J. Environ. Treat. Tech.
ISSN: 2309-1185

Journal web link: http://www.jett.dormaj.com

A Formulation of Big Data Analytics Model in Strengthening the Disaster Risk Reduction

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Received: 13/08/2019 Accepted: 18/01/2020 Published: 20/02/2020

Abstract

A natural disaster is a serious event that contributes to the damage of infrastructures and property losses, the demand of budgetary allocation, disruption of economic and social activities, damages to the environment, and threat to human life. In disaster management, one of the aims is to reduce the impact of natural disaster through disaster risk management. However, the traditional data risk management mechanism to store and analyse huge disasters has become a challenge for relevant organizations due to its massive datasets, especially when it deals with big data and analytics. Therefore, the aim of this paper is to formulate a big data analytics model to strengthen the disaster risk reduction for Selangor State, Malaysia, comprehending both traditional datasets (geospatial data) and big data analytics (nonspatial data). To this end, 59 factors and available datasets were classified into six categories: ecology, economic, environment, organisation, social, and technology. These factors were derived from existing studies and then validated in a focus group discussion with 54 government agencies involved disaster risk management in Selangor State, Malaysia. The final output of this paper is Big Data Analytics Model for Disaster Risk Reduction, which will be useful to all stakeholders related to disaster risk management and disaster risk reduction initiatives.

Keywords: Disaster risk management; Disaster risk reduction; Big data analytics; Selangor state

1 Introduction

Disaster is an event that occurs around the globe; as a key challenge, it contributes to serious disruptions to human life, economy, and sustainable development. Several factors have most significant contribution to disaster: hazard inherent from the nature, the extent to which people and their belongings are exposed to it, vulnerability of affected human and assets, and their ability to minimize or manage with the possible harm[1]. Briefly, disaster definition reflects the losses and the ability to cope with the impact. The United Nations International Strategy for Disaster Reduction (UNISDR) referred disaster as a serious disruption towards the society or a functional community, involving economic or environmental impacts and also loss of human life and properties, which is beyond the ability of the affected community and society to survive using its own supplies and resources [2].

Disaster Risk Reduction (DRR) is clearly accepted as the development and implementation of policies, strategies, and practices to reduce vulnerabilities and disaster risks across society. Often used in the same context, the term 'Disaster Risk Management' (DRM) refers to a systematic approach to identifying, assessing, and reducing risks of any disaster. DRM is known to be more focused on implementing supports and plan for achieving DRR identified goals, but these two terms are used interchangeably and have some overlap that provides very similar meaning in practice.

In this modern age, decision-makers have started to focus on applying enormous data to their decision-making processes. Enormous data, which is also referred to as Big Data, is a huge dataset that is high in volume, variety, and velocity; in this regard, a challenging issue is how to manage it using traditional techniques and tools[3]. Thus, to satisfy these managing requirements and extract the value and knowledge from huge datasets that are growing every second, a modern solution need to be developed. In addition, solution provided might be beneficial to decision-makers for their valuable insights into such diverse and rapidly changing data (involving structured, semi-structures, and unstructured data) ranging from daily transactions to customer interactions and social network data. Big data analytics can help to produce the value of big data that later can be harvested [4].

No doubt that good governance and fast decision making process influence the impact of disaster to community as suggested by previous studies by Sukowati and Nelwan [5] and Waheed and Ali [6]. In addition, the ability of big data in visualising, analysing, and predicting disasters has been

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focused on much work done by researchers to help to manage disasters [7, 8]. Furthermore, big data analytics provide a value that is able to support crisis management and enhance humanitarian operations. However, the challenges with the big data are how to manage regarding issues such as data mining (storing, interlinking, and processing), which is due to the characteristics of the volume and velocity of the data itself [9, 10]. In addition, disaster-related data consist of both spatial and nonspatial data, which makes the data analysis process more complex [8, 11]. From the recent studies, there is still a gap in integrating the big data analytics with DRR practices. Such integration would help to reduce complexity in traditional data management mechanisms and enable new kind of disaster preparedness and prevention services. Therefore, the aim of this paper is to formulate a big data analytics model applicable to disaster risk reduction.

2 Related Work

In 2015, the United Nations Office for Disaster Risk Reduction (UNISDR) reported that globally, disasters contributed to over 1.3 trillion USD economic losses over a 10-year period [2]. More importantly, 144 million people were displaced, over 1.4 million injured, and roughly 23 million left homeless. Asia, as home to 60% of the world's population, is considered one of the largest disaster-prone areas. Based on the international disaster database OFDA/CRED 1990-2015, Malaysia has reported an average annual loss of more than 1.3 billion USD from multi-hazards disasters [12].

In Malaysia, the December 2014 floods in East Coast Peninsular affected the life of more than half a million people and inflicted damages up to RM 2.85 billion on public infrastructure [13]. In June 2015, the Sabah earthquake, with more than 200 aftershocks, caused 18 human casualties, tormenting the local community in the Borneo's most popular tourist area and its UNESCO World Heritage sites. While in the Cameron Highlands, Malaysia, the 2013-2014 disasters caused direct socioeconomic impacts, with tourism numbers falling 20%. These impacts remind us there is still much to be done to strengthen the nation's resilience to disasters and sustainable development.

No doubt, DRM is crucial in reducing the impacts and losses due to unexpected disasters. DRM involves conceptual practices together with an organized strategy to deal and mitigate the risks through a systematic approach to understanding, analysing, monitoring, predicting, and managing the factors and the occurrences of disaster. In general, disaster management consists of the combination of many interrelated processes of continual, dynamic management, and plan for responding to emergency events [14]. Disaster management may not be able to eliminate the risk; however, it is able to give prediction for early warning, which can help to minimize the threats towards humanity.

2.1 Disaster Risk Reduction

To reduce the damage caused by a natural disaster, an initiative by the United Nations called Disaster Risk Reduction (DRR) was introduced. The aim is to minimize the affected damage caused by natural hazards through an ethic of prevention[2]. DRR includes disciplines like disaster management, disaster mitigation, and disaster preparedness. DRR must be incorporated to ensure that the goals of sustainable development can be achieved. Another initiative from the United Nations called Sustainable Development Goals (SDGs) was also introduced (SDGs, 2018; SDSN, 2015). The achievement of the stated SDGs requires major transformation in the ecosystem of major areas such as urban planning, energy use, healthcare, educational system, land use, and technologies deployment. Yet, few challenges have arisen when incorporating the SDGs 2030 perspective into budget planning, audits, procurement policies, human resource management, regulations, and related public policy needed.

2.1 Big Data Role in Disaster Risk Reduction

Emerging technology in big data is known as innovative technology that provides new ways to extract value from the tsunami of available information. The interpretation of big data may differ in the defined concept and term as there is no commonly-accepted definition for the Big Data term. In the context of big data for DRR, data must be diverse in Variety, high in Velocity, and huge in Volume, which is known as the 3Vs big data model [15]. Researchers have extended the Vs up to 9Vs, adding terms like Visualization, Veracity, Value, and Viability.

A data-driven solution in reducing disaster risks have long been recognized for their cross-cutting linkage among key stakeholders such as scientists, policymakers, emergency responders, and practitioners, and their major influential role. This is explained well through the reviews done by Arslan, Roxin [10] and Akter and Wamba [16]. There are a growing number of studies of Big Data Analytics (BDA) in the area of disaster, among them are Zobel and Khansa [17] in characterizing multi-event disaster resilience; Emmanouil and Nikolaos [18] on how big data analytics is utilized in prevention, preparedness, response, and recovery in crisis and disaster management; Papadopoulos, Gunasekaran [19] on big data role for disaster resilience; and Masood, So [20] focusing on BDA for supply chain during disaster. In Malaysia, Abdullah, Ibrahim [12] proposed a Big Data Analytics Framework for Natural Disaster Management in their studies.

One of the most important benefits of applying BDA to DRR is that value of information resulting from the analysis of Big Data can assist to do advanced prediction of disaster or, at least, minimize the disaster-induced risks affecting the ecosystem [18]. Researchers found that the use of big data in disaster analysis results in disaster preparedness with suggested proactive deployment of required resources for coping with an impeding type of disaster in disaster management [12, 18]. The application of real time big data analysis is able to alert the risk administration or person involved in the area about the need for most urgent attention together with directive approach of recovery procedure including coordination of volunteer and related logistics needed during the event of disaster [21].

Establishing an effective DRR is a global challenge. It has become an essential factor in promoting big data analytics towards the capabilities of strengthening and improving the area of DRR to save lives, prevent and reduce losses, and strengthen the resilience of cities [9]. Application of big data technology requires involvement of different parties, which needs having experts from various backgrounds such as environmental science, social science, statistics, meteorology, and computer science. Identifying the different sets of data of different types of disaster from various agencies and the ability to integrate it has become one of the key challenges in this field. This integration may be able to provide valuable insight for the policymakers, civil society organisations, research centres, business, and related stakeholders to make informed decisions.

3 Methodology

The study started with a review of DRM and DRR models proposed already in literature with aim of identifying the dimensions and key elements of disaster. This study analysed four models and proposed six dimensions, which are ecology, economic, environment, organisation, social, and technology. There are also 15 key elements identified related to these dimensions. Then, it was followed by a focus group discussion (FGD) with Selangor State Disaster Management Unit (SDMU) and 54 Malaysian government agencies involved in DRM/DRR. The aim of FGD was to verify the DRR dimension and key elements and to confirm the related datasets of each key elements.

During FGD, all participants were given a set of questionnaire and interview questions to validate the proposed dimensions and key elements. Meanwhile for the datasets information, a guided interview session was conducted during the FGD. The results obtained from the FGD session confirmed all the 6 dimensions, 15 key elements, and the identification of new 60 datasets.

4 Results and Discussion

This section presents the results and discussion in regard to the topic of the research that started by the review of the existing models, and followed by the discussion on FGD results.

Table 1: Comparison of Disaster Management frameworks and models

Code	Model Name	Dimensions	Theory	Key elements
M1	Technology, Organisation, Social, Economy (TOSE) Framework [22]	• Technology • Organisation • Social • Economy	TOSE	• Disaster emergency management • Training • Leadership experience • Community/social vulnerability • Information system management • Economic process and activity
M2	The PEOPLES Framework [23]	• Population and Demographics (Social) • Environmental/Ecosystem Services (Environment) • Organized Governmental Services (Organisation) • Physical Infrastructure (Technical) • Lifestyle and Community Competence (Social) • Economic Development (Economic) • Social-Cultural Capital (Social)	N/A	• The functionality of population and demographics • Community/Social vulnerability • Cultural values • The ability of the ecological system to return to or near its pre-event state • Disaster emergency management • Information system management • Facilities (housing, commercial facilities, and cultural facilities) • Lifeline (food supply, health care, utilities, transportation, and communication networks) • Economic process and activity • Community and social support • Resource allocation
M3	Disaster Press & Release Model [24]	• Social • Economy • Political	Crunch Model	• Infrastructure environment • Economic process and activity • Community and social support • Training • Leadership experience • Community/social vulnerability • The functionality of population and demographics • Facilities (housing, commercial facilities, and cultural facilities) • Political influence • Resource allocation • Disaster emergency management
M4	Complex adaptive system (CAS) theory [25]	• Social • Economic • Political, • Physical, • Ecological	Complex Adaptive System (CAS) theory	• The functionality of population and demographics • Community/social vulnerability • Disaster emergency management • Political influence • Economic process and activity

4.1 Review of Existing Related Models

Current literature comprises a limited number of models designed by different researchers working in relevant field of study. A review of literature was done searching with five keywords: 'disaster risk reduction', 'disaster management', 'disaster risk management', 'big data', and 'big data analytics'. Based on extensive review and analysis of the relevant literature, four related models were found, as follow:

M1: Technology, Organisation, Social, Economy (TOSE) Framework (Vugrin et al., 2010) [22]
M2: The PEOPLES Framework (Renschler et al., 2010) [23]
M3: Disaster Press & Release Model (Hai & Smyth, 2012) [24]
M4: Complex Adaptive System (CAS) theory (Coetzee, Van Niekerk, & Raju, 2016) [25]

Table 1 highlights the findings of recent studies, which consist of dimensions (how the study view the DRM/DRR solution), the theory used in the study, and key elements (what are the associated factors/items). Based on the comparison of the models and the theories and frameworks presented, two gaps were identified. Firstly, each model, framework, and theory has a different dimension in measuring DRM and DRR. Secondly, the key elements extracted from all models have no consistency. Therefore, this study captures all the identified key elements and dimensions that contribute to DRR and expands them by identifying the related datasets in order to formulate the big data analytics solution. Table 2 presents the proposed BDA in DRR dimensions and key elements.

Table 2: The identified dimensions and key elements for Big Data Analytics in Disaster Risk Reduction

Category	Key Element(s)
Technology	Information system management
Organisation	Disaster emergency management
	Training
	Leadership experience
	Facilities (housing, commercial facilities, and cultural facilities)
	Lifeline (food supply, health care, utilities, transportation, and communication networks)
	Political influence
Social	Community/social vulnerability
	The functionality of population and demographics
	Cultural values
	Community and social support
Ecology	The ability of the ecological system to return to or near its pre-event state
Economic	Economic process and activity
	Resource allocation
	Infrastructure environment

4.2 Focus Group Discussion Results

Findings from FGD resulted in 59 datasets related to DRM/DRR. These findings are results of the consolidation of the FGD participants from 54 agencies. Table 3 presents the list of datasets categorized by the dimensions determined earlier.

4.3 BDA DRR Model Formulation

The next step is the formulation of BDA for the DRR model. The dimensions, key elements, and datasets were verified through the FGD sessions. The underpinning theory for this model is Technology, Organisation, Social, Environment, Economic, and Ecology (TOSEEE) suggested by Vugrin [22]. The chosen model has been previously used in disaster resilience measurement, and this study extended its scope into DRR context. The model dimension is originated from TOSEEE, while the key components and datasets are derived from the study scope, which is DRR in Selangor State, Malaysia. Figure 1 shows the completed model of this study. To validate the model, all FGD respondents were given a set of questionnaires to rank the importance and relevancy of the dimensions, key elements, and datasets. A total of 57 respondents participated during the session. In the survey, each respondent was asked to select their answers based on review score from 1 to 5, which represent: Respondent Score (RS) 1: Very Low Importance, RS 2: Low Importance, RS 3: Medium Importance, RS 4: High Importance, and RS 5: Very High Importance.

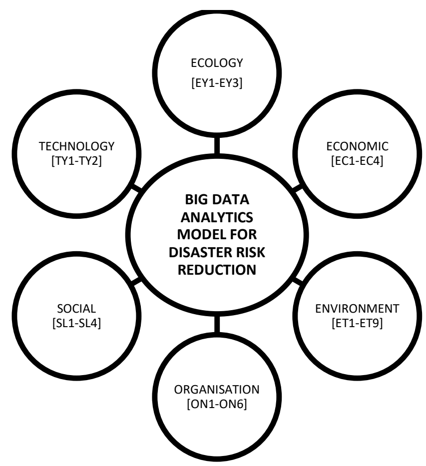

Figure 1: Big Data Analytics Model for Disaster Risk Reduction

It was found out that all key elements and datasets were rated as important; with value starting from 0.80. Based on the mean scores of all six dimensions, Organisation has received the highest score and first ranking with the average RII score of 0.895; thus, it was considered as the most important component in this model. Meanwhile the second most important component was Social with the RII score of 0.882. Both Technology and Ecology components received a score in-between range of mean value RII 0.87. The lowest mean RII score was for Environment (RII=0.853) and Economic (RII=0.837). The summary of all six dimensions ranking, components, and influence for the big data model is presented in Table 4.

Table 3: The identified datasets for Big Data Analytics in Disaster Risk Reduction

Dimension	Dataset code	Dataset Description
Ecology	EY-1	1. Ecological system to return to or near its pre-event state
Ecology	EY-2	2. Relocation and Evacuation centre
Ecology	EY-3	3. Zoning Map
Economic	EC-1	4. Infrastructure Asset Value (Building, etc.)
Economic	EC-2	5. Land Production Value
Economic	EC-3	6. Land Use (Economic process and activity)
Economic	EC-4	7. Resource allocation for Disaster Risk Management Activity
Environment	ET-1	8. Aerial imagery
Environment	ET-2	9. Air pollution index
Environment	ET-3	10. Bathymetry
Environment	ET-4	11. Coordinates of Rainfall (RF) & Water Level (WL) Stations
Environment	ET-5	12. Cross Section Data
Environment	ET-6	13. Dam and water supply monitoring
Environment	ET-7	14. Flood Extent Map due to sea level rise
Environment	ET-8	15. Flood Extent Map for river
Environment	ET-9	16. Flood Hazard Map
Environment	ET-10	17. Flood protection measures
Environment	ET-11	18. Flood, river level, and rainfall monitoring
Environment	ET-12	19. High and low tide forecasting
Environment	ET-13	20. Historical Flood Report
Environment	ET-14	21. Historical records of hazard events
Environment	ET-15	22. Hydrological gauge data
Environment	ET-16	23. Inundation Map
Environment	ET-17	24. Mean wind & max wind in 3 areas: KLIA, Subang, and Petaling
Environment	ET-18	25. Meteorological gauge data
Environment	ET-19	26. Nearshore tsunami wave height
Environment	ET-20	27. Peta Bahaya dan Risiko Cerun (PBRC)
Environment	ET-21	28. Radar & Weather Monitoring
Environment	ET-22	29. Rainfall (RF) Data daily
Environment	ET-23	30. Rainfall at Dam Data
Environment	ET-24	31. Regional haze and hotspots
Environment	ET-25	32. Report of Port Klang Sea Level Rise Research
Environment	ET-26	33. River Basin Map in Shapefiles
Environment	ET-27	34. Road access
Environment	ET-28	35. Satellite – Flood Monitoring
Environment	ET-29	36. Satellite image of hazard location (hazard map)
Environment	ET-30	37. Slope data
Environment	ET-31	38. Soil Type
Environment	ET-32	39. Storm surge gauge data
Environment	ET-33	40. Stream Flow Data
Environment	ET-34	41. Topography Map (LiDAR, IFSAR)
Environment	ET-35	42. Water Level (WL) Data daily
Environment	ET-36	43. Watershed boundaries
Environment	ET-37	44. Wind rose summary at KLIA, Subang, and Petaling
Organisation	ON-1	45. Disaster emergency management (management of disaster preparedness, response, mitigation, and recovery process)
Organisation	ON-2	46. Disaster Management Leadership Experience (the disaster management experience and skill obtained by the organisation's leaders/top management)
Organisation	ON-3	47. Disaster Management Training (training in disaster management)
Organisation	ON-4	48. Facilities organisation (housing, commercial facilities, and cultural facilities)
Organisation	ON-5	49. Lifeline cycle (food supply, health care, utilities, transportation, and communication networks)
Organisation	ON-6	50. Political influence (Trust in politicians and satisfaction with the Government in managing the disaster)
Social	SL-1	51. Community and social support (citizen trust, cooperation)
Social	SL-2	52. Community and social risk acceptance (citizen level of risk resilience)
Social	SL-3	53. Disaster Relocation and Evacuation Centre
Social	SL-4	54. Population and demographics of the disaster area
Technology	TY-1	55. Tech Technology Capacity (durability, the efficiency of machine processing)
Technology	TY-2	56. Technology Infrastructure (no machines, specifications, storage)
Technology	TY-3	57. Big Data Analytics Solution for Disaster Management
Technology	TY-4	58. Disaster Management Metamodel and Metadata
Technology	TY-5	59. Disaster Management, Knowledge Management, and Data Exchange Platform

Table 4: Mean value and ranking of dimension in big data analytics model for disaster risk reduction

Key Component	Average of Relative Importance Index ($0 \leq$ RII 1)	Ranking
Organisation	0.895	1
Social	0.882	2
Technology	0.876	3
Ecology	0.874	4
Environment	0.853	5
Economic	0.837	6

5 Conclusion

The study successfully described the formulation of BDA for DRR model within the scope of Selangor State, Malaysia. From an extensive literature analysis and an FGD session with all the relevant agencies that responded with the DRM/DRR, it is believed that this model is able to assist further work in development of data analytics solution. The model covers almost all angles of disaster-related aspects such as ecology, economic, environment, organization, social, and technology. It also goes in-depth by identifying the related datasets both in spatial and nonspatial form. The next step will be the evaluation of the model functionality in the disaster-related case study environment. Apart from the aim to formulate a big data analytics model for DRR, this discovery also will be useful in developing strategies and plans for DRR for Selangor State and the agencies itself. Enormous growth of data has the ability and potential to improve understanding of the historical information to shape a better-informed future in the context of visualising the story, identifying related cost incurred, together with new connections and opportunities for DRR. The incorporation of Big Data into DRR contributes to a more sustainably developed society, economy, and nation.

Acknowledgement

Hereby, we declare a highest appreciation to the Selangor State Disaster Management Unit and all Malaysian Public Sector agencies that involved in this research. The authors also thank following reviewers to review this article. The research is financially supported by Universiti Teknologi Malaysia under Q.K130000.3556.06G26.

Ethical issue

Authors are aware of, and comply with, best practice in publication ethics specifically with regard to authorship (avoidance of guest authorship), dual submission, manipulation of figures, competing interests and compliance with policies on research ethics. Authors adhere to publication requirements that submitted work is original and has not been published elsewhere in any language.

Competing interests

The authors declare that there is no conflict of interest that would prejudice the impartiality of this scientific work.

Authors' contribution

All authors of this study have a complete contribution for data collection, data analyses and manuscript writing

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