Analysis of Enablers for Disaster Waste Management

Devendra Kumar Yadav and Akhilesh Barve

***Abstract*—Apart from the destruction of the human lives, infrastructure and economic impacts, disasters often generate large volumes of waste. These volumes are, sometimes, beyond the scope of local waste management people and facilities. To manage such waste is very difficult due to the mixing of disaster waste in it. The review articles of disaster waste management and post-disaster debris management conclude that there is ample discussion on factors affecting the disaster waste management, but rarely on considering them altogether. Keeping meaningful aspects from enablers of disaster waste management, this paper examines how to manage these wastes to bring effective response and recovery process. The various activities in the form of enablers have been identified and an analysis of how these enablers could be categorized in cause and effect group, Decision Making Trail and Evaluation Laboratory (DEMATEL) has been applied to bring greater clarity. The result of this study indicates that the successful management of disaster waste needs to focus the cause group enablers rather than effect group enablers.**

***Index Terms*—Disasters, disaster waste management, DEMATEL, enablers.**

I. Introduction

Over the years, escalating number of disasters have affected different regions of the earth, killed so many people and made indirect sufferers to millions [1]. With growing frequency and strength of weather-related extremes and ongoing changes force exacerbate these impacts [2]. Recent disasters, such as the super cyclone in Odisha, India during October 1999, earthquake in Gujarat, India in 2001, Indian Ocean Tsunami 2004, the earthquake/tsunami, earthquake during Haiti in 2010, and nuclear disaster of Japan in 2011, and Haiyan cyclone, Philippines 2013, prove the susceptibility of developed countries, in addition to developing countries, to disasters. As per Centre for Research on the Epidemiology of Disasters (CRED) [3] a disaster is "a situation or event which overwhelms local capacity, necessitating a request to a national or international level for external assistance; an unforeseen and often sudden event that causes great damage, destruction and human suffering". As per definition, disaster overwhelms local capacity because available resource may be damaged or away from the reach; secondly, damaged infrastructure and chaotic environment forced the affected community to depend on external assistance; third is the unpredictable scale and nature of disasters itself make the relief process complicated and often with a very short lead time. Apart from the destruction of the human lives, infrastructure and economic impacts, disasters also generate large volumes of waste. These volumes are, sometimes, beyond the scope of local waste management people and facilities [4] and the disaster waste generation rate goes beyond five to fifteen times of the annual waste generation rate in the affected region [5], [6]. The occurrence of disaster waste affects, more or less each aspect of disaster response and recovery or rescue effort [6]. Uttarakhand, a northern state of India was hit by a flash flood during June 2013 that resulted in the death of more than 5,000 and a large amount of debris, was formed by massive heaps of rock sediments under which several uprooted trees and dead bodies were buried [7]. The very severe cyclone Phailin that hit Odisha coast on 12th October 213 resulting the death of 44 and affected a million hectares of crops, forest and destroyed thousands mud and pucca houses in the state. The damage and debris created by cyclone Phailin are still yet to be removed from the some part of coastal districts in Odisha.

Disaster Waste Management

Disaster waste and debris are used interchangeably in various studies. Debris has been used in literature as vegetable waste and collapsed building materials and disaster waste includes vegetation, natural masses, manufacture and devastation debris (material, bricks, metal, timber, etc.), vehicles, boats, electrical goods and contraption [8]. Every year natural disasters generate large amounts of waste that includes building materials, vegetable waste, collapsed building materials, household wastes and other materials [9]. After the emerging of United States Environmental Protection Agency's (USEPA's), the requirement of catastrophe debris planning has been recognized [6], [9]. Disaster debris may become the cause of road blockages, which delay in emergency relief [6], [10] and further lead to more casualties. The quantity and form of wreckage created from a disaster vary from circumstances to circumstances. In any disaster, vegetative debris is the largest portion of the debris or wreckage. To manage such wastes is very difficult due to mixing nature of disaster wastes, which is difficult to separate [5], [11]. Different aspects of Disaster Waste Management (DWM) may include planning for debris and waste, waste treatment options, funding mechanism, community partnership and various other socioeconomic and environment concerns. A disaster waste management should take care of human health, environment and appropriate relief to the affected communities. As per the study of [12], [13] in most of the developing countries, disaster waste management guidelines and manual are not available, despite their frequent exposure to disasters.

Derived from a critical review of the appropriate literature the authors [6], [14] conclude that the study of disaster waste, mostly focus on either event oriented and their qualitative analysis or policy associated issues such as handover tasks and register governmental processes. Although, most of the

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studies [5], [15]-[17] have highlighted the various issues of disaster waste, but taking into account all the factors that influence the disaster waste management success is needed to analyse [4]. Keeping all such aspects of disaster waste management, this paper examines how to manage these wastes to bring effective response and recovery process. The various activities in the form of enablers have been identified and an analysis of how these enablers could be categorized in cause and effect group, DEMATEL has been used to bring greater clarity.

This leftover of this research article is given as follows. Section II is based on the related review literature of DWM and enablers. Section III describes the solution methodology. Section IV of this study reveals the important findings. The findings are discussed along with managerial/practical implications. Finally, conclusions have been drawn with the limitations and implications of the study and the future directions for DWM based research.

II. Literature Review and Theory Development

Numerous authors have referred to the DWM over the past decade due to growing trends in disasters and their effect on human and the environment. This section gives a brief statement of the important points of the existing research on DWM by recognizing the important topics and issues in existing literature. Brown *et al.* [6] present a systematic summary of DWM studies. The authors conclude that most of the existing studies are either case based or guideline based. A country based study of [13] addresses post DWM policies applied in underdeveloped countries and appropriateness of the best worldwide performs of the challenges faced. The study presents that approaches, issues, problems and challenges vary as per the kind of disaster, extent, place, and the nation. The recent study of [8] analyses the key factors that influence the possibility of post processing of disaster waste materials. The findings of their study include the volume of waste, community preference, and availability of the resource, type of waste, government policies, and funding mechanism as the key factors.

Trivedi *et al.* [4] identify and analyse the factors that affect the successful implementation of disaster waste management. The major findings of the authors include community participation, donor involvements, contract management, type of disaster, training, waste treatment options, communication and coordination. The authors concluded that proper planning and management of disaster waste have been recognized as critical for achieving a successful humanitarian response by researchers and practitioners in the past. Pike [18] designated that DWM initiates instantly subsequent a disaster and continues throughout restoration and reconstruction.

Subsequent to the widespread earthquakes, floods, and waste flows that have happened all over Taiwan for so many years, the academy is in progress to encourage the community-based DWM notion following the 2001 Typhoon Toraji and Typhoon Nali [19]. The factors those promote and make thing happen, to perform a system effectively are known as enablers [20]. Without the necessary enablers, a system doesn't work smoothly and this study is an attempt to identify those enablers that help in effective DWM.

The review articles of DWM and post-disaster debris management concludes that there is ample discussion of factors affecting disaster waste management i.e. enablers. It can also be seen from the literature review that very rare studies have been done to investigate the interactions among enablers of disaster waste management. So, in order to overcome this gap this research paper is designed to propose a framework to bring sustainability in post disaster waste management rather than ongoing ad-hoc practices. The summary of identified enablers along with related literature is shown in Table I.

TABLE I: Enablers and Relevant Literatures

S. No.	Enablers	Authors
E1	Community involvement	[4],[9],[15],[19]
E2	Trained manpower	[4],[15],[21]
E3	Advance arrangement of physical capacity	[4],[22],[23]
E4	Lesson learnt from previous events (Information sharing)	[15]
E5	Disaster waste management planning along with disaster preparedness	[17],[23],[24]
E6	Development of sustainable waste management systems	[4],[5],[8],[25],[26]
E7	Partnership and coordination	[4],[6],[25],[27]
E8	Selection of suitable contractors	[4],[14],[15]
E9	Availability of temporary disposal sites in vulnerable regions	[4],[9],[14],[17],[25],[28]
E10	Commitment and support of government and donors	[4],[27]

III. Methodology

Decision Making Trail and Evaluation Laboratory (DEMATEL), a graph theory-based technique has been developed during 1972 to study and determine the complex problems. DEMATEL is able to to analyze the causal relationships and interaction influences, identify the core driving factors and help the stakeholders to make the correct decision on the complicated problems. The complex relations among variables of a system can be exhibited through DEMATEL [29] in the form of matrices or digraphs. DEMATEL has already been successfully applied in various technical, management issues.

A. Steps of DEMATEL

Step 1: Calculate average initial direct relation matrix: Factors influencing the objectives should be figured out through investigation tools like extensive literature review and questionnaire survey. Thereafter, the group of experts is selected to give their decision for every interaction between each pair of influential factors [30]. For the development of an initial direct relation matrix, expert's view from the same field is the most important part by using scale 0 (no influence), 1 (very low influence), 2 (low influence), 3 (high influence), and 4 (very high influence). By doing so, an initial direct relation matrix $Z = [z_{ij}]$, can be obtained. Where *Z* is the *n* X *n* non-negative matrix, and z_{ij} indicates the direct influence of factor *i* on factor *j*; and if *i*=*j*, then the diagonal elements $z_{ij} = 0$ [31], [32]. If there are *H* number of experts then, for each expert, an *n* X *n* non-negative matrix could be recognised as $Z^k = [z_{ij}^k]$, where *k* is the number of experts with $1 \le k \le H$, and n is the total number of influential factors [33].

$$Z^k = \begin{bmatrix} 0 & z_{12}^k & \cdots & z_{1n}^k \\ z_{21}^k & 0 & \cdots & z_{2n}^k \\ \cdots & \cdots & \cdots & \cdots \\ z_{n1}^k & z_{n2}^k & \cdots & 0 \end{bmatrix} \quad (1)$$

Then, the average matrix A of all H experts can be calculated as:

$$A = [a_{ij}] = \left(\frac{1}{H}\right)\sum_{k=1}^{H} z_{ij}^k \quad (2)$$

Step 2: Calculate normalized initial direct-relation matrix (matrix D): To obtain the meaningful decisions from the average initial direct relation matrix A, it is converted into a normalize direct matrix $D = [d_{ij}]$. Each element in the matrix D falls in the range of $0 \le d_{ij} \le 1$ and all main oblique elements are equivalent to zero.

$$D = \frac{1}{\max_{1 \le i \le n} \sum_{j=1}^{n} a_{ij}} A \quad (3)$$

Step 3: Calculate total influence matrix (matrix T): The total relative matrix T can be calculated applying the equation (4) in which I is an $n \times n$ identity matrix. The element t_{ij} designates the secondary effects that factor i has on factor j, so the matrix T be able to reveal the entire link between respectively brace of selected factors.

$$T = (t_{ij}) = D(I - D)^{-1} \quad (4)$$

Step 4: Prominent and impact of each enabler: - The summation of row i that is symbolized as R, characterizes all direct and indirect influence given by factor i to all other factors, and so R could be entitled as degree of effective influence.

Likewise, the summation of column j that is represented as C and could be called as the degree of effective influence, since C belongs to both types of direct and indirect influence established by factor j from all other factors.

$$R = \sum\nolimits_{1 \le j \le n} t_{ij} \quad (5)$$

$$C = \sum\nolimits_{1 \le i \le n} t_{ij} \quad (6)$$

Therefore, logically, when $i=j$, $R+C$ shows all effects given and received by factor i. That is, $R+C$ indicate both factors i's impact on the whole system and other system factors' impact on factor i. So, the indicator $R+C$ can represent the degree of importance that factor i play in the entire system. On the contrary, the difference of the two, $R–C$ shows the net effect that factor i has on the system. Specifically, if the value of $R−C$ is positive, the factor i is the net cause, exposing net causal effect on the system. When $R–C$ is negative, the factor is a net result clustered into the effect group.

B. Applications of Proposed Method

Step 1: Average initial direct relation matrix: After finalizing the ten enables of disaster waste management a number of disaster experts were consulted. Due to the busy schedule of experts, only four of them were agreed to participate in the desired discussion. Based on their relative judgement on five scales total four matrices of 10 ×10 were recorded. Based on those four matrices an average matrix is prepared using equation (1) and also revealed in Table II.

Step 2: Normalized preliminary direct relation matrix (matrix D): It could be calculated using the equation (3). Normalized direct matrix D has been presented in Table III.

Step 3: Total influence matrix (matrix T): the total influence matrix T (shown in Table IV) is calculated from the normalized matrix D and equation (4).

TABLE II: AVERAGE INITIAL DIRECT RELATION MATRIX

	E1	E2	E3	E4	E5	E6	E7	E8	E9	E10
E1	0	1.25	2.25	2.75	1.75	2.75	2.25	0.50	2.50	1.00
E2	1.25	0	1.25	1.25	1.50	3.25	3.25	2.00	3.25	1.50
E3	1.50	1.75	0	0.25	1.00	2.50	1.50	2.00	1.00	0.50
E4	2.75	4.00	3.25	0	3.25	3.50	3.25	3.50	3.50	2.50
E5	2.50	3.25	3.00	2.00	0	2.75	2.75	2.00	2.75	2.50
E6	1.00	1.25	2.00	1.00	1.25	0	1.75	1.50	3.00	2.50
E7	3.00	3.25	3.50	2.50	3.00	3.50	0	2.50	2.50	3.25
E8	0.25	0.00	1.50	1.00	1.00	3.00	1.50	0	2.50	1.25
E9	1.25	0.25	1.25	2.00	0.50	2.75	1.50	1.50	0	0.75
E10	2.00	2.50	3.25	2.25	2.50	3.50	3.00	2.25	3.00	0

TABLE III: NORMALIZED INITIAL DIRECT RELATION MATRIX

	E1	E2	E3	E4	E5	E6	E7	E8	E9	E10
E1	0.000	0.042	0.076	0.093	0.059	0.093	0.076	0.017	0.085	0.034
E2	0.042	0.000	0.042	0.042	0.051	0.110	0.110	0.068	0.110	0.051
E3	0.051	0.059	0.000	0.008	0.034	0.085	0.051	0.068	0.034	0.017
E4	0.093	0.136	0.110	0.000	0.110	0.119	0.110	0.119	0.119	0.085
E5	0.085	0.110	0.102	0.068	0.000	0.093	0.093	0.068	0.093	0.085
E6	0.034	0.042	0.068	0.034	0.042	0.000	0.059	0.051	0.102	0.085
E7	0.102	0.110	0.119	0.085	0.102	0.119	0.000	0.085	0.085	0.110
E8	0.008	0.000	0.051	0.034	0.034	0.102	0.051	0.000	0.085	0.042
E9	0.042	0.008	0.042	0.068	0.017	0.093	0.051	0.051	0.000	0.025
E10	0.068	0.085	0.110	0.076	0.085	0.119	0.102	0.076	0.102	0.000

TABLE IV: TOTAL INFLUENCE MATRIX

	E1	E2	E3	E4	E5	E6	E7	E8	E9	E10
E1	0.088	0.138	0.188	0.170	0.143	0.234	0.183	0.118	0.209	0.124
E2	0.131	0.097	0.162	0.129	0.138	0.257	0.217	0.167	0.239	0.144
E3	0.103	0.115	0.075	0.064	0.088	0.177	0.121	0.127	0.121	0.077
E4	0.224	0.274	0.287	0.135	0.239	0.349	0.282	0.268	0.321	0.223
E5	0.192	0.226	0.246	0.174	0.114	0.283	0.235	0.194	0.259	0.196
E6	0.107	0.121	0.164	0.106	0.114	0.130	0.152	0.134	0.206	0.155
E7	0.222	0.244	0.283	0.203	0.223	0.332	0.170	0.227	0.276	0.235
E8	0.067	0.064	0.127	0.088	0.089	0.193	0.121	0.067	0.166	0.102
E9	0.099	0.075	0.121	0.120	0.078	0.188	0.124	0.117	0.091	0.088
E10	0.180	0.207	0.258	0.183	0.195	0.309	0.245	0.205	0.270	0.122

Step 4: Prominent and influence of each criterion: The summation of row i is symbolized as R and summation of column j is denoted as C can be calculated using equation (5) and equation (6) as depicted in Table V. Thereafter, cause and effect diagram is also drawn with coordinate values ($R+C$, $R-C$) to show the causal relations among the identified enablers as depicted in Fig. 1.

TABLE V: VALUES OF $R+C$, $R-C$

S. No.	R	C	$R+C$	$R-C$
E1	1.596	1.413	3.009	0.183
E2	1.682	1.559	3.241	0.123
E3	1.069	1.911	2.980	-0.842
E4	2.602	1.372	3.974	1.230
E5	2.117	1.421	3.538	0.696
E6	1.387	2.452	3.840	-1.065
E7	2.415	1.850	4.265	0.564
E8	1.084	1.623	2.707	-0.539
E9	1.100	2.158	3.258	-1.058
E10	2.173	1.465	3.639	0.708

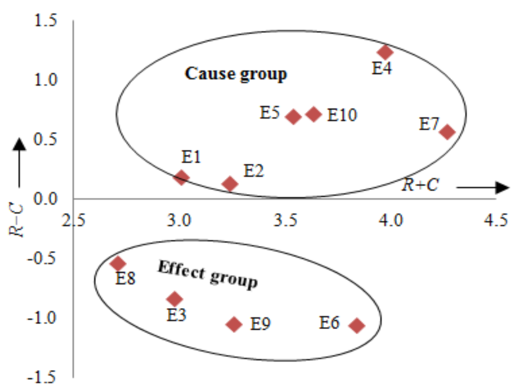

Fig. 1. Causal (cause and effect) diagram.

IV. DISCUSSION

According to the values of $R+C$ the importance of disaster waste management enablers can be prioritized as E7>E4>E6>E10>E5>E9>E2>E1>E3>E8.

This prioritization reveals that the enabler E7 'Partnerships and coordination' are most important and enabler E8 'Selection of suitable contractors' is least important among selected enablers. Disaster waste management is a cumulative effort of various organizations because it is not possible for a single organization to deal with huge amount of debris and uprooted trees, electric and telephone lines, collapsed buildings and public infrastructure during a short time of time. Even though, the selection of a suitable contractor is found as one of the enablers in literature, but might not assume much importance in the context of study under consideration. The cause and effect diagram illustrate that the enablers in cause group with positive $R-C$ values, including E1, E2, E4, E5, E7, and E10 whereas enablers with negative $R-C$ values E3, E, E8, and E9 composed in effect group factors. Although, few enablers of cause groups have fewer $R+C$ values, and need more attention long with other cause group enablers. The cause group enablers are not depending on any other enablers, but affects and influence other enablers falls in effect group. Therefore, the more focus should be on the net cause group enablers for improving effect group enablers simultaneously. DWM is an integral part of disaster management because poor management of disaster waste not only inhibits the relief process but also cause several health problems. Advance availability of machinery for removing blockage and debris from the road could help in assisting the disaster victims on time. But, availability of machinery itself is not sufficient for disaster waste management, because it requires trained manpower, advance planning, community involvement and continuous support from the government as well from other stakeholders. The enabler E3 'Availability of temporary disposal sites in vulnerable regions' will always depend on other factors like advance planning, community involvement, government support and partnership for effective results

The enabler E6 'sustainable waste management system development' and E8 'selection of suitable contractors' also depend on other enablers like government support and lesson learnt from past events (information sharing) and partnerships. From the above discussion, it can be concluded that effect group enablers are the result of continuous attention on cause group enablers.

V. CONCLUSION AND FUTURE SCOPE

This research is chosen to explore the enablers of disaster waste management. Based on extensive literature review and experts consultation ten enablers have been finalised. In order to finalize the enabler list various disaster management agencies, including government, NGOs and community-based organizations have been contacted. The chosen methodology DEMATEL enables to solve the given problem visually and able to divide the selected enablers into cause and effect grouping to understand the hidden causal relationship among different enablers. This study reveals that the fruitful and successful management of disaster waste needs to focus the cause group enablers 'Community involvement', 'Trained manpower', 'Lesson learnt from previous events (Information sharing)', 'Disaster waste management planning along with disaster preparedness'

'Partnership and coordination' and 'Commitment and support of government and donors'.

The outcomes of this research are not restricted to any country specific, but are applicable to all the countries facing disasters. The findings also suggest that the disaster waste management should be considered as an essential part of disaster management and all the necessary provision must be made during disaster preparedness itself. Although, this study highlights the various enablers of disaster waste management, but is based on human judgement and may vary with increase in the numbers of experts and their judgements. A case study with a number of experts and to minimize the human judgement ambiguity, the fuzzy set theory can be included as a future work.

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