized the importance of the roles of simulations of different waste management scenarios, which can be used to provide decision-support inputs for improving the resilience of DWM systems (Kim and Kim, 2017; Kim et al., 2018).

**Conclusions:** (1) Compared with the previous studies regarding waste separation, authors of recently published papers are beginning to address the impacts of disaster contexts (e.g. affected areas and the types and levels of hazards) on waste management, although general studies are still common; (2) The measurement methods of waste volumes were highlighted and reported on by many researchers. The waste measurement methods can be divided into mathematical modeling and technology-based analysis approaches. It should be noted that GIS technology (e.g. high -resolution satellite and aerial image) is widely used in estimation of quantities and locations of post-disaster wastes. However, the prediction of disaster waste is still absent. In addition to that, tools to detect the dispersal of waste is limited (Prasetya et al., 2012), especially tree debris in the context of hurricanes and wastes in the entire coastal area of affected regions; (3) This review of DWM systems contributes highlighting how to improve DWM decision-making.

### 4.3 Waste treatment options

**Research gaps**: (1) Location and management aspects of temporary staging sites should be investigated by more future research; (2) There was no quantitative method to assess the preparedness, feasibility and effectiveness of waste recycling; (3) Waste-to energy was an emerging topic which received some attention but there was no review of the success of these initiatives; (4) The practice of open burning was not specially analyzed after a disaster; (5) The actual environmental impacts of land reclamation and disaster disposal sites were absent.

Due to the consideration of cost-efficiency, environmental protection and minimization of psycho-social impact, waste treatment options are closely associated with the efficiency of disaster responses and disaster recoveries (Tabata et al., 2017; Lorca et al., 2017). Based on the classification developed by Brown et al. (2011a), waste treatment was analyzed from fives aspects: a. temporary storage, b. recycling, c. open burning, d. landfilling and e. waste-to-energy.

**Temporary storage**

Temporary storage was one of the most important approaches for the management of disaster wastes. Such storage often serves as an intermediate point to store wastes which will be transported to incineration plants, recycling areas and landfill sites. In order to cope with the challenge of considerable amounts of waste in a large-scale disaster, two levels of temporary sites can be established (Tabata et al., 2017; Sakai et al., 2019).

In detail, the primary 'temporary storage site' must serve to store wastes for a limited time and they often located near the affected areas. In contrast, the secondary sites must be designed to store large amounts of waste in locations further away from the affected areas, the residential zones and the pollution-prone district (FEMA, 2007). It is important to note that decisions about the selection of locations of temporary, secondary and other waste management facilities, are influenced by many constraints, which are addressed in the subsection of waste management systems.

**Recycling**

As an eco-friendly waste treatment option, recycling is beneficial for recovery of economic value from recovery of materials, for recovery of energy, for job creation and for reduction of landfill space used (Brown and Milke., 2016) and can result in cost reductions (Fetter and Rakes, 2012). The papers by Regattieri et al. (2016), Regattieri et al. (2018) and Faleschini et al. (2017) provided data on successful experiences of recycling materials from disaster-related solid wastes. Unfortunately, few authors documented that recycling is widely used in DWM practice.

For example, due to the lack of professional knowledge (Karunasena et al., 2009) and lack of sufficient funds (Karunasena and Amaratunga, 2015), large quantities of reusable and recyclable materials continue to be disposed of in landfills and or via incineration, especially in developing countries (Brown and Milke, 2016). Besides, over aggressive recycling can be counterproductive, and can increase the total costs (Fetter and Rakes, 2012).

Consequently, it is necessary to design a quantitative method to help disaster waste managers to decide when to recycle and how to perform a well-functioning recycling system. Authors Brown and Milke (2016) provided guidance to waste managers by analyzing the feasibility of successful recycling (e.g. volume of waste, degree of mixing of waste, human and environmental health hazards, areal extent of waste, community priorities, funding mechanisms and regulations) and effectiveness of recycling in a qualitative way.

**Open burning**

As Brown et al. (2011a) noted, open burning was strictly prohibited in some countries and regions, which resulted from the bad impacts of toxic gases on the environment and upon public health. However, many authors stated that incineration had a greatly positive impact on performance improvement of DWM, especially in a time-pressure situation (Asari et al., 2013; Sasao, 2016). Also, after a comparation analysis among several waste treatments approaches, more incineration plants were suggested to achieve the rapid disaster response actions (Lorca et al., 2017; Kim and Kim, 2017).

**Landfilling**

Thanks to the efficiency of disposing of disaster wastes (e.g. cost reduction and rapid disposal), landfilling has been widely adopted by disaster managers, especially in developing countries. The application of such treatment relies on a suitable space (e.g. land near to lakes and rivers may not be used for landfills), landfill capacities, safety of materials, classification treatment and well-planned project of DWM (Lorca et al., 2017).

**Waste-to-energy**

This approach can be an eco-friendly waste treatment method which produces liquid fuels (e.g. FT-Diesel) and electricity with the help of advanced technologies (e.g. Combined heat and power, Gasification and Fischer-Tropsch), although high costs and the accessibly of the advanced technology should be considered (Portugal-Pereira and Lee, 2016). The application of high-quality waste-to-energy systems in Japan provided successful examples that confirmed their benefits for management of disaster-related wastes as well as on-going management of municipal wastes. Also, such cases address some of the gaps identified by Brown et al. (2011a).

**Conclusion:** In this subsection, the research gaps (e.g. no specific case of open burning and waste-to-energy, ignorance of environmental effects of landfill, as well as the limited research with regard to the location of temporary storage site) what were identified by Brown et al. (2011a) were extensively and effectively addressed by Portugal-Pereira and Lee (2016), Tabata et al. (2016) and Wakabayashi et al. (2017). However, the quantitative method to assess the feasibility and effectiveness of waste treatment was not adequately addressed in any of the papers include in this literature review.

### 4.4 Environment

**Research gap**: No author attempted to quantify the environmental impacts of altering peace-time waste management standards to manage disaster wastes.

Disasters and environment are inextricably linked (Brown et al., 2011a). Disaster operations management is closely associated with the environment, especially in managing the disaster waste (Galindo and Batta, 2013). For example, carbon emissions from transportation (Tabata et al., 2016), pollution generated from incineration and landfilling (Wakabayashi et al., 2017), the risks of waste exposure (Hu and Sheu, 2013) and environmental effects of temporary storage and disposal (Lorca et al., 2017) were considered as environmental aspects for which there are urgent needs to minimize the negative impacts of the disaster -related wastes and to therefore, to protect humans and the environment.

To provide useful guidance for decision-making, environmental aspects were generally tested by three methods. Firstly, based on life cycle assessment, indicators concerning $CO_2$, SOx, NOx and PM emissions were used to test the environmental effects of various activities (Wakabayashi et al., 2017; Tabata et al., 2016). In research published by Hu and Sheu (2013), the author used risk analysis to examine the environmental effects of waste collection, processing, transportation and disposal. Similarly, Lorca et al. (2017) investigated the environmental effects via environmental costs which were estimated by local governments. Based on their study, environmental effects can be measured, and are compared with the economic effect and psychological cost, which provided an effective decision-support tool for balancing the conflicts among economic, environment and psychological burden. Obviously, those two methods were based upon a strong subjectively, although they seemed to be practical for DWM practice within a limited time.

**Conclusion:** Environment effects were effectively estimated by different methods. Unfortunately, there is still no research which investigates the environment impacts of changing peace-time waste management standards and practices to improve management of disaster-related solid wastes.

### 4.5 Economics

**Research gap**: The economic impacts (both direct and indirect) of DWM programs was limited.

Cost efficiency is always highlighted in managing disaster waste. Direct economic effects (Fig. 2) are related to the process of DWM (e.g. waste identification, collection, separation, storage and transportation), and the costs are generally captured within transportation costs, classification costs, storage costs, treatment costs, disposal costs and potential returns from recycling (Lorca et al., 2017; Hu and Sheu, 2013; Fetter and Rakes, 2012; Tabata et al., 2016), to measure and optimize the total direct costs of DWM. Apart from direct economic effects, the fixed costs of opening a temporary site were also considered (Lorca et al., 2017; Wang et al., 2019).

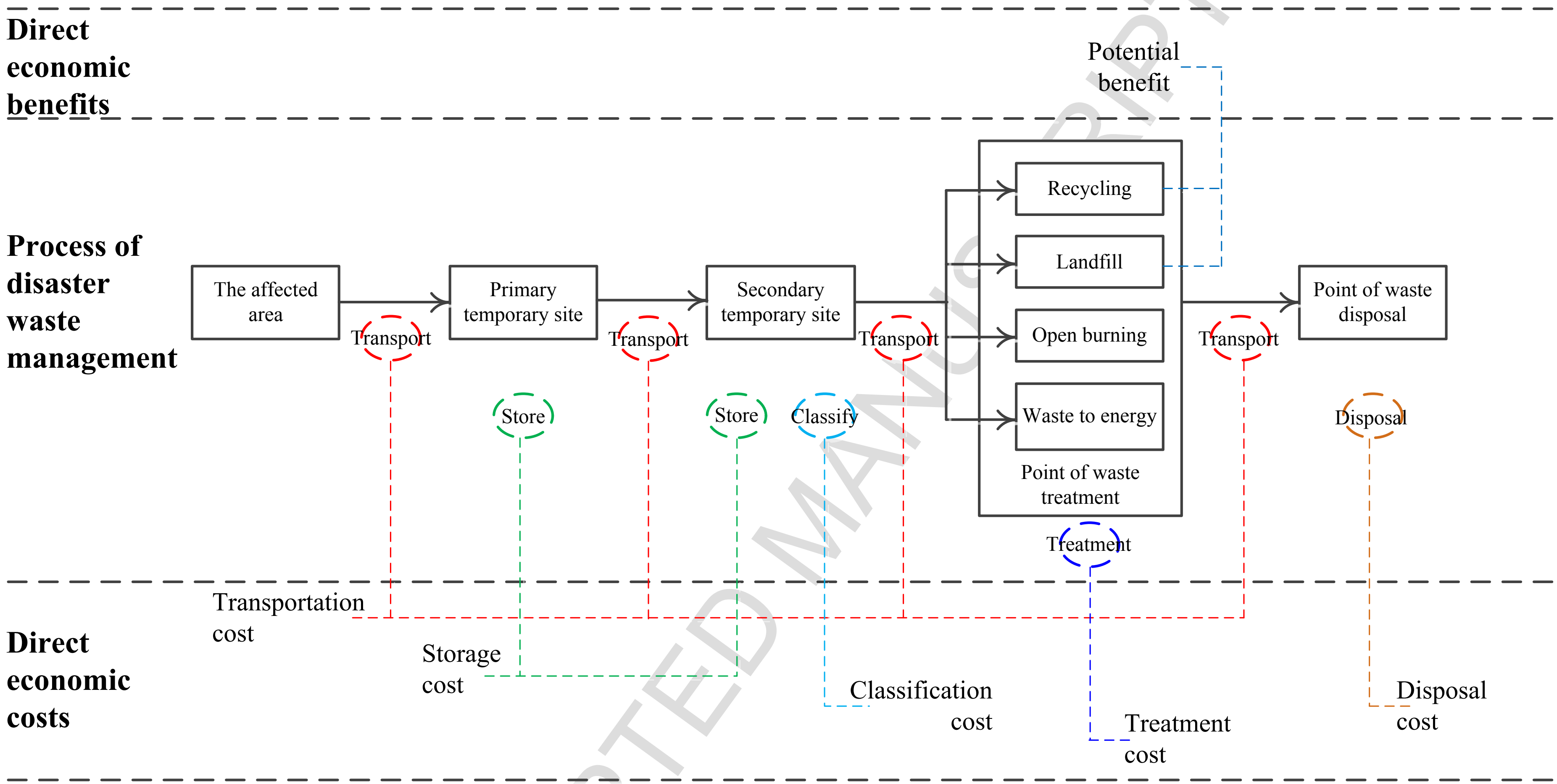


**Fig. 2 Direct economic effect of DWM which should be considered in the DWM programs**

Indirect economic effects are also of great significance, which can be divided into costs and returns. On the one hand, the sustainable development of affected area is always influenced by the indirect costs regarding disruption of critical infrastructure, risk to public health, delays of waste disposal and rebuilding, as well as road blockages. On the other hand, job opportunities (Habib et al., 2019), development of new technologies (Portugal-Pereira and Lee, 2016) as well as expansion of business scope of transportation enterprises (Hu and Sheu, 2013) were regarded as indirect economic returns.

**Conclusion:** Compared with the previous studies, direct economic effects were well measured, while the measurements of indirect economic effects were still limited.

### 4.6 Social considerations

**Research gaps**: Research on social considerations (both qualitative and quantitative) was limited, especially the impact of DWM on community recovery and a post-disaster community behavior on the functioning of the program of DWM.

Motivated by Hu and Sheu (2013) and Brown et al. (2011a), the social considerations were discussed from the perspectives of the victims, employees and the communities.

**Victims**

Rapid post-disaster waste cleanup is closely associated with psychological recovery because of the awareness of available social support, which is more important than the reconstruction of building and infrastructure (Hu and Sheu, 2013). In detail, anxiety and stress accumulate within societies after long time waiting periods, which results in a deep sense of frustration due to wasted time and uncertainty about when something will be done to 'solve' the problems.

**Employees**

The authors of one article addressed employees, although many workers, managers and volunteers participated in waste cleanup processes. The social consideration was captured by the anxiety of vehicle drivers and debris treatments workers (Hu and Sheu, 2013). The worker anxiety was different from the negative emotions of the victims, more broadly, who had to wait and wait for service systems to be established and implemented.

**Communities**

The potential risks to the public health was highlighted by residents near to waste disposal sites, especially those sites responsible for managing hazardous materials. By means of oxidative stress biomarkers, Noh et al. (2015) verified that there was a significant relation between long-term cleanup and threats to human health. Similarly, waste generated from the Fukushima nuclear exposure incident was rejected by numerous residents due to consideration of safety, especially families with children four years old or younger (Aoki, 2018). Indeed, an inappropriate disposal of disaster waste may result in resistance of residents. But if done properly (e.g. guarantee the safety of waste disposal, increase the perceived benefit, improve the credibility of the government and communicate with residents) (Aoki, 2018; Brown et al., 2011a), the operational rate of DWM (especially quality change) can be significantly improved by a cooperative network among the community's members (Kawamoto and Kim, 2016).

**Conclusion:** The ignorance of post-disaster community behavior is well addressed in a qualitative way. However, how to quantitatively measure the social considerations is still limited, although Hu and Sheu (2013) employed the waiting time to test the emotions of anxiety and stress.

### 4.7 Organizational aspects

**Research gaps**: (1) The organizational structures were not critically discussed in literature; (2) No author critically investigated what factors should be considered in the organizational design of the physical works associated with disaster waste program; (3) The effect of pre-arranged contracts and rates with contractors were absent; (4) There was little data on suitable GIS technologies and their effectiveness.

In this context, 'organization' is defined as human resources to manage the activities of DWM. Not only professional groups (e.g. government, non-profit organization and military) but also individual teams (e.g. volunteers) are involved (Karunasena and Amaratunga, 2016; Kawamoto and Kim, 2016; Kawamoto and Kim, 2019). Regarding organizations, no single organization is capable of addressing the uncertainties of disasters and being able to provide the coordinated efforts required to aggregate them. If not addressed properly, the suffering of the affected populations and the losses of property may be increased and prolonged (Dubey and Altay., 2018). Not surprisingly, linkages and collaborations (focus on building partnership with external organizations) as well as communication and coordination (concentrate on internal coordination) were highlighted (Karunasena and Amaratunga, 2016) in the process of DWM. However, the method regarding how to achieve the coordination (e.g. coordinated network and coordination mechanism) was not addressed.

Moreover, Brown et al. (2011b) contended that the roles and responsibilities of organizations were unclear as a result of the temporary establishment of coordination, especially when the pre-disaster plan was absent. A similar viewpoint was presented by Hooper (2019) who stated that the establishment of professional organization was necessary.

**Conclusion:** Organizational aspects are still not well discussed by researchers.

### 4.8 The legal frameworks

**Research gap**: The existing regulations were often unclear to what degree and in what circumstance legal or regulatory relaxations are acceptable. In other words, the legislation was inconclusive and gave no guidance on future use of legal waivers.

Based on this literature review, the recent development of legal framework can be divided into two types. On the one hand, the unavailability of enforceable legislation is often highlighted in practice of DWM, especially in developing countries (Karunasena et al., 2012; Yusof et al., 2016; Memon, 2015). On the other hand, in developed countries and a few developing countries, the official documents were composed by governments, to guide the management of DWM, such as "Planning for Disaster Debris", "Planning for Natural Disaster Debris" and "Public Assistance: Debris Management Guide", "Guidance of Disaster Debris Management", "Japan Society of Material Cycles and Waste Management" and "National Solid Waste Management Strategy" (USEPA, 1995; USEPA, 2008; The Central People's Government of the People's Republic of China, 2008; Crowley and Flachsbart, 2018; Asari et al., 2013).

Compared with the results of Brown et al. (2011a), there has been progress in the development documents pertaining to the legal frameworks. However, the documents were designed to serve to provide guidance for DWM practice, therefore, the requirements stated in the documents were not legally enforceable (USPEA, 2008; The Central People's Government of the People's Republic of China, 2008).

Additionally, the documents, due to their ambiguous statements, they played limited roles in practice. For example, given the conflicts between environmental protection and cost reductions, situations for when the adoption of open burning is appropriate led to difficulties of decision-making (Wakabayashi et al., 2017; Lorca et al., 2017; Karunasena et al., 2012). Also, it was difficult to select the optimal location of waste disposal sites because of challenges associated with environmental justice or injustice (Allen, 2007). As Brown et al. (2011a) reported, the ambiguous statements may be caused by a lack of adequate details and to cases in recent documents, which resulted in managerial confusion.

**Conclusion:** Although there was increasing attention by authors of papers reviewed for this review, the establishment of legislation, the related regulations should be expanded, clarified and enforced within more detailed cases.

### 4.9 Funding

**Research gap**: The effective mechanisms (private, public and insurance) for funding DWM in different disaster contexts was absent.

Funding plays a fundamental role in allocation of resource during disaster contexts, although humanitarian aid was usually treated as non-profit activities. Karunasena et al. (2009) and Karunasena et al. (2012) argued that the sufficiency of funds was closely associated with the acquirement of the required technology and equipment, and it determined the difference between successful and failed DWM (Saat et al., 2016). However, the lack of fund was generally identified as a major barrier (Memon, 2015) because of the conflicts between fund-provider and fund-receiver. On the one hand, for fund-receivers, they often complained that there was no strict law to protect their financing behavior, which leads to their inability to obtain sufficient funds within a short time (Fetter and Rakes, 2012). Under such circumstances, they usually have to choose the cost-efficient treatment (e.g. open burning and landfill) to clean up disaster waste. On the other hand, fund-provider contended that they were willing to provide more funds, so long as the receiving organizations provide a detailed implementation plan. Unfortunately, the detailed plan (e.g. planning for recycling) was not provided by the anticipated fund-receiver (Crowley and Flachsbart, 2018).

**Conclusion:** Although funds were identified as a big challenge for DWM, the effective financial mechanism was still absent.

### 4.10 Summary

To answer whether the research gaps identified by Brown et al. (2011a) were covered or not, the contents of Table. 8 present the detailed results of the literature reviewed for this article.

Following Table. 8, Results indicated that there are no obvious changes or developments in the field of DWM, although a few research gaps have been well addressed, such as waste separation, waste quantities, case study of incineration and waste to energy, directly economic effect, social considerations as well as application of GIS technologies.

**Table. 8 The detailed results of the literature reviewed for this article**

| Classification | Research gaps identified by Brown et al. (2011a) | Covered (√) or not covered (×) |
|---|---|---|
| *Planning* | The existing plans focused on technical interventions but ignored the guidance on decision making in different disaster contexts. | × |
| | There was no guidance document which can be readily applied to other developed countries, especially regarding the establishment of effective organizational, financial and legal structures for DWM. | × |
| | Plans of DWM seldom existed in developing countries. | × |
| *Waste* | The nature of disaster waste should not only be analyzed from the point of disaster type. | √ |
| | The method to measure, calculated and estimated the waste quantities was not explicitly stated, although lots of studies reported the data of waste quantities. | √ |
| | The general method for estimating quantities of waste in different disaster contexts was absent. | √ |
| | Evaluation model for predicting the waste volumes was limited. | × |
| *Waste treatment options* | Location and management aspects of temporary staging sites should be investigated by more future research. | √ |
| | There was no quantitative method to assess the preparedness, feasibility and effectiveness of waste recycling. | × |
| | Waste-to energy was an emerging topic which received a little attention, and there was no review of the success of these initiatives. | √ |
| | The practice of open burning of waste was not specially analyzed after a disaster. | √ |
| | The actual environment effects of land reclamation and disaster disposal sites were absent. | × |
| *Environment* | No author attempted to quantify the environmental impacts of altering peace-time waste management standards to manage disaster waste. | × |
| *Economics* | The economic impact (both direct and indirect) of DWM program was limited. | Partially covered |
| *Social considerations* | Research on social considerations (both qualitative and quantitative) was limited, especially the impact of DWM on community recovery and a post-disaster community behavior on waste management. | Partially covered |
| *Organizational aspects* | The organizational structures were not critically discussed in literature. | × |
| | No author critically investigated what factors should be considered in the organizational design of the physical works associated with DWM program. | × |
| | The effect of pre-arranged contracts and rates with contractors were absent. | × |
| | There was little data on suitable GIS technology and its effectiveness. | √ |
| *Legal frameworks* | The existing regulations were often unclear to what degree and in what circumstance legal relaxations are acceptable. | × |
| *Funding* | The effective mechanism (private, public and insurance) for funding DWM in different disaster contexts was absent. | × |

## 5. Discussion

The authors of this literature review analyzed gaps in knowledge highlighted by Brown et al. (2011a), to determine which have been addressed in the 82 papers selected for this literature review and which gaps still need to be addressed by future research.

In brief, much progress has been made but many gaps still exist as discussed in the following sections.

**5.1 Planning**

Based on our reviewing, the desire of preparing a plan is not high in practice (Brown et al., 2011b), although the importance of establishing a plan was suggested by lots of researchers (Zawawi et al., 2018; Brown et al., 2011a; Memon, 2015). According to Brown et al. (2011b) and Maryono et al. (2015), such a phenomenon may be caused by the success of DWM practice (implemented without a plan) and the impact of rich experience on successful operations. As Crowley (2017) identified, a well-established plan was beneficial to achieve the programmatic goals (e.g. implementing a recycle plan and removing more waste per day), but disposal cost could not be reduced by a pre-disaster waste management plan. Under this circumstance, it is necessary to reconfirm the positive relationship between plans and performance improvement.

**5.2 Waste**

As Table 6 presented in subsection 3.4, general studies and earthquake cases were widely discussed in recent years, which provides considerable amounts of knowledge and experience for researchers and practitioners. However, it seems not beneficial to develop the field of DWM research.

On the one hand, disasters are so different, and general studies may not fit all (Gupta et al., 2016). In other words, DWM relies on disaster context, which requires a specific approach to manage disaster wastes. On the other hand, the ignorance of other types of disasters (e.g. hurricane and man-made disaster) results in inadequate research of DWM. Deconstruction of brick- and concrete-based materials is the main work of DWM after an earthquake, which indicates that such activities will last for a long time. Unfortunately, the related knowledge, experience and model cannot be well applied in time-pressure situations. For example, Super Typhoon Mangkhut landed in Shenzhen and Zhuhai in China, it caused a large number of trees to be blown down by the wind on September 16, 2018. In this context, road blockage caused by fallen trees that had to be transported in a short time, has a different urgency than the long-time waste management of building wastes after earthquakes. Consequently, it is necessary to investigate the specific method/model for managing wastes in different types of disasters.

Differing from the previous studies focusing on separation methods which are based on diverse disaster types, several methods to classify disaster wastes were developed (e.g. the affected areas, the level of hazards and the ability to recycle the wastes). The authors of these studies did a good work in separation of waste which was directly caused by disasters. However, investigation on the waste which was caused by indirect effects was very limited (e.g. medical waste and waste from evacuation shelters) (Asari et al., 2013; Raila and Anderson, 2017). To our knowledge, few scholars used qualitative method to discuss the innovative solutions for reusing packaging waste materials (Regattieri et al. 2018), the data-based theoretical framework for managing healthcare wastes (Sahni et al. 2018) and management of plastic bottle and filter water (Wang et al., 2019). The authors of following paper mainly focused on collection and disposal of disaster wastes but ignored the transportation of such wastes. In this regard, the main differences between other types of waste and the two wastes related to the logistics system (e.g. reverse logistics system is common in managing waste directly generated by disaster, while the transportation of medical waste refers to the practice of close-loop logistic supply chain). In detail, relief materials (e.g. medical, food, water and tent) are transported into the affected area. Then, when the relief materials are used, the related wastes (e.g. medical waste, plastic bag and bottle) must be transported from the affected area to other processing site. In this process, a complete close-loop supply chain is composed of the input of relief materials and the output of the related waste.

As Caniato et al. (2016) noted, uncollected waste (especially healthcare waste) exposing in the air for a long time poses a potential public health risk. Besides, optimization of logistic system can accelerate the speed of clean-up (Hu and Sheu, 2013). Thus, it is valuable for scholars interested in supply chain management to discuss the related issues in such a context.

Quantification of waste received a growing attention by many researchers, but the accuracy of estimation model and the prediction of waste quantities poses challenges for future research. On the one hand, under- and over-estimation of waste quantities can result in problems in estimation of costs and benefits (Lorca et al., 2017), especially post-disaster waste estimation. Based on the existing studies, the accuracy of estimation model (both mathematical model and technology-based analysis tool) was significantly influenced by the completeness of inventory data and the quality of imaging processes. Thus, the degree of accuracy should be increased from two perspectives.

On the other hand, the lack of accuracy of the predictive estimation model may be caused by the lack of high technology. The prediction of waste volumes closely related to the prediction of disaster contexts, the potential damage to social system and the characteristic of system, which needs to collect the related information and then to analyze it. To achieve this goal, Misra et al. (2018) proposed an IoT-based system to automatically monitor maximum waste level of bin and hazardous waste. It is helpful for practitioner to dynamically acknowledge the risk of waste management process and discussing the prevention strategies before the occurrence of an event.

Inspired by them, the IoT-based system can be used for the prediction of disaster waste. In detail, not only waste bin but also infrastructures (e.g. buildings and trees) can be combined by sensors and intelligently monitored by cloud technologies. Once a disaster occurs, the quantities of collapsed buildings and fallen trees can be predicted by simulation of disaster contexts, and it beneficial to decision making. Consequently, it is necessary to further study the predictive method of waste volumes based on IoT technology.

**5.3 Waste treatment options**

Based on the literature review for this article, the authors found that with regard to waste management options, research gaps identified by Brown et al. (2011a) were well addressed by Wakabayashi et al. (2017), Tabata et al. (2017), Portugal-Pereira and Lee (2016) and Brown and Milke (2016). However, the quantitative analyses regarding effectiveness and feasibility of waste treatments (e.g. incineration, landfill, recycling and waste to energy) were still absent, and it should be highlighted here that is due to two reasons.

Firstly, as an eco-friendly waste treatment, waste-to-energy has received growing attention but was abandoned by disaster managers because of the high initial costs (Yepsen. 2008). On the other hand, Portugal-Pereira and Lee (2016) contended that waste-to-energy approach was more cost-effective than other treatment approaches. Under this circumstance, it is important to further investigate these two completely opposite viewpoints.

Secondly, open burning is an effective way to dispose of disaster wastes within a limited time, but many people object to this process (Brown et al., 2011a). Additionally, overly aggressive recycling is counterproductive and can increase costs (Fetter and Rakes, 2012), although it is usually promoted by disaster managers and researchers. Consequently, the selection of waste treatment approaches is context specific, and many dimensions must be evaluated in the decision-making processes.

In summary, quantitative research is essential for helping to solve the problems that need to be more effectively addressed in improving the management of disaster-generated wastes.

### 5.4 Environment

According to Brown et al. (2011a), the standard of "peace-time" waste management followed the sequence of source reduction, recycling and waste incineration. However, such a standard is hard to use in the context of DWM, especially in time-pressure situations. Therefore, it is necessary to change the standard of "peace-time" waste management, to provide guidance for initial waste clean-up in the context of disasters.

### 5.5 Economics

The measurement of indirect economic effects is not well researched. To our knowledge, it is hard to distinguish indirect economic effects and social impacts. For example, job opportunities were identified as indirect economic effects according to the study of Brown et al. (2011a), which was supported by the research of Habib et al. (2019). Therefore, the measurement of indirect economic effects is discussed in subsection 5.6.

### 5.6 Social considerations

In recent years, qualitative analyses with respect to social considerations were effectively addressed, especially within the group of community interactions. However, investigations on psychological impacts of victims and of employees was limited. As Cao et al. (2018) and Cao et al. (2017) noted, the sustainability of the forward humanitarian supply chain was particularly impacted by the victim's perception of accessibility, equity and fulfillment. Similarly, management of disaster wastes was also linked to the perception about of accessibility, equity and fulfillment, which resulted from non-transparent priorities of waste management (Berktas et al., 2016). Additionally, the participant's direct access to humanitarian aid, and related social considerations (e.g. the potential risk of health and benefits from disaster waste cleanup) need to be considered to improve performance of waste management. (Aoki, 2018; Noh et al., 2015). Therefore, it is essential to work intensively with social considerations from the perspective of victims and employee and society as a whole, in the short and long-term.

As Hu and Sheu (2013) stated, that is it is essential to aggress social considerations in a quantitative way, which was also highlighted in DWM research of Hu et al. (2019). Idea is recommended to adopt the "prospect theory" to measure and response the psychological effects of victims (e.g. the perception of equity and fulfillment) as part of the process of recovering from the shocks of the disasters.

### 5.7 Organizational aspects

Regarding organizational aspects, '*coordination*' was identified as a critical factor in achieving successful management of disaster wastes (Domingo and Luo, 2017; Hooper, 2019). However, there were no detailed directives of ways to establish the needed coordination. Based upon the extensive experiences in disaster operations management (Balcik et al., 2010; Li et al., 2019), organizational coordination was suggested as essential from three perspectives: a. stakeholder identification, b. coordinated network and c. coordination mechanism. Coordinated network is composed of several stakeholders, and it managed by coordination mechanism.

Based on the studies of Brown et al. (2011a), Karunasena et al. (2012), Kawamoto and Kim (2016) and Aoki (2018), government, the private sector and the communities are critical actors which influence the effectiveness of DWM. However, due to diverse norms, weak plans, lack of awareness regarding low level of trust (Hooper, 2019; Kawamoto and Kim, 2016; Aoki, 2018; Domingo and Luo, 2017), the effective coordinated network is hard to establish. Additionally, coordination mechanisms with regard to procurement, inventory, transportation and maintenance are often weak or totally absent. For example, coordinated decision-making processes between government and private sector are weak or non-existent but should be thoroughly investigated and integrated into the preparatory pre-contact phases (Brown et al., 2011a), to help to ensure answers to, whether to coordinate, when to coordinate and how to perform properly (Li et al., 2019).

### 5.8 Legal frameworks

Research gaps regarding legal frameworks can be summarized under two headings. Firstly, the lack of enforceable legislation was identified as a crucial capacity gap in developing countries, which resulted from little experience of DWM practice (Karunasena et al., 2012). Thus, how to establish enforceable regulations that a consistent with evolving legal frameworks (e.g. USEPA, 2008) to guide waste clean-up, are essential. Secondly, because regulations are mentioned generally but detailed components are not discussed in detailed cases and examples (Crowley and Flachsbart, 2018), consequently, the ambiguity of the relevant document results in managerial confusion. For example, the boundaries of adopting incineration plans is hard to be answered based upon existing legislation, therefore, this lack of clarity, negatively influences the effectiveness of waste clean-up planning and implementation of those plans (Brown et al., 2011a). Consequently, it is urgent that improvements are made in clarification of authority and operability of legal frameworks.

### 5.9 Funding

The conflict between fund-provider and fund-receiver was identified in subsection 4.9, which can be regarded as an integrated issue concerning disaster management and the financial problems. Generally, authors recognized that performance improvement is positively associated with sufficient funds, although such a viewpoint was opposed, due to cost of capital (Modigliani and Miller, 1958). Given the scarcity of funds, the needs of fund-receivers and the intentions of fund-providers should be well matched in the characteristics of funds, so that fund types (e.g. monetary funds, professional equipment and necessary relief), quantities of funds, qualities of funds (e.g. consistency of delivery time between actual and expected, risk of capital), temporary and spatial use of funds are fully clarified, at the beginning of the clean-up processes.

For example, excessive unwanted donations (e.g. food and other supplies) sometimes cause extensive problem for responders and victims (Ekici et al., 2009), while other managers complained about lack of funds (Ardani et al., 2009) in the disposal of wastes. This example highlights the important roles of fund quantities in DWM. Consequently, it is important to design clear financial processes for raising and using the funds for the right places, with a high quality and in a certain time.

## 6. Conclusions

This paper provides an updated review of DWM. In detail, 82 papers were selected and systematically for this comprehensive literature review. The primary focus was upon pertaining to responses to disasters caused by diverse causes, with regard to: planning of responses in general, planning of quantification and management of the array of solid wastes according to diverse waste treatment options, in the context of environmental, economic, social considerations, organizational aspects, legal frameworks and funding.

The literature analyses revealed that there have been few dramatic improvements in the last 9 years in the field of DWM research, especially in the part of planning, organizational aspects, legislation and funding.

Although some of the technical aspects have been thoroughly investigated by researchers, to attract more interested researchers to address the research gaps, the following future research directions were outlined: a. establishing the DWM plan in terms of legal framework, organizational aspects and funding mechanism, b. analyzing case studies based on the specific disaster type, c. improving of the accuracy model with regard to estimate/predict disaster waste, d. designing a quantitative analysis for analyzing the effectiveness and efficiency of waste treatment, e. analyzing the indirect economic effects and social considerations.

The limitations of this paper include:

a. the authors decide to limit our search to academic journals and conferences. However, policy statements, environmental programs and best-practice examples (e.g. Planning for Disaster Debris 1995; Public Assistance: Debris Management Guide 2007; Planning for Natural Disaster Debris 2008) were ignored, although these works provided useful and practical management insights for researchers (Brown et al., 2011a; Asari et al., 2013).

b. due to the keywords-based searching of publications, it was possible that publications matching the research question were not found, although the related contexts were discussed in the paper.

c. the selected papers were only published in English. Papers published in Japanese, Chinese, German, French and other languages were excluded, which may impact the results of the descriptive analysis and of the thematic analysis.

d. subjectivity may have influenced the process of the systematical literature review, such as the manual scrutiny of papers and the classification of papers.

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# Highlights

- A systematic review is done towards recent advances in disaster waste management.
- There are no dramatic development in the field of disaster waste management.
- Recent studies also focus on technical aspects.
- Planning, legislation, organizations and funding are still not well addressed.
- Future research directions are proposed.