Investigating causal relationship of disaster risk reduction activities in the Indian context

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Abstract: This study focuses on the identification of disaster risk reduction (DRR) activities which are carried out during pre and post-disasters to save the lives of the population under risk of disasters. Odisha, one of the disaster-prone states in India has been taken as a case study to identify the relevant DRR activities for cyclone and later the efforts were made to explore the strength of identified DRR activities and causal relationship between them by using decision-making trial and evaluation laboratory (DEMATEL) method. The activities used in these processes were finalised after the detailed discussion with policymakers and academicians working at the various levels and capacities of disaster management and allied domain of DRR. The results of this study show that cause group activities influence effect group activities, and emergency planning at various levels was found to be the most influencing DRR activity among other activities.

Keywords: DRR; disaster risk reduction; Odisha; DEMATEL; decision-making trial and evaluation laboratory.

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1 Introduction

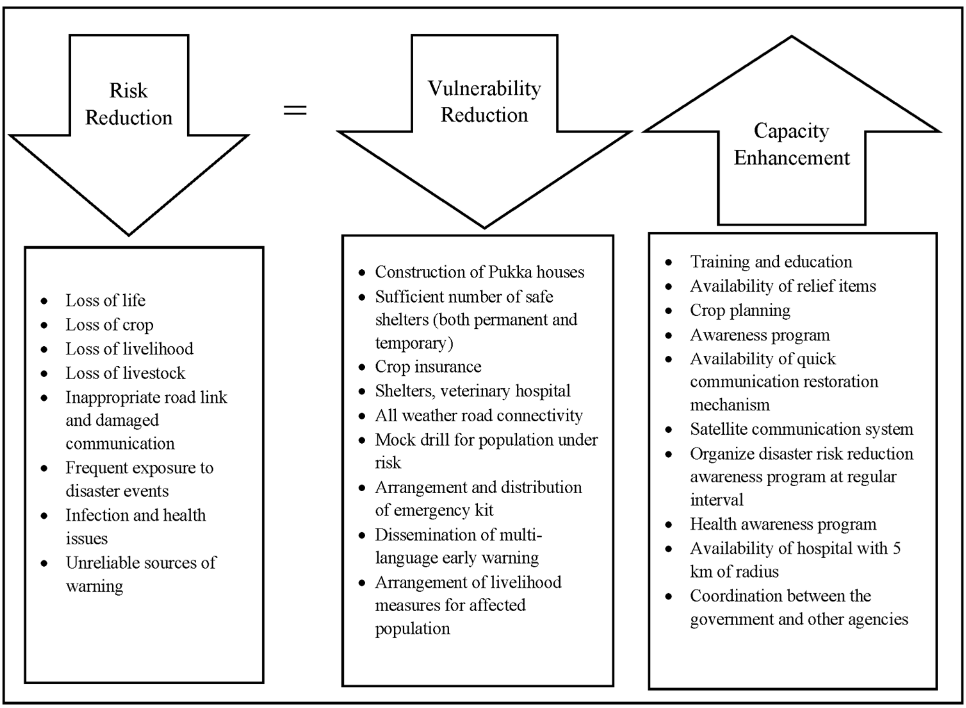
The economic destruction associated with global natural disasters has dramatically gone up, particularly in the coastal areas (Weinkle et al., 2012). The coastal areas are heavily inhabited due to their fiscal importance (McGranahan et al., 2007; Small and Nicholls, 2003). The degree to which coastal populations are exposed to potential hazards is dependent not only on the proximity to the sea but also on their socioeconomic vulnerability (Stock et al., 2019; Shirley et al., 2012) and poor infrastructure (Adger, 2006; Borden et al., 2007; Balica et al., 2012). Recent disasters have demonstrated the vulnerability of the affected societies by requiring additional support from humanitarian organisations (Leiras et al., 2014). The focus of disaster relief operations is to design the transportation of first aid material, food, equipment, and rescue personnel from supply points to many destination nodes geographically scattered over the disaster region. Thus, disaster management is a key factor that drives the successful execution of disaster risk reduction (DRR) measures (Tomasini and van Wassenhove, 2009).

1.1 Disaster risk reduction

Disaster risk refers to the potential losses by a disaster on human lives, livelihood, livestock, infrastructure, environment, services, shelters and assets. Theoretically, disaster risk is the multiplication of potential hazard and the vulnerability of a community, which is exposed to a hazard (UNDHA, 1992). At the same time, disaster risk is inversely proportional to the coping capacity of the community at risk. The effect of hazard differs from community to community and place to place because the level of vulnerability differs from one community to another (Shirley et al., 2012). An impoverished or vulnerable community suffers more than a community that has a relatively more coping capacity.

The disasters cause different consequences to different people such as loss of life, loss of livestock, loss of agriculture, infrastructural loss, etc. However, all these losses can be minimised by practising risk reduction activities at various levels (national, state, districts, block, village and household level). These activities are performed by the government and NGOs to reduce the inherent risk posed by disasters. For instance, dissemination of early warnings of imminent disaster can save the lives of those who are unaware of it and its consequences due to the inadequate communication system (Pettit et al., 2006) and provide sufficient time for evacuation to safe locations, such as cyclone shelters (UNEP, 2013; Yadav and Barve, 2019). Construction of sufficient permanent and temporary cyclone shelters and arrangement of temporary shelters along the coast, in cyclone-prone regions, are among the most important measures needed during natural disasters (Thomalla and Schmuck, 2004; Yadav and Barve, 2019). However, relief material can be made available during the first 72 h of the disaster to the disaster-affected population. This study proposes a framework that summarises the various risks facing by the community residing in the coastal area of Odisha, mainly due to flood and cyclone. The various preventive measure carries out to reduce the risk are presented in Figure 1.

Figure 1 Proposed framework of disaster risk reduction



The left block of the framework, as depicted in Figure 1, represents various risk caused by disasters. The middle and right blocks of the framework represent risk reduction measures, which are sub-categorised into two parts viz. vulnerability reduction and capacity building. The vulnerability may be expressed as the degree of loss resulting from a potential hazard, which can be minimised by measure like the construction of *pucca houses*, constructing shelters (cyclone shelters), all-weather road connectivity to facilitate quick relief operations, etc. Right block of the risk reduction measures is capacity enhancement, which includes lessons learned from past disasters, increasing coping capacity by performing various training and education tasks (Yadav and Barve, 2015); ensure availability of quick communication restoration mechanism (OSDMA, 2014; Yadav and Barve, 2019), and many health awareness programs (Bahinipati, 2014).

1.2 Research gap

In recent years, various issues of disasters have been addressed by researchers to improve responsiveness to disaster. Researchers have stressed the importance of preparation for effective disaster response. Authors (Pettit et al., 2006; Oloruntoba, 2010; Zhou et al., 2011) stressed to focus on the most urgent and important factors of disaster relief and their implementation in a stepwise manner. On the contrary, a few other researchers (Kovács and Spens, 2009; Ergun et al., 2009; John and Ramesh, 2016) focused on identification and analysis of challenges in disaster response to improve the entire relief chain. Other issues appearing in the recent literature include coordination, knowledge management and uses of information and communication technology in disaster management (Kabra et al., 2015), the role of donors and volunteers in humanitarian operation, and sustainable disaster relief and recovery (Oloruntoba, 2010; Dubey and Gunasekaran, 2016). Most of the studies assessed the vulnerability and hazard at different levels (Bahinipati, 2014; Mazumdar and Paul, 2016), proposed measures for coping capacity and adaptation, identified relevant factors to improve disaster relief chain, and many other aspects related to disaster and risk reduction. However, we hardly find any study that focused on the DRR activities and its analysis.

2 Problem description

The coastal belt of India extends 7516 km of which Odisha accounts for 480 km of it in the East to the Bay of Bengal. Due to its sub-tropical location, the state is highly prone to the tropical cyclone, storm surge and river flood. This makes Odisha one of the states most affected by multiple disasters arising from flood, cyclone, and storm surge (Yadav and Barve, 2019). Dense rainfall at the time of monsoon causes an increase in the level of river water, which leads to flooding. Odisha has experienced powerful cyclones in the years 1999, 2013, 2014 and 2018, respectively. Cyclone Phailin in 2013, cyclone Helen in 2013, cyclone Hudhud in 2014, a flash flood in 2015, cyclone Komen in 2015, floods and landslides in 2016, flood in July 2017, cyclone Titli in the year 2018 and cyclone Fani in 2019 have affected the many parts of the state.

As mentioned in Figure 1, disasters bring the varying intensity of risk, which can be reduced if risk reduction activities are performed much before the disaster period. As an outcome, the activities, which are being carried over the past years, are unplanned and directionless and led to disrepute in the achievement of risk reduction goals. Nonetheless, DRR activities, whose concepts are parallel with disaster management, have demonstrated their usefulness in response to recent disasters in India as well as in other countries. Followed by literature review and opinion of informed individuals, 14 DRR activities are finalised for further analysis. Table 1 summarises these activities, their brief description, and relevant literature.

Table 1 List of DRR activities and relevant literature

Factors	*List of DRR activities*	*Description*	*Sources*
D_1	Availability of quick communication restoration mechanism	Availability of quick restoration mechanism can restore the roads and railway lines to facilitate the movement of relief equipped vehicles and personnel	Zhou et al. (2011), Barbarosoğlu et al. (2002)
D_2	Organise disaster risk reduction awareness programs at regular interval	Vulnerable communities need to be trained on measures need to take during a disaster, use of provided materials, emergency routes, safe location during awareness programs, and adopt right measures if a disaster hits them	Mazumdar and Paul (2016)
D_3	Sufficient number of cyclone shelters (both temporary and permanent)	Cyclone-resistant-shelters act as a safe location for displaced people during disaster periods	UNEP (2013), OSDMA (2013), Yadav and Barve (2015)
D_4	Coordination between government and other agencies	Government and local and international NGOs agencies can come forward to provide support in the affected areas and assist the communities in all possible ways to save lives and property of population under risk	Pettit et al. (2006), Zhou et al. (2011), Davidson (2006)
D_5	All-weather road connectivity	All-weather roads are constructed with a purpose to reach till the last mile location during disaster periods	Primary data
D_6	Dissemination of multi-language early warning	Prior to any disaster, the communities under risk of a disaster should be informed immediately through available communication means like TV, Radio, Newspaper, loudspeakers, etc.	Pettit et al. (2006), Zhou et al. (2011)
D_7	Emergency planning at various level (State, district, village, household)	A plan is a detailed document of measures need to be taken by authorities at various levels during disasters	OSDMA (2014)
D_8	Arrangement and distribution of emergency kit	Availability and timely distribution of emergency kit may reduce the loss of lives by feeding to needy and affected people	Yadav and Barve (2015), Yadav and Barve (2019)
D_9	Availability of relief items at the various relief distribution centre	The government agency can hold small inventory at the various strategic level (state, district, panchayat and village) but away from disaster-prone locations	OSDMA (2014), OSDMA (2013), World Bank (2013)
D_{10}	Mock drill for the population under risk	Mock drill to be carried out in the disaster-prone zone to sensitise the population under risk. It is often performed during cyclone seasons (in May and October/November)	OSDMA (2013), Yadav and Barve (2018)
D_{11}	Arrangement of medical facilities (temporary and permanent health centre)	Cyclone causes flood-like situations in many areas and eventually disrupt communication means. Additionally, many water-borne diseases may affect the cyclone-affected communities	Alexander (2003), UNEP (2013)

Table 1 List of DRR activities and relevant literature (continued)

Factors	*List of DRR activities*	*Description*	*Sources*
D_{12}	Hazard, risk and vulnerability assessments	It helps in identifying risk zones, causes of vulnerability and vulnerability zones, and developing hazard maps and emergency planning for those areas	Mazumdar and Paul (2016), Yadav and Barve (2018)
D_{13}	Arrangement of livelihood measures for the affected population	Disaster brings a huge loss to the economy and livelihood. Thus, an affected community may require the livelihood support of local government and NGOs to recover themselves	Primary data
D_{14}	Strengthening capacity of disaster management institutions	Creation and development of allied disaster management bodies, training of personnel, and their deployment at various risk zones	UNEP (2013), UNISDR (2004), Thomalla et al. (2006)

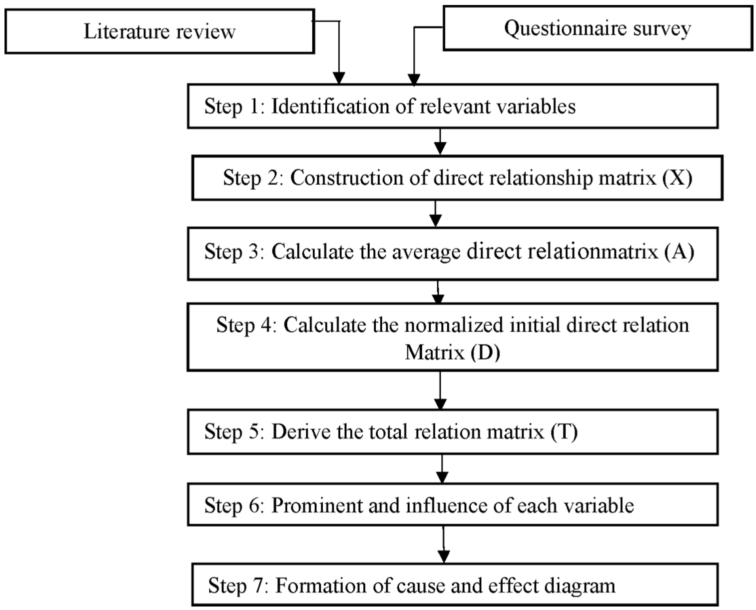
The varying characteristics of the identified DRR activities make it difficult to measure and conclude altogether. Thus, to facilitate decision making in such a scenario, causal knowledge using causal analysis can be proved useful. Decision-making trial and evaluation laboratory (DEMATEL) is one of the multi-attribute decisions making methods which can solve such management and technical cases (Bai and Sarkis, 2013). This study will also develop a causal relationship diagram by using DEMATEL methodology to explore the mutual influence of identified DRR activities.

3 Solution methodology

DEMATEL was developed at Battle Memorial Institute of Geneva Research Centre during 1972–1976 by Gabus and Fontela (1972) and their associates. As suggested by Lin and Wu (2008), Yadav and Barve (2018), Luthra et al. (2018), DEMATEL is a powerful technique in the causal analysis because it separates the variables of a problem into two groups, i.e., cause and effect groups (Gandhi et al., 2016; Mangla et al., 2016; Mangla et al., 2018; Luthra et al., 2019). Moreover, this methodology has several advantages over other multi-criteria decision making (MCDM) approaches like analytical hierarchy process (AHP), TOPSIS, analytical network process (ANP), interpretive structural modelling (ISM), etc.

This method has successfully been utilised by many researchers in their respective disciplines. For instance, identifying critical factors in emergency management (Zhou et al., 2011), analysing critical success factors of knowledge management (Patil and Kant, 2014), identification of critical success factors of humanitarian supply chains (Yadav and Barve, 2018), green supply chain management (Hsu et al., 2013) etc. are a few of the major application areas. Therefore, this study utilises DEMATEL method to explore the key activities required for DRR in the study area as per the independent strength of each activity with respect to other activities. We have followed the methodology flowchart, as shown in Figure 2, which outlines the steps, to explore the key activities for DRR.

Figure 2 Flowchart of DEMATEL



3.1 Steps of DEMATEL

Step 1: Identification of relevant variables: The relevant variables can be extracted from both primary as well as secondary sources. Primary data collection methods like Delphi survey can be utilised if variables are not explored previously. However, variables collected from secondary sources need to be verified with experts through a questionnaire survey. This study follows the latter approach to identify relevant activities.

This study utilised a questionnaire survey to finalise the identified DRR activities. As mentioned previously in Table 1, 12 activities were explored from literature and later, two more were included in the list of finalised DRR activities. These two activities were suggested by experts. These experts belong to various government and non-government disaster management organisations located in Odisha state of India. The experts were chosen from different fields of expertise and have significant contributions to disaster management during recent cyclones and floods in the Odisha. Table 2 illustrates the profiles of 18 experts who agreed to participate in the desired discussion. The experience of these experts provided a conceptual understanding of disasters, disaster risk and required measures to reduce it.

Step 2: Construction of a direct relation matrix: In this step, experts were asked to develop an initial direct relation matrix as per their expertise and field of knowledge. This process requires input from more than one expert to avoid any biased result.

After identifying the relevant DRR activities, four of the 18 experts mentioned in Table 2 were again interviewed and their assessments, using the linguistic scale of 0–4; where 0 represents no influence, 1 represents very small influence, 2 represents small influence, 3 represents high influence, and 4 represents very high influence, were recorded to explore the relative importance of each activity with respect to other activities. Although the input of four experts appears to be very small for DEMATEL method; other studies have incorporated the inputs from similar numbers of experts. In this study, the selected experts have rich experience in managing disaster and disaster-led risk. Thus, their inputs can be considered worthy to proceed the analysis. The linguistic assessments of direct relations among 14 DRR activities were obtained as an initial direct-relation matrix as indicated by equation (1).

$$X_k = x_{ij}^k \tag{1}$$

where k represents the number of experts, 'X_k' is the direct relation matrix for kth expert, x_{ij} indicates the direct impact of activity i on activities j; and when $i = j$, the diagonal elements $x_{ij} = 0$. Thus, from four experts, a total of four numbers of 14 × 14 non-negative initial direct-relation matrices were prepared.

Table 2 Profile of experts selected for study

Designation	*Experience (years)*	*Field expertise*
Block development officer (BDO)	13	Administrative management of the block
Emergency officer	08	Coping capacity, risk reduction
High school principal	15	Social and welfare issues
Account officer (block office)	16	Administrative office
Block development officer	13	Administrative management of the block
NGO President	11	Social worker
Block development officer	12	Administrative management of the block
Fire and safety officer	14	Emergency officer
Sr. Manager	15	Cyclone shelter management
Head clerk, block office	13	Administrative office
NGO Head	25	Capacity building
Associate Professor	10	Disaster management
Chairmen of panchayat	16	Social worker
Block development officer	15	Administrative management of the block
NGO coordinator	10	Inventory management
Superintendent of police (SP)	12	Law and administration
Agricultural officer	17	Relief material stock, warehousing
Assistant General Manager	15	Administrative responsibilities of the training, education and capacity building

Step 3: Calculate the average direct relation matrix (A): In this step, an average matrix A was calculated from k number of initial direct relation matrices recorded by k number of experts. Equation (2) is used for the construction of the 'average direct-relation matrix' from the direct-relation matrices developed in step 2.

$$A = [a_{ij}] = \frac{1}{K} \sum_{k}^{1 \le k \le K} x_{ij}^k \tag{2}$$

where a_{ij} represents the elements of the average direct relation matrix A. Table 3 represents the average direct relation matrix recorded from four number of experts.

Table 3 Average direct relation matrix

Factors	D_1	D_2	D_3	D_4	D_5	D_6	D_7	D_8	D_9	D_{10}	D_{11}	D_{12}	D_{13}	D_{14}
$\mathbf{D_1}$	0	1	1.5	2	1.25	1.25	2.25	1.25	1.5	0.75	1.5	1.25	0.5	1.75
$\mathbf{D_2}$	2	0	0.5	3.5	0.75	1.5	2.5	1	1.25	2.25	1.75	1.25	1	2.5
$\mathbf{D_3}$	1.75	1.25	0	1.25	0.5	1	2	1.5	2.25	1.5	1.25	2.25	0.5	0.75
$\mathbf{D_4}$	3	2.25	1	0	1	2.5	2.5	2.25	2	2.25	1.75	1.25	1.75	2.5
$\mathbf{D_5}$	2	1.25	0.25	1.5	0	2	1.25	1.75	1.25	1.5	1.25	1	0	1.5
$\mathbf{D_6}$	2.75	1.5	0	2	0.25	0	2	1.75	1	1	0.25	0.5	0.75	0.5
$\mathbf{D_7}$	3.25	1.75	1.75	2.75	2	2	0	2.25	2.25	2.5	2.5	2	2	3.25
$\mathbf{D_8}$	2	1.5	0.25	1.5	0.25	0.25	1	0	1	0.5	0.75	0.25	0.25	0.75
$\mathbf{D_9}$	2.5	0.5	0.75	2.5	0.75	0.75	2	1.5	0	1	1.25	1.5	0.5	1
$\mathbf{D_{10}}$	2.25	2.25	0.75	1	0.25	1	1.5	1.25	0.75	0	0.5	0.75	0	2
$\mathbf{D_{11}}$	1.75	1.25	0.25	2	0.5	0.25	1.25	1.5	0.75	1.25	0	0.75	0.25	1
$\mathbf{D_{12}}$	2.25	0.5	0.75	1.25	1	1.5	1.5	1.75	1.25	1.5	1	0	0.75	1
$\mathbf{D_{13}}$	0.75	0	0	0.75	0.25	0.25	1	0	0.75	0	0.5	0.75	0	0.25
$\mathbf{D_{14}}$	2.5	2.5	0.75	2.5	0	2	2.25	1.72	1	1.25	1.5	1.5	0.75	0

Table 4 Normalised initial direct relation matrix

Factors	D_1	D_2	D_3	D_4	D_5	D_6	D_7	D_8	D_9	D_{10}	D_{11}	D_{12}	D_{13}	D_{14}
D1	0.000	0.033	0.050	0.066	0.041	0.041	0.074	0.041	0.050	0.025	0.050	0.041	0.017	0.058
D2	0.066	0.000	0.017	0.116	0.025	0.050	0.083	0.033	0.041	0.074	0.058	0.041	0.033	0.083
D3	0.058	0.041	0.000	0.041	0.017	0.033	0.066	0.050	0.074	0.050	0.041	0.074	0.017	0.025
D4	0.099	0.074	0.033	0.000	0.033	0.083	0.083	0.074	0.066	0.074	0.058	0.041	0.058	0.083
D5	0.066	0.041	0.008	0.050	0.000	0.066	0.041	0.058	0.041	0.050	0.041	0.033	0.000	0.050
D6	0.091	0.050	0.000	0.066	0.008	0.000	0.066	0.058	0.033	0.033	0.008	0.017	0.025	0.017
D7	0.107	0.058	0.058	0.091	0.066	0.066	0.000	0.074	0.074	0.083	0.083	0.066	0.066	0.107
D8	0.066	0.050	0.008	0.050	0.008	0.008	0.033	0.000	0.033	0.017	0.025	0.008	0.008	0.025
D9	0.083	0.017	0.025	0.083	0.025	0.025	0.066	0.050	0.000	0.033	0.041	0.050	0.017	0.033
D10	0.074	0.074	0.025	0.033	0.008	0.033	0.050	0.041	0.025	0.000	0.017	0.025	0.000	0.066
D11	0.058	0.041	0.008	0.066	0.017	0.008	0.041	0.050	0.025	0.041	0.000	0.025	0.008	0.033
D12	0.074	0.017	0.025	0.041	0.033	0.050	0.050	0.058	0.041	0.050	0.033	0.000	0.025	0.033
D13	0.025	0.000	0.000	0.025	0.008	0.008	0.033	0.000	0.025	0.000	0.017	0.025	0.000	0.008
D14	0.083	0.083	0.025	0.083	0.000	0.066	0.074	0.057	0.033	0.041	0.050	0.050	0.025	0.000

Table 5 Total relation matrix *T*

Factors	D_1	D_2	D_3	D_4	D_5	D_6	D_7	D_8	D_9	D_{10}	D_{11}	D_{12}	D_{13}	D_{14}
$\mathbf{D_1}$	0.107	0.100	0.084	0.154	0.076	0.103	0.155	0.114	0.112	0.091	0.109	0.096	0.054	0.129
$\mathbf{D_2}$	0.193	0.085	0.062	0.219	0.068	0.126	0.183	0.122	0.117	0.151	0.130	0.107	0.079	0.171
$\mathbf{D_3}$	0.158	0.103	0.036	0.128	0.052	0.091	0.145	0.119	0.132	0.111	0.099	0.125	0.052	0.096
$\mathbf{D_4}$	0.237	0.163	0.081	0.127	0.080	0.162	0.195	0.169	0.148	0.158	0.138	0.115	0.105	0.179
$\mathbf{D_5}$	0.159	0.102	0.041	0.131	0.032	0.119	0.117	0.122	0.096	0.106	0.094	0.080	0.033	0.115
$\mathbf{D_6}$	0.171	0.102	0.032	0.138	0.039	0.051	0.133	0.114	0.084	0.085	0.060	0.061	0.056	0.080
$\mathbf{D_7}$	0.265	0.161	0.110	0.227	0.117	0.160	0.135	0.184	0.168	0.178	0.172	0.149	0.118	0.214
$\mathbf{D_8}$	0.126	0.088	0.031	0.104	0.031	0.047	0.085	0.044	0.070	0.056	0.062	0.042	0.031	0.071
$\mathbf{D_9}$	0.176	0.079	0.059	0.161	0.059	0.083	0.142	0.116	0.060	0.093	0.097	0.099	0.052	0.102
$\mathbf{D_{10}}$	0.157	0.127	0.055	0.110	0.038	0.084	0.120	0.100	0.077	0.055	0.068	0.070	0.032	0.126
$\mathbf{D_{11}}$	0.132	0.090	0.036	0.129	0.043	0.055	0.102	0.101	0.071	0.088	0.045	0.064	0.036	0.088
$\mathbf{D_{12}}$	0.161	0.074	0.055	0.117	0.063	0.100	0.120	0.118	0.094	0.102	0.083	0.047	0.055	0.095
$\mathbf{D_{13}}$	0.057	0.020	0.012	0.052	0.021	0.028	0.058	0.024	0.044	0.021	0.036	0.042	0.012	0.032
$\mathbf{D_{14}}$	0.197	0.154	0.066	0.182	0.042	0.133	0.168	0.136	0.104	0.114	0.117	0.109	0.068	0.086

Step 4: Calculate the normalised initial direct relation matrix (D): This step requires getting a normalised matrix for further calculation. As per this step, each element in the matrix *D* falls in the range of $0 \le d_{ij} \le 1$, and all principal diagonal elements are equal to zero. Table 4 shows the normalised initial direct relation matrix.

$$D = \left[d_{ij}\right] = \frac{1}{\max_{1 \le i \le n} \sum_{j=1}^{n} a_{ij}} A \tag{3}$$

Step 5: Derive the total relation matrix (T): This matrix gives the strength of influence given by each variable on other variables as well as received by each variable from other variables.

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

where '*I*' is the identity matrix. Table 5 shows the total relation matrix *T*.

Step 6: Prominence and influence of each activity: This step gives the overall degree of influence of each variable on the entire system as well as received by the entire system. This step is utilised to develop the causal model as well as cause and effect group model. The sum of the *i*th row r_i of the matrix '*T*' is done to calculate total effects both direct and indirect, exerted by the *i*th factor on other factors. Next, the sum of *j*th column 'c_j' of the matrix '*T*' is calculated to assess the total effect, direct and indirect, received by *j*th factor from other factors. The sum of rows and column, which are separately calculated, are represented as the vector r_i and c_j, respectively, obtained utilising the equations (5) and (6).

$$r_i = \sum_{1 \le j \le n} t_{ij} \tag{5}$$

$$c_i = \sum_{1 \le i \le n} t_{ij} \tag{6}$$

when $j = i$, the expression $(r_i + c_j)$ denotes the degree of effect of the variable '*i*' on the system, and $(r_i - c_j)$ indicates the net influence variable '*i*' contributes to the system (Shieh et al., 2010; Yadav and Barve, 2018; Luthra et al., 2019). Table 6 shows the cause/effect parameters for activities of DRR.

Step 7: Formation of cause and effect diagram: The cause and effect graph represented in Figure 3 is the outcome of the dataset $(r_i + c_j, r_i - c_j)$ for all $i = j$. The 'cause and effect diagram' was developed by following the two sub-steps.

Step 8a: Set up a threshold value: A suitable threshold value is obtained from *T* matrix (Yadav and Barve, 2018) to identify the key variables. In this research, the threshold value is calculated by adding one standard deviation to the mean of all values in total matrix *T*. The values of mean and standard deviation were 0.1005 and 0.0448 respectively. So, the threshold value becomes 0.1492. All the values equal and greater than this threshold value in Table 7, which are written in Bold, were used to obtain a causal digraph to represent the interaction between the DRR activities.

Step 8b: Formation of overall prominence-causal relationship diagram: Figure 4 illustrates the causal relationship among DRR activities, which was developed with the results given in Tables 6 and 7, to observe general patterns and hidden relationships among selected activities. The values shown in Table 6 were used for categorising enablers into cause and effect group, and the values equal and greater than the threshold value in Table 7 have been used to represent the influence of individual activities on other activities. The arrow represents the direction from cause activities to effect activities. For example, activity D7, which appears in cause group, affects most of the DRR activities including D1, D2, D4, D8, D9, D10, D11, D12, and D14. These influences are represented in Figure 4 through one-directional arrows. Two-way relationships between activities are represented through broken lines in Figure 4. For example, activities D2 and D4 are affecting each other.

Table 6 Cause/effect parameters for DRR activities

Factors	r_i	c_j	$r_i + c_j$	$r_i - c_j$
D_1	1.482	2.2968	3.778	–0.8153
D_2	1.813	1.4490	3.262	0.3639
D_3	1.446	0.7600	2.206	0.6865
D_4	2.056	1.9812	4.038	0.0752
D_5	1.348	0.7588	2.107	0.5895
D_6	1.205	1.3410	2.546	–0.1360
D_7	2.357	1.8555	4.213	0.5017
D_8	0.888	1.5821	2.470	–0.6941
D_9	1.378	1.3781	2.756	0.0002
D_{10}	1.219	1.4063	2.626	–0.1872
D_{11}	1.079	1.3108	2.390	–0.2316
D_{12}	1.282	1.2056	2.488	0.0768
D_{13}	0.458	0.7823	1.240	–0.3243
D_{14}	1.676	1.5816	3.258	0.0948

Figure 3 Cause and effect diagram (see online version for colours)

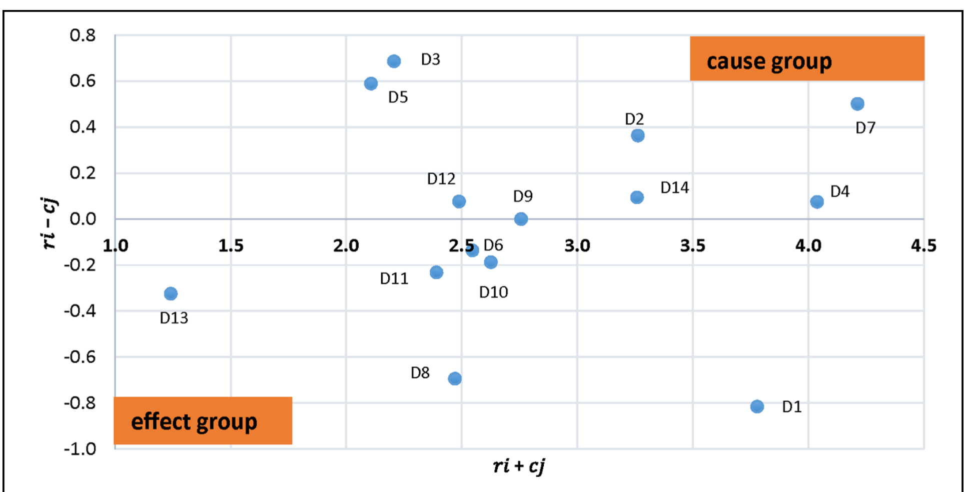
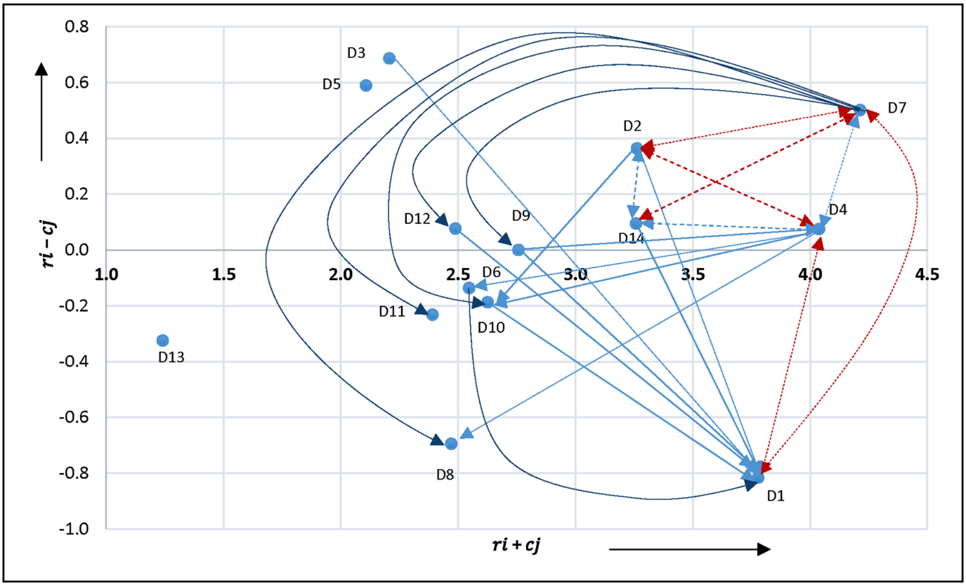


Table 7 Total relation matrix *T* with threshold values

Factors	*D1*	*D2*	*D3*	*D4*	*D5*	*D6*	*D7*	*D8*	*D9*	*D10*	*D11*	*D12*	*D13*	*D14*
D1	0.107	0.1	0.084	**0.154**	0.076	0.103	**0.155**	0.114	0.112	0.091	0.109	0.096	0.054	0.129
D2	**0.193**	0.085	0.062	**0.219**	0.068	0.126	**0.183**	0.122	0.117	**0.151**	0.13	0.107	0.079	**0.171**
D3	**0.158**	0.103	0.036	0.128	0.052	0.091	0.145	0.119	0.132	0.111	0.099	0.125	0.052	0.096
D4	**0.237**	**0.163**	0.081	0.127	0.08	**0.162**	**0.195**	**0.169**	0.148	**0.158**	0.138	0.115	0.105	**0.179**
D5	**0.159**	0.102	0.041	0.131	0.032	0.119	0.117	0.122	0.096	0.106	0.094	0.08	0.033	0.115
D6	**0.171**	0.102	0.032	0.138	0.039	0.051	0.133	0.114	0.084	0.085	0.06	0.061	0.056	0.08
D7	**0.265**	**0.161**	0.11	**0.227**	0.117	0.16	0.135	**0.184**	**0.168**	**0.178**	**0.172**	**0.149**	0.118	**0.214**
D8	0.126	0.088	0.031	0.104	0.031	0.047	0.085	0.044	0.07	0.056	0.062	0.042	0.031	0.071
D9	**0.176**	0.079	0.059	**0.161**	0.059	0.083	0.142	0.116	0.06	0.093	0.097	0.099	0.052	0.102
D10	**0.157**	0.127	0.055	0.11	0.038	0.084	0.12	0.1	0.077	0.055	0.068	0.07	0.032	0.126
D11	0.132	0.09	0.036	0.129	0.043	0.055	0.102	0.101	0.071	0.088	0.045	0.064	0.036	0.088
D12	**0.161**	0.074	0.055	0.117	0.063	0.1	0.12	0.118	0.094	0.102	0.083	0.047	0.055	0.095
D13	0.057	0.02	0.012	0.052	0.021	0.028	0.058	0.024	0.044	0.021	0.036	0.042	0.012	0.032
D14	**0.197**	**0.154**	0.066	**0.182**	0.042	0.133	**0.168**	0.136	0.104	0.114	0.117	0.109	0.068	0.086

Figure 4 Digraph showing causal relations among DRR activities (see online version for colours)



4 Discussion

Table 6 shows the impact levels of each factor and their segmentation in cause and effect groups. As per the DEMATEL theory, the factors with positive values of '$r_i - c_j$' are considered as cause group factors while those are with negative scores appear in effect group. The DRR activities having positive '$r_i - c_j$' values are: "Organizing disaster risk reduction awareness program at regular interval" (D_2), "Sufficient number of cyclone shelter (both temporary and permanent)" (D_3), "Coordination between government and other agencies" (D_4), "all-weather road connectivity" (D_5), "Emergency planning at various level" (D_7), "Availability of relief items at the various relief distribution centre" (D_9), "Hazard, risk and vulnerability assessments" (D_{12}), and "Strengthening capacity of disaster management institutions" (D_{14}). The factors with negative values of '$r_i - c_j$' are: "Availability of quick communication restoration mechanism" (D_1), "Dissemination of multi-language early warning" (D_6), "Arrangement and distribution of emergency kit" (D8), "Mock drill for population under risk" (D_{10}), "Arrangement of medical facility (temporary and permanent health centre)" (D_{11}), and "Arrangement of livelihood measures for affected population" (D_{13}).

As per the ($r_i + c_j$) values in Table 6, the importance of the DRR criteria can be prioritised as $D_7 > D_4 > D_1 > D_2 > D_{14} > D_9 > D_{10} > D_6 > D_{12} > D_8 > D_{11} > D_3 > D_5 > D_{13}$. Here, "Emergency planning at various levels" (D_7) is the most important criterion with the ($r_i + c_j$) value of 4.213, while "Arrangement of livelihood measures for affected population" (D_{13}) is the least important criterion with the value of 1.240. In contrast to the importance, "Sufficient number of cyclone shelter (both temporary and permanent)" (D_3), "All-weather road connectivity" (D_5), "Hazard, risk and vulnerability assessments" (D_{12}), are appearing as cause group factor, while "Dissemination of multi-language early warning" (D_6), "Mock drill for population under risk" (D_{10}), "Arrangement and distribution of emergency kit" (D_8), and "Availability of quick communication restoration mechanism" (D_1), are effect group factors on the basis of their $r_i - c_j$ values. Therefore, unlike other studies simply considering the cause group as important factors, this study explicitly analyses $r_i + c_j$ and $r_i - c_j$ score of each DRR activity to identify the important measures for DRR.

As per $r_i - c_j$ values, "sufficient number of cyclone shelters (both temporary and permanent)" (D_3) ranks first with value of 0.6865, which means that D3 shows more impact on the whole system, then it receives from other activities. This finding is supported by the findings of Yadav and Barve (2018). Thus, the construction of cyclone shelters along the coastline of Odisha would result in minimising the cyclone-led risk. Moreover, the availability of all-weather road (D_5) is also important to facilitate the arrival of relief material on time.

DRR activity "Emergency planning at various level (state, district, block, village and household)" (D_7) appears at the third place in cause group factors, and meanwhile, its influential impact index r_i is as high as 2.357. This indicates that D_7 has a significant influence on the whole system. So, all the evidence suggests that D_7 is an important activity. As per the literature on emergency management (Zhou et al., 2014) and humanitarian supply chains (Yadav and Barve, 2019) emergency planning at all levels (D_7) is one of the most influencing factors, which drives all pre and post-disaster measures. Therefore, this activity can be considered as one of the important DRR activities.

Although, the $r_i - c_j$ score of "Coordination between government and other agencies" (D_4) is in the seventh place in all-cause factors, the value of $r_i + c_j$ is relatively high. So, this evidence suggests that D_4 is an important activity that influences other activities to reduce disaster risk.

As per the cause-effect relationship diagram in Figure 4, we can see that "Availability of quick communication restoration mechanism" (D_1) is an effect factor with $r_i - c_j$ as –0.8153. It means that this activity highly depends on other DRR activities, although it has a considerable impact on the system at the same time. Therefore, D_1 cannot be added in the priority list of activities because if other activities performed properly, then effective relief will certainly reach to the needy.

According to the outcomes derived from DEMATEL method, the impact dispatched from D_9 and D_{12} on other factors is greater than the impact they receive from all other activities. As per the r_i and c_j scores, it is obvious that D_9 and D_{12} do not have a notable impact on the whole system, but their importance during and before disasters makes them significant factors for DRR. Thus "Availability of relief items at various relief distribution centre" (D_9) and "Hazard, risk and vulnerability assessments" (D_{12}), can be considered as highly valued DRR activities.

"Organizing disaster risk reduction awareness program at regular interval" (D_2) ranks fourth among '$r_i - c_j$' values. As Figure 4 shows, D_2 is affecting the five activities: D_1, D_4, D_7, D_{10}, and D_{14}. In addition, '$r_i + c_j$' score of D_2 suggests that it has a considerable impact on the entire disaster management system. Therefore, D_2 can be considered among those on the list of priority activities.

Similarly, as per '$r_i - c_j$' score, "strengthening the capacity of disaster management institutions" (D_{14}) ranks fifth among all DRR activities. This activity is highly important to achieve a successful response due to the high involvement of various stakeholders in DRR. Its '$r_i + c_j$' is 3.258, which suggest that this activity (D_{14}) has notable/significant impact in the process of DRR. It can be concluded from Figure 4 that the cause group

DRR activities have the potential to influence effect group activities. Therefore, this study suggests performing the activities based on '$r_i - c_j$' values. To summarise, disaster management organisations should focus on cause group DRR activities (D_3, D_5, D_7, D_2, D_{14}, D_{12}, D_4, D_9). Every household, village, panchayat, district and state should consider having their own detailed and independent emergency plan (D_7), making the community aware about the various disaster with the help of organising DRR awareness program at a regular interval (D2). Strengthening the capacity of disaster management institutions (D_{14}) could help in assisting each other. A successful relief operation demands coordination between government and other agencies (D_4). If there is a lack of coordination among agencies, the activities performed or rescue plans will not be effective and successful; and it helps in making sure that the relief items will be available at various relief distribution centres (D_9). This shows that DRR can be achieved only when there are pre-planned activities pertaining to disaster management. If pre-disaster activities are effectively planned then there will be less chance of being affected during disasters. Though other activities are carried out to minimise disaster risk, such as dissemination of multi-language early warning (D_6), mock drill for population under risk (D_{10}), arrangement of medical facility (temporary and permanent health centre) (D_{11}), arrangement of livelihood measures for affected population (D_{13}), arrangement and distribution of emergency kit (D_8), availability of quick communication restoration mechanism (D_1), these activities have relatively less influences on risk reduction and here they are categorised as effect (dependent) group activities.

5 Managerial implications

Some of the implications emerging from this study include:

- The segmentation of DRR activities into cause and effect groups helps in recognising the important activities needed to focus on minimising disasters-led risk.
- The sufficient number of cyclone shelters (both temporary and permanent) is appearing as a significant activity. Hence HROs (Humanitarian relief organisation) should work to construct the adequate number of cyclone shelters in high-cyclone risk zones.
- As per the results, the appearance of 'Emergency planning at various levels' as one of the significant DRR activities indicates the growing importance of planning in an emergency scenario. Hence various relief organisations should focus first on emergency planning at various levels (state, districts, village, and individual household) rather than only to be an aid distribution organisation.
- Figure 4 replicates the impact of each activity in comparison to the other activities. It can be seen in Figure 4 that D_7 has more impact on other activities (i.e., it affects D_1, D_2, D_4, D_8, D_9, D_{10}, D_{11}, D_{12}, D_{14}). Thus, disaster relief agencies should identify such activities and start adopting the strategy to practise them.

6 Conclusion and scope for future work

This study has endeavoured to identify and determine the causal relationships between various DRRs activities needed for mitigating cyclones-led risk in Odisha. Initially, the study discussed why DRR activities are important in the context of cyclones; later, experts' opinions were taken to identify and develop a causal model among the identified 14 DRR activities. In this study, DEMATEL method has been used to segregate the selected activities into two groups, cause group and effect group; and develops the causal structure of relationships among the activities. As per the result of the analysis, activities "Organising disaster risk reduction awareness program at regular interval" (D_2), "Sufficient number of cyclone shelter (both temporary and permanent)" (D_3), "Coordination between government and other agencies" (D_4), "all weather road connectivity" (D_5), "Emergency planning at various level" (D_7), "Availability of relief items at the various relief distribution centre" (D_9), "Hazard, risk and vulnerability assessments" (D_{12}), "Strengthening capacity of disaster management institutions" (D_{14}), have been segregated as the cause group, whereas "Availability of quick communication restoration mechanism" (D_1), "Dissemination of multi-language early warning" (D_6), "Arrangement and distribution of emergency kit" (D_8), "Mock drill for population under risk" (D_{10}), "Arrangement of medical facility (temporary and permanent health centre)" (D_{11}), "Arrangement of livelihood measures for affected population" (D_{13}) have been segregated as effect group activities.

The activities appearing in the cause group were determined to be the most influencing activities, meaning that they affect other DRR activities belonging to both cause and effect groups. Some of the activities do not influence any other activity. Activities "all-weather road connectivity" D_5, and "Availability of communication restoration mechanism" D_{12} of cause group and D_6, D_8, and D_{11} of effect group were found as independent, meaning that these are not influencing other activities despite belonging to cause-effect group activities. The activities – Sufficient number of cyclone shelter (both temporary and permanent), Emergency planning at various level, strengthening of disaster management institutions, Organising DRR awareness program at regular interval, and Coordination between government and other agencies – have been found as the most influencing DRR activities in the context of managing disaster-led risk of cyclones in Odisha. Nonetheless, the successful implementation of DRR practices requires adequate planning and commitment to execute those plans in both the short-term and the long term.

However, the present study has its limitations, which could open new directions for future research. Firstly, the qualitative perceptions of the experts were analysed to suggest policy implication; the output of the applied method could be verified using quantitative methods. Secondly, limited data were collected through personal interviews with persons associated with disaster management, while in a study focused on DRR; inputs could have been collected from the affected population too. Future research can be progressed to confirm the importance and impact of different dimensions of DRR in other parts of the globe.

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