Title:
Analysis on Complexity in Natech Disaster Risk Reduction and Management: The case study of Cilegon, Indonesia

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ABSTRACT:
Complex disaster may arise as a resulted from natural disasters in conjunction with industrial disasters or technological disaster, these also called “natech disaster”. Currently, there is an increasing awareness on the hazard of these natech disaster. Natural disasters could trigger the technological disasters including release of hazardous materials, toxic chemicals, oil spills and flammable materials, and caused a cascading events. The damaging impact for the public health and safety could be catastrophes as it may effect massive loss of life, environmental destruction, asset and property loss, business disruptions and affect country reputation. This paper will explain a case study on the application of disaster risk reduction and management for natech disasters in Cilegon, Indonesia. The analysis of how risk assessment been done in Cilegon is conducted, the preparedness of Cilegon City government, contingency plan which have been developed, and industrial zones disaster preparedness. Natural and technological disaster risks is discussed, identified multiple stakeholders is determined and several emergency preparedness efforts also discussed. The results discussed in this paper serve as a foundation for future research to address natech disasters.

Keywords:
complex disaster, natech disasters, industrial disasters, technological disasters, emergency and disaster management.
1. INTRODUCTION
Complex disaster could arise from natural disasters in combination with industrial disasters or technological disaster. Industrial disaster include a release of hazardous materials and toxic chemicals, oil spills, fire and explosions from flammable materials. As the authors intended to emphasize complicated nature of the compounding situations generated by both natural and industrial disasters, we adopted a term “complex” in the occasion of a session titled “Interdisciplinary Study of Disaster Science and Contribution to Global Community” at the World Bosai Forum, which was held in Sendai City (Japan) on November 2017.
Combination between natural disaster and technological disaster is also called “NATECH”. Currently, there is an increasing awareness on the hazard of these natech disaster. However, there is still limited research and publications related to this.
The number of natech disasters have been increasing during the last 20 years [1], [2]. It is an emerging challenges for the 21st century. Natech disasters have created huge consequences in diverse area in the world, and it is now a new emerging issue to public health and safety. Even though the probability of natech disaster occurrence is relatively lower, the major consequences and a high level of complexity in disaster risk management can be expected, because of its snowballing effects. Natural disasters can initiate the technological disasters including release of hazardous materials, toxic chemicals, oil spills and flammable materials, and caused cascading effects [1], [2]. The damaging consequences for the public health and safety could be catastrophes since it may cause more loss of life, environmental damage, asset and property damage, business interruption and country reputation. Compare to those single event natural disaster, the challenges also include a more complex interdependent system, increasing potential cascading incidents, and complex problem solving due to a complex disasters. Natech disasters may cause huge risks to some areas, which are not prepared for these complex disasters.
Several examples derived from natech disasters include releases of hazardous materials in Turkey, 1999; damage to lifeline systems in Portugal, 2001; damage to oil and gas pipeline in France 2002; damage to oil storage due to Tsunami Aceh in 2004; damage to oil and gas industries due to hurricane Katrina and Rita New Orleans in 2005; damage to nuclear and oil and gas facilities due to Great East Japan Earthquake 2011[1], [2], [3], [4], [5]. These catastrophic events caused massive public health and safety problems. The huge number of people were affected. Releases of oil spills in the scale of thousands barrels damaged significant oil, gas, chemicals and nuclear facilities. Consequently, these phenomena caused major business interruptions, scattered hazardous materials in a large areas and influenced country reputations.
This paper will describe a case study on the implementation of disaster risk reduction and management to address natech disasters in Cilegon, Indonesia. In this paper, it will be described on the analysis of how risk assessment been done in Cilegon, the preparedness of Cilegon City government, contingency plan which have been developed, industry and community preparedness. A conceptual framework, lessons learned and gap analysis also introduced, to further improve the natech disaster preparedness in this area. The results discussed in this paper serve as a platform for future research to address complex disasters.

2. METHOD

2.1. Case Description of Cilegon

Cilegon City is located in Banten Province, Indonesia. It is located at the western part of Java Island with an administrative area of 17,550 Ha, with 8 districts (locally known as “kecamatan”): Ciwandan, Citangkil, Pulomerak, Grogol, Purwakarta, Cilegon, Jombang, and Cibeber. Under the district level, 43 subdistricts (locally known as “kelurahan”) with population 418,705 people. Figure 1 shows the location of Cilegon City in Java Island and its heavy industrial zones. Cilegon is one of the most famous and significant heavy industrial zone [6], [7], [8]. Historically, the first development of the Cilegon industrial zone was organized in the steel industry, and then the chemical industries have been added gradually [9].

![Figure 1](image1.png)

**Figure 1** Cilegon City Location (a) and Industrial zones (b).
Source: (a) [10], (b) [11]
2.2. Selection of Key Policy Documents
In order to examine the complex nature of the natech disaster risk in Cilegon City, we selected key policy documents and conducted the document analysis (see Table. 1). These documents cover both of natural and technological aspects. Also, they are published by the national and local government agencies. Although the number of documents is limited, the selection of the documents is considerably relevant to analysis.

Several source of information provides justification of selection for the document analysis. In the national government, the National Disaster Management Agency (Badan Nasional Penanggulangan Bencana: hereinafter referred to as "BNPB") is responsible for natural disaster issues, and its document is required to be reviewed in this article. Besides BNPB, the Ministry of Health deals with chemical hazards and they have already implemented an assessment in Cilegon City. As a research body in the national government, Agency for the Assessment and Application of Technology (Badan Pengkajian dan Penerapan Teknologi: hereinafter referred to as "BPPT") also conducted a study of technological incident, adopting Cilegon City as its case study. The Cilegon City government developed its contingency plan and it contains natural and technological issues. In addition with the planning, the city government implemented exercises and drills in the past, and is preparing an exercise, which will be scheduled on November in the year of 2018. These events and preparation make scenarios, and these scenarios include assessment. Therefore, these activities also need to be explored.

Table.1 List of key policy documents

<table>
<thead>
<tr>
<th>Title of document</th>
<th>Source</th>
<th>Reference No</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Risk Assessment Cilegon City 2016-2020</td>
<td>BNPB</td>
<td>[12]</td>
</tr>
<tr>
<td>3. Recommendation for Technological Failure in Cilegon City for Disaster Risk Reduction</td>
<td>BPPT</td>
<td>[13]</td>
</tr>
<tr>
<td>4. Contingency Plan at Cilegon City, facing the possibility of earthquake and tsunami threat</td>
<td>Cilegon City</td>
<td>[14]</td>
</tr>
<tr>
<td>5. Multiple materials<em>1 for the 2007 simulation, the ARDEX</em>2*3 2011 and the ARDEX 2018.</td>
<td>Cilegon City</td>
<td>[15],[16],[17]</td>
</tr>
<tr>
<td>6. Quantitative Fire and Explosion Risk Analysis for LPG storage tank</td>
<td>Lestari (2015)</td>
<td>[18]</td>
</tr>
</tbody>
</table>

Note:
*1. These materials were provided to the authors by the Cilegon City government.
*2. ARDEX stands for ASEAN Regional Disaster Emergency Response Simulation Exercise.
*3. The implementation of ARDEX was originally planned in the year of 2011 in Indonesia.
However, due to reasons that some major disasters repeatedly happened, including the Mt. Merapi eruption and the West Papua flood, in the year of 2010, the ARDEX was eventually not held in Indonesia.

Source: Authors
3. RESULTS
Without indicating specific reference source, this section is described based on materials shown in Table. 1 accordingly.

3.1. Risk Assessment by BNPB
Cilegon City is prone to natural disaster risks including volcano eruption derived from Anak Krakatau Mountain. Krakatau Mountain generated a historical experience of earthquakes and tsunami of the Krakatau eruption in 1883. Cilegon City also locates nearby the center of earthquake potentially tsunami, Indo-Australian and Eurasian plate subduction at the south of Sunda Strait. It makes Cilegon City high-risk to the threat of 8.5 magnitude-scale earthquake, which may trigger tsunami. Indeed, Cilegon City is also a place at which heavy industrial zones are located from medium to large scale worldwide industries. Due to these conditions, Cilegon City is exposed to natech disasters derived from natural disasters (earthquake, tsunami, volcano eruption, floods) as well as industrial disasters. Cilegon City is one of the 136 cities or districts with a high economic growth and high disaster risk index. Figure. 2 demonstrates risk assessment results of hazards index for technological disaster based on BNPB Risk Assessment 2016-2020 for Cilegon City. The risk assessment of BNPB clearly illustrated potential threats of natech disasters in Cilegon.

![Image](image_url)

**Figure. 2** Cilegon City Technological Disaster - Hazards Index.
Source: [10]
3.2. Chemical Risk Mapping by Ministry of Health

Studies on Chemical Risk Mapping in Cilegon City were conducted by Health Crisis Centre in the Ministry of Health in 2016. They considered that Cilegon area is prone to chemical disasters which may affect more than 47,920 people. The studies showed that local hospitals can be affected by the chemical disasters. Also, they identified that there are a lot of vehicles on the streets and the high way, and they are transporting chemical materials. As a result, not only industrial zones, but also the road network is highly exposed to chemical disaster risks.

However, the analysis of the Ministry of Health has limitation. The analysis does not consider effects and damages by the earthquake shaking and tsunami inundation. And, it does not clearly estimate social impacts due to the chemical disasters.

![Figure 3 Result images of chemical risk mapping](image)

Source: [11]

3.3. Technological Failure Analysis by BPPT

Several scenarios have been developed by BPPT including the leakage of ethylene in one of the industry. The consequence modeling is conducted using a computing application “ALOHA” (Areal Locations of Hazardous Atmospheres) on selected area, which includes the toxic gas release and fire hazards. It is suggested that the toxic chemical release during scenario modeled in December 2011 is at concentration of 7500 ppm can spread within 1 hour time along at 275 m from the leakage source at high hazard level (red zone), moderate hazard level within 756 m at the concentration of 1500 ppm while the low hazard level can spread along to 1.3 km at the concentration of 600 ppm.

Fire hazards consequences modeling also been done in scenario in July 2011, and it is suggested that the high fire hazard level is at 321 m which is red zone with gas concentration at 16.200 ppm (60% LEL(lower explosion level) = flame pocket), moderate fire hazards area is within 961 m with gas concentration at 2.700 ppm (10% LEL).
Results from this study indicated that the chemical toxic gas dispersion and fire hazards might have impact on large areas and can affected large number of local people.

3.4. Contingency Plan of the Cilegon City government

BNPB and Cilegon City government have developed Risk Assessment for multi-hazard risks and it clarified that Cilegon City is categorized as “HIGH” risks index. Efforts that have been done by the Cilegon City government include development of a contingency plan and mitigation plan, which addressed the earthquake and tsunami. The contingency plan considers natech disasters.

Cilegon City has determined there are 15 points for tsunami evacuations as presented in Figure. 4. Comparing with Figure. 3 and Figure. 4, some evacuation routes are exposed to chemical hazard risks. Such comparison and inter-governmental discussion increase capacities to cope with natech disasters in Cilegon.

![Figure 4: Tsunami Evacuation Points and Evacuation Route in Cilegon City](source: [15])

![Figure 5: Tsunami Early Warning System in Cilegon City](source: [15])

A typical industrial site in Cilegon city is presented in Table 2. The Local Disaster Management Agency (Badan Penanggulangan Bencana Daerah: hereinafter referred to as "BPBD") of Cilegon City was founded in 2015 under the City Law Number 5/2015. BPBD has a role as the disaster management coordinator in this city, while the Cilegon City Secretary (called “SEKDA”) has a role as the Incident Commander. The authority of the Incident Commander is to command the agencies and institutions during including
search and rescue operations, mobilization of human resources, deployment of equipment and logistics as well as financial and administrative. BPBD also plays role as an institution connection to BNPB. In normal time, BPBD is responsible for disaster issues and it has expertise to do their mission. Contrary, SEKDA usually needs to supervise wide range of administrative operations in daily life. Even though SEKDA and BPBD exist in the same city government, their function is different. Thus, relationship between them needs to be considered in the natech disaster risk reduction and management.

Table 2 A typical industrial sites in Cilegon City

<table>
<thead>
<tr>
<th>Type of Industries in Cilegon</th>
<th>Quantity (number)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chemical &amp; Petrochemical Industries</td>
<td>25</td>
</tr>
<tr>
<td>Oil &amp; Gas Company (Storage, Jetty)</td>
<td>26</td>
</tr>
<tr>
<td>Blending &amp; Mixing - Pelumas</td>
<td>3</td>
</tr>
<tr>
<td>Sugar, salt and powder industry</td>
<td>6</td>
</tr>
<tr>
<td>Coal stockpile</td>
<td>2</td>
</tr>
<tr>
<td>Wooden Industry</td>
<td>1</td>
</tr>
<tr>
<td>Cement Factory</td>
<td>3</td>
</tr>
<tr>
<td>Steel &amp; Construction</td>
<td>2</td>
</tr>
<tr>
<td>Energy &amp; Power Generation</td>
<td>2</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>84</strong></td>
</tr>
</tbody>
</table>

Source: [15]

3.5. Exercises and Drills

Several exercises and preparation drills have been done to address natech disasters. For example, the Local Development Planning Agency (Badan Perencanaan Pembangunan Daerah: locally known as “BAPPEDA”) of Cilegon City organized drills for earthquake, tsunami and technological disaster in 2007. BAPPEDA also coordinated preparation of ARDEX (ASEAN Regional Disaster Emergency Response Simulation Exercise) in 2011 and it is now in preparation for ARDEX 2018. The city government along with industries have determined 3 tier levels of emergency response:

- **Level 1**: emergency condition which can responded by the industry itself
- **Level 2**: emergency conditions which cannot be responded by the internal company and needs help from the industrial zone
- **Level 3**: emergency conditions which cannot be responded by the internal company and the industrial zone, and need helps from the activation of Crisis Centre Cilegon BPBD or from higher level Disaster Management Agency (BNPB, National Search and Rescue Agency, and others)
Cilegon City government along with industries have developed an industrial zone emergency response including Ciwandan Emergency Response Team, Anyer-Merak Emergency Response Team and other industrial zone emergency response team (ERT). These Industrial zone ERT teams consist of several industries within those regions in connection with BPBD Cilegon City. It has a routine meetings and drills, which involves different stakeholders including government, industries, hospitals, schools, and community at their locations. Cilegon City also build a Crisis Centre, which can be used in the case of natech disaster strikes, including to manage disaster operations, rescue, modeling gas dispersion and fire hazards, planning disaster response, manage logistics, foods, equipment for disaster response, financial and administrative response.

We can observe individual preparations, but integration of these individual parts is still weak. An ERT conducts their own activities, but these activities are not linked with other ERTs’ activities. Taking into consideration with the size and complex natures of natech disasters, mutual support mechanism is necessary, and joint activities between certain ERTs are helpful.

3.6. Quantitative Fire and Explosion Risk Analysis

Other study to determine Quantitative Fire and Explosion Risk Analysis for LPG storage tank in Cilegon has also been done, including in the area of Lebak Gede, Cilegon. It is suggested that if there is a fire on LPG storage tank, the heat radiation will be in the area of 297 m (high heat radiation hazard level – red zone), 421 m (moderate heat radiation hazard level – orange zone) and more than 665 m (low heat radiation hazard level – yellow zone) from the source of storage area (see Figure 6). Internally, this Oil and Gas Company has done quantitative risk analysis to determine the level of risks for their plants and workers. It is suggested that the quantitative risks to the workers are within tolerable and acceptable ALARP (as low as reasonably practicable) zone as indicated in Figure 6 the risks are between 10^{-4} – 10^{-7} / year. When it is plotted in the FN Curve, it shows that the level of risks is within tolerable and acceptable risks.

This study indicated that this oil and gas industry has been implementing a good process safety management, industrial safety management system and other safe work best practices. However, if the worst scenario happens, the heat radiation can reach the residential area surrounding the oil and gas facility. According to a preliminary analysis, the facility has not yet finished developing the response system cooperating with the surrounding communities [19]. For further investigation, since the study does not consider the effects and damages of tsunami, additional and applied calculation needs to be run.
Figure. 6 Quantitative Fire and Explosion Risk Analysis for LPG storage tank  
Source: [18]

4. DISCUSSION
Cilegon City has been conducted efforts towards the natech disasters. However, the emergency and disaster preparedness need to be evaluated including the community disaster preparedness, the community awareness on complex disasters, and disaster risk reduction if the natech disaster strikes.

In addressing natech disasters, the identification of all related sectors and stakeholders is very important. In terms of Cilegon City area, it has been identified a diverse sectors as represents in Figure. 7. The previous sections revealed that natech risk assessment has already been implemented in Cilegon. On the other hand, the authors have not been able to gather evidence that information sharing of the assessments results has also been made amongst sectors and stakeholders. It can be happened and reasonable that governmental organizations and industrial actors hesitate in disseminating all of information to the public. However, if communication does not work, any actions cannot be taken appropriately.

A concept of “participatory technology assessment (pTA)” can be a useful tool for that
the multisector and diverse stakeholders proceed discussions and implementation natech disaster risk reduction and management [20]. The pTA promotes direct interaction among member and experts to discuss issues and reach consensus for mitigation through provision of information and knowledge of science and technology [21]. As Cilegon City has already conducted exercises and drills in the past, these events themselves and their preparatory and reviewing process can be utilized for the pTA. One of the examples which the pTA practice was adopted is Muhari et.al (2010), which conducted the pTA packages in West Sumattra Province, Indonesia [21]. Muhari et.al argued, with citing Imamura (2009) [22], importance of opportunities of evacuation drills. Particularly, level of evacuation drills (community-scale) and their frequency are emphasized. The drills aim to identify and dissolve the knowledge gaps amongst the multisector and diverse stakeholders. The year of 2018 is a year that the ARDEX will be held, and such an ASEAN-level opportunity associates with relevant drills at national and local level. The preparatory and reviewing process in ARDEX can be a case of the pTA implementation for natech disaster risk reduction and management.

Further evaluation and future research is needed to include a more advanced fire, explosion, gas dispersion modeling and community evacuation modeling using a more comprehensive tools and software. This effort to further understand a better disaster risk reduction as the consequences is catastrophes.

![Multisector and diverse stakeholders relevant to natech disasters.](image)

**Figure.** 7 Multisector and diverse stakeholders relevant to natech disasters.
REFERENCES:

[14] Cilegon City, “Rencana koordinasi tingkat Kota Cilegon, Menghadapi kemungkinan ancaman bencana gempa bumi dan tsunami (Contingency Plan at Cilegon City, facing the possibility
of earthquake and tsunami threat),” July 2010.

END.