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Industrial and Environmental Disaster Risk Assessment for Hazardous Materials in Balikpapan City, East Kalimantan, Indonesia

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Abstract: Industrial disasters may cause massive public health problems, as they create large environmental damage and major loss of life. Balikpapan City has experienced a large oil spill which caused an industrial and environmental disaster: five fishermen died, various public health problems arose, and damage to environmental wildlife and ecosystems occurred. The objective of this study was to evaluate the industrial and environmental disaster risk related to hazardous material (hazmat) in Balikpapan. The research method involved the use of a semi-quantitative risk analysis with an originally organized checklist, a risk matrix, and a Geographic Information System (GIS) analysis. The results suggested that the risk score in Balikpapan's City is 32 (MEDIUM; the dominant types of hazmat were flammables and corrosives). The major sectors contributing to the risk appeared to be the mining, energy, and oil and gas industries, with a medium risk (average risk score 33), while one clean water industry showed a low risk (risk score 24) using the checklist and risk matrix. According to the results from the GIS mapping, the areas t the highest risks appeared to be located within Balikpapan City coastal regions. The industries and the government of Balikpapan must be prepared for industrial and environmental disasters by educating competent major hazmat responders and ensuring a large spills response equipment, extensive environmental monitoring and measurement, procedures to deal with major fire and explosions and adequate disaster communication and coordination.

Keywords: industrial disaster; environmental disaster; hazardous materials; disaster risk assessment

1. Introduction

Industrial development has become an integral part of economic growth around the world, particularly in developing countries such as China, Korea, Taiwan and Indonesia [1]. In addition, industrialization has promoted the economic expansion by increasing the productivity, creating jobs, and finding resources and materials for optimal production [2,3]. Moreover, industrial development has been identified as a fundamental key to achieving a sustainable development, and there is a significant association between output's manufacturing growth and GDP advancement [4]. Industrialization, however, also has a negative impact on the environment, due, for example to the large amount of waste it produces. Unfortunately, 1 million tons of hazardous waste is produced daily in Asia Pacific [5]. In Indonesia, for instance, hazardous waste is generated by various industries such as mining, oil and gas, chemical, shipbuilding, manufacturing, health sectors and so on [6–8]. It has been reported that Indonesia generated 60 million tons of waste in 2021 from 947 industries [9]. The increase of industrial output associated with industrial activity and growth has led to the production of waste from various raw materials used during production, particularly hazardous and toxic wastes [10–12].

A hazard is defined as a process, phenomenon or human activity that has the potential to cause death, injury or other health effects, property damage, social and economic disruption, or environmental degradation [13,14]. A hazardous event is the appearance of a hazard at a location for a specified period of time [13]. In other words, hazardous events can affect communities and have dimensions of time and space [15].

Interestingly, the emergence of technology has induced a novel machine growth in industrial sectors. This development is considered as the key to provide clean and safe innovation. However, it has automatically influenced the demand for things, since everything is being manufactured. As a result, this development and digitalization might contribute to the rise of hazardous events around the world such as chemical, toxic, explosive hazards and danger to nature [16].

As far as the amount of hazardous waste is concerned, the largest contribution from the industry was identified to derive from chemical manufacturing and petroleum which have an impact on the environment. In the United States, this industry contributes to 84% of hazardous waste generation [17]. A study conducted in Poland reported that the contribution of hazardous waste of this industry during 2016–2018 was 80.22% [18]. In Australia, 8 million tons were generated during 2016–2017, and the manufacturing industry was the largest contributor which producing 24% of the hazardous waste [19]. In addition, a study on the Iranian petroleum industry reported that it produced more than 160 hazardous chemical substances, and 73% of the chemical waste was disposed of in sanitary landfills [20].

Importantly, both hazardous and toxic materials and their waste must be managed in accordance with current regulations. An improper hazardous materials management will cause environmental leakage of hazardous materials, pollution and public health problems, leading to become emergencies or human-induced technical disasters [21]. The improper management of hazardous materials and/or their waste has the potential to trigger an emergency condition related to industrial disasters. This situation can cause material losses, loss of life and even pollution and/or environmental damage, for example, as a consequence of the occurrence of fire, explosions, spills, and leakage of hazardous and toxic waste. These emergencies are part of industrial disaster, which can result in uncontrollable events such as the dispersion of toxic substances that aggravate both the public and the industrial environment. It has been reported that disasters occurred due to the failure of the security system in industries and had a detrimental impacts on public health, causing fatalities and damage to facilities, infrastructure and communities surrounding the company areas [22].

One of the industrial areas in Indonesia is Balikpapan, in the province of Kalimantan, where oil and gas exploration were first established. In its development, industrial activities in Balikpapan City have grown, both industrial activities that support the oil processing industry and other industrial activities such as building material industries, mining, construction industries and others [23]. Balikpapan City has a population of 688,318 people. Balikpapan City occupies a hilly area with a slight slope around the river and the coast. Natural hazards that occurred in Balikpapan City included floods and landslides. There were 83 incidents of flooding recorded throughout 2020, and 38 incidents of landslides occurred. The installation of an initial detection tool for an early warning system such as a buoy for the new tsunami natural hazard is planned in the Balikpapan–West Sulawesi segment [24]. The total amount of hazardous and toxic materials in Balikpapan City as of

2021 was about 10 tons, with materials with flammable properties and extremely flammable amounting to one to four tons. Statistically, the total of hazardous and toxic waste in the City of Balikpapan as of 2021 was approximately 77 tons. In the year 2018, Balikpapan City experienced an industrial and environmental disaster, due to a large fire and oil spill. This industrial and environmental disaster caused the death of five fishermen, large public health problems and damage to wildlife and ecosystems [25–27].

The occurrence of an emergency in the management of hazardous and toxic materials and its wastes can be prevented through the implementation of an emergency response system for the management of hazardous and toxic materials and its waste by various parties. This is in line with the mandate in Government Regulation Number 22 of 2021 concerning the implementation of environmental protection and management, concerning the management of hazardous and toxic waste and the management of non-hazardous and toxic waste. This regulation states that every person who generates, collects, transports, utilizes, treats and landfills hazardous and toxic materials is required to have an emergency response system which consists of emergency prevention through the preparation of an emergency hazardous and waste management program, preparedness through training and drills, as well as an emergency response for hazardous and toxic waste management. This emergency response system must also be implemented and owned by the district/city regional government, as well as by the province and the government at the central level. Nonetheless, studies on industrial disaster and hazardous and toxic materials in Indonesia are scarce.

Currently, there are limited information and knowledge gaps on hazardous material produced by particular industrial activities in Balikpapan. At the same time, Balikpapan is a growing city, and its population may be impacted by the presences and the emissions of hazardous and toxic materials. This study, therefore, aimed to explore the potential risks of industrial disasters caused by hazardous and toxic materials and their wastes in Balikpapan and to provide recommendations regarding control measures and strategies to mitigate the industrial disaster risk that can lead to illness or even deaths and contamination of populated areas and decrease the productivity of regions.

2. Materials and Methods

This research was conducted in Balikpapan City, East Kalimantan province. The study methodology used a cross-sectional design and consisted of data collection using developed checklists, semi-quantitative risk analysis, risk assessment and GIS risk mapping.

2.1. Study Area

This study was carried out in the city of Balikpapan, East Kalimantan province (see Figure 1), and this city consists of five sub-districts including Balikpapan Kota, Balikpapan Barat, Balikpapan Utara, Balikpapan Timur and Balikpapan Selatan. Balikpapan's geo coordinates are 116.7290°–117.0215° east longitude and 1.0421°–1.2851° south latitude. Balikpapan, covering 503.3 km^2, is largely hilly (85%), with only a few flat sections (15%) around the shore and bordering the steep hills. The hills are just about 100 m higher than the lowlands below. Balikpapan's elevation ranges from 0 to 80 m above sea level. The city proper is situated on the eastern side of Balikpapan bay. The majority of the soil of Balikpapan is yellow-reddish podzolic soil with alluvial and quartz sand, making it prone to erosion. Due to the lack of precipitation, Balikpapan has a tropical rainforest climate (Af). The city receives 2400 mm of rain per year on average. Throughout the year, the weather in Balikpapan is quite consistent. The city does not have noticeably wetter or drier seasons, and the typical temperatures are practically comparable throughout the year, hovering around 26–27 °C.

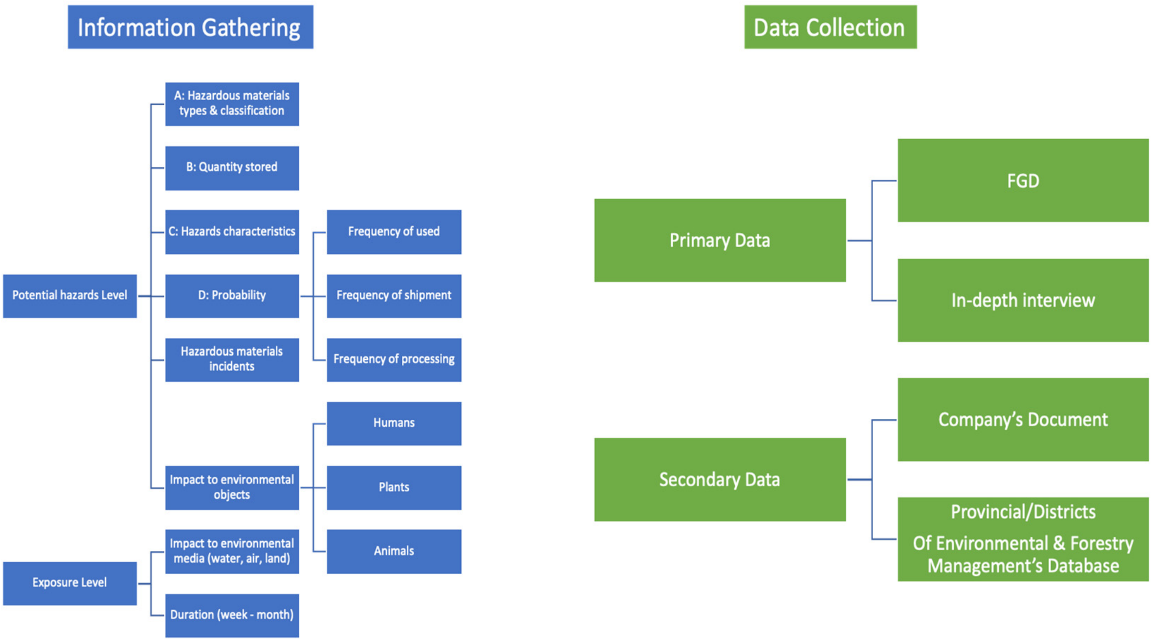


Figure 1. Information gathering, data collection and methodological framework.

Balikpapan is the second most populous city in East Kalimantan, after Samarinda, with a population of 688,318 according to the 2020 census. Balikpapan began as a fishing community constructed by Buginese people in the nineteenth century. The first oil drilling began in Balikpapan on 10 February 1897, which was later designated as the city's anniversary. Balikpapan was awarded municipal status by the Dutch East Indies colonial authority in 1899. Bataafsche Petroleum Maatschappij (BPM) established the city as its headquarters in 1907 and hired skilled laborers, engineers and managers from abroad. Following Indonesia's independence, BPM expanded its operations in Balikpapan until 1965, when Indonesia's national oil company, Indonesia's state-owned oil corporation, assumed the control of BPM and its oil exploration efforts.

2.2. Data Collection

Data collection included a Focus Group Discussion (FGD) which was conducted online through the Zoom platform and an in-depth interview with local industries and the Environmental Health District, Balikpapan City, East Kalimantan, Indonesia. We selected participants or companies whose activities used high amounts of hazardous materials; in this research, they were mining oil and gas companies and clean water providers. During the FGD, each company representative presented their hazardous materials, then an in-depth interview was conducted between the researcher and the company representatives to gain more detailed information. Data collection involved the use of a systematic checklist of hazards and exposure criteria, which was obtained from the Ministry of Environment and Forestry (MEF) (Table 1) and Risk Matrix (Figure 2). Risk assessment was performed using a semi-quantitative analysis, using likelihood, vulnerability and hazard criteria based on methodologies approved by the MEF. A risk assessment was conducted considering potential hazards and exposure levels. According to MEF Regulation No. 74 of 2019 on Hazardous Substances and Hazardous Waste Emergency Management Programs, the data and information required for risk assessment are:

- Types of hazardous materials disposal activities;
- Industry sector;
- Hazardous substance category characteristics;
- Volume of hazardous materials;
- Potential threat to life safety;
- Potential threats to environmental functions.

Table 1. Risk score calculation. (See Excel file risk calculation).

No.	Industry Sectors	Industry Subsectors (Oil and Gas, Energy Power, Utility, etc.)	Quantity (Tons)	Hazardous Materials Activities
Fill in with Number	Describe the industry sectors such as oil and gas, mining, water treatment, etc.	Describe industry subsectors such as oil and gas, energy power, utility, etc.	Describe the quantity in tons	Describe hazardous materials activities such as storage, shipment, process, usage, distribution

Hazards Potential Level		Hazards Level										
		Hazmat Classification		Hazards Characteristics			Frequencies (Used/Shipment/Processing)			Impact to Environmental Objects		
Types of Hazardous Materials	Hazards Characteristics/Hazards Classification	Medium	High	Low	Medium	High	Rare	Medium	Frequent	Low	Medium	High
Describe types of hazardous materials such as gasoline, crude oil, coal, chemicals, LPG, biodiesel, etc.	Describe characteristics of hazardous materials such as flammables, explosives, infectious materials, corrosive materials. For hazards classification, describe whether the hazmat is classified as category 1 (acute category 1 is for hazardous materials that have an acute (fast or sudden) and direct impact on humans, as well as a negative impact on the environment. Category 2 is for a hazardous material that has a non-acute effect (delay) and an indirect impact on humans and the environment. This category has toxicity that tends to be sub-chronic or chronic (long-term). Category 1 can be classified as HIGH hazard level, while Category 2 is classified as MEDIUM hazard level	Category 2 classified as MEDIUM hazard level	Category 1 classified as HIGH hazard level	Corrosive, irritant and environmental hazards	Toxic	Reactive, flammable, and explosive	Storage Infrequent: <7 times/month Shipment Infrequent: <4 times/year Processing Infrequent: <3 times/year	Storage: Medium: 7–14 times/month Shipment: Medium: 4–12 times/year Processing: Medium: 3–9 times/year	Storage: Frequent: >15–30 times/month Shipment: Frequent: >12 times/year Processing: Frequent: >9 times/year	Impact to the environment	Impact to people/animals and plants	Impact to people/animals, plants and environment

Exposure Level						Risk Score	Level of Risk	Recommendation of Hazards & Exposure Control
Exposure to Environmental Media (Water, Air, Land)			Exposure Duration					
Low	Medium	High	Low	Medium	High			
Exposure to one environmental medium	Exposure to two environmental media	Exposure to three environmental media	<1 (one) week	1 (one) week–1 (one) month	>1 (one) month	Risk score is calculated based on the multiplication results from HAZARDS Level Sum [Hazmat classification + x EXPOSURE Level Sum]	Describe the level of risk: LOW: <29; MEDIUM: 30–59; HIGH: >60	Describe the recommendations for hazard and exposure control such as hazardous materials handling, emergencies caused by hazardous materials such as oil and chemical spills, fire and explosions, prevention of hazardous materials incidents, etc.

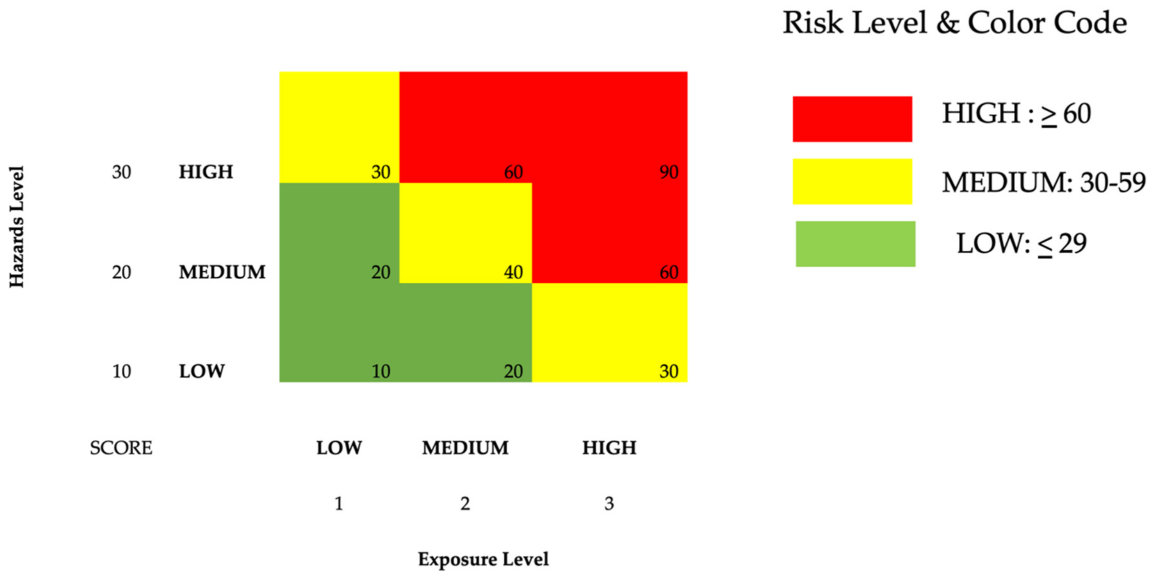


Figure 2. Hazardous materials risk matrix.

Information gathering, data collection and methodological framework are described in Figure 1. Figure 1 explains the information gathered, the data collected and the methodological framework of this study. The process involved information gathering for potential hazard levels such as hazardous material types and classification, quantity stored, hazards characteristics, hazard probability, possible hazardous materials incidents, and impact on environmental objects; for exposure level such as the impact on environmental media and its duration. In addition, data collection was carried out by acquiring both primary data (from focus group discussion and in-dept interviews) and secondary data (from companies' documents).

After information and data collection were concluded, data analysis was conducted based on the analytical framework presented in Figure 3.

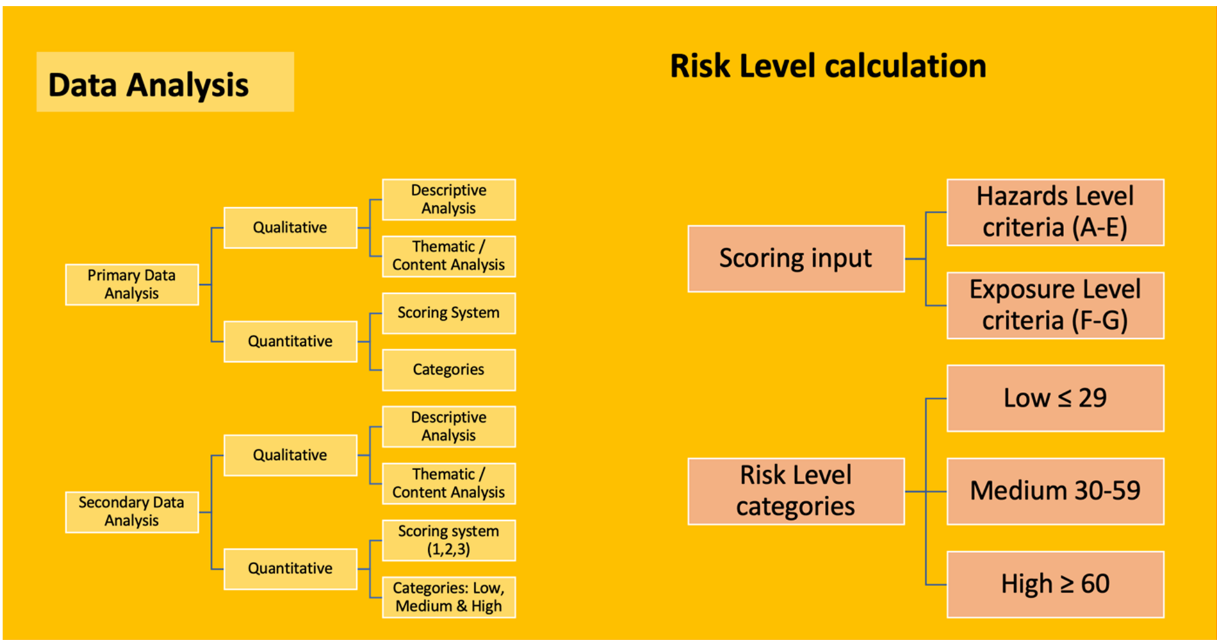


Figure 3. Data analysis, risk level calculation and analytical framework of the study.

The scoring formula for the assessment of hazardous materials was as follows:

$$\text{RISK} = \text{HAZARD} \times \text{EXPOSURE}$$

The risk score was calculated based on the results from the formula:

$$[\text{HAZARDS Level Sum}] \times [\text{EXPOSURE Level Sum}]$$

HAZARD Level: Sum of the Scoring [Hazmat Classification + Hazards characteristics + Frequencies of used/shipment/processing + Impact to environmental objects]

EXPOSURE Level: Sum of the Scoring [Exposure to environmental media + Exposure duration]

The risk level calculation is detailed in Table 1. Table 1 reports the industrial sectors and sub-sectors such as oil and gas, mining and water treatment, hazardous material quantities and hazardous materials activities.

2.3. Hazards and Exposure Risk Analysis

Hazards and exposure risk analysis were conducted based on hazard classification criteria and exposure criteria, as shown in Table 2. Hazards analysis included the data from the analysis concerning hazardous substances, categorized by hazard class, amount, frequency and impact as follows:

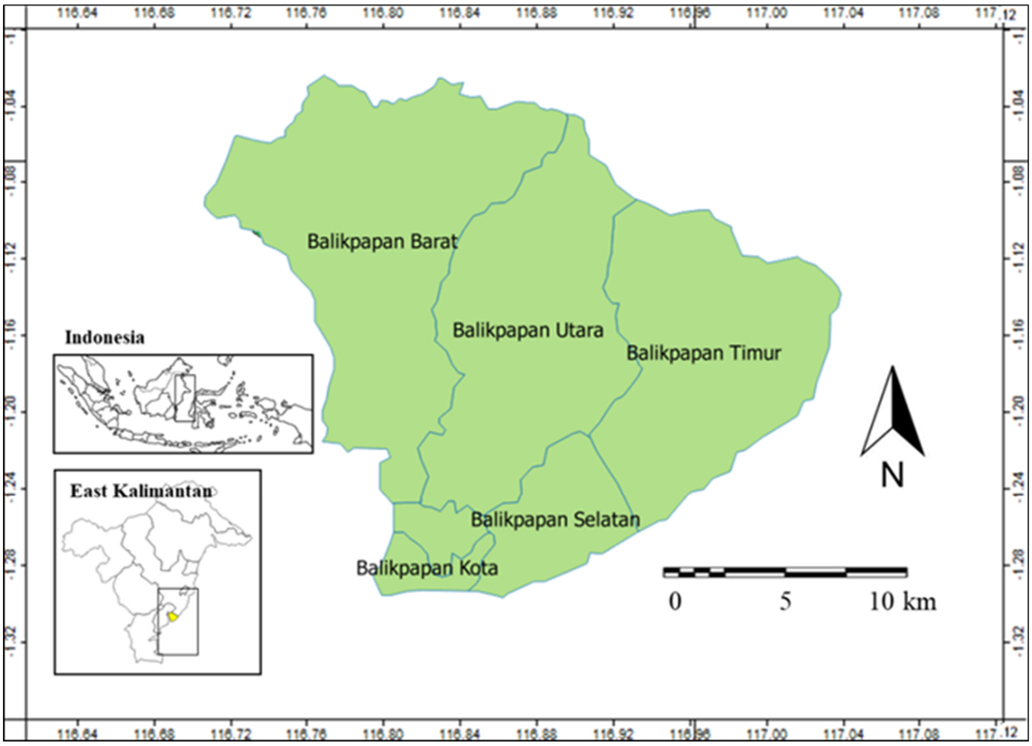
- Hazard class; the hazard class was classified as low, moderate and high. According to Peraturan Pemerintah Republik Indonesia No. 22/2021, category 1 is for hazardous materials that have an acute (fast or sudden) and direct impact on humans, as well as a negative impact on the environment. Category 2 is for hazardous materials that have a non-acute effect (delay) and an indirect impact on humans and the environment. This category has toxicity that tends to be sub-chronic or chronic (long-term);
- Amount; the amount was classified as <10 tons, 10–30 tons and >30 tons;
- Frequency; frequency was classified as <7 times/month, 7–14 times/month and >14 time/month;
- Impact; impact was classified as environment, environment and humans, and environment, humans, and plants.
- Exposure analyses were based on the following criteria:
- Environmental media, including exposure to one medium, two environmental media and three environmental media such as water, air, earth.
- Exposure duration: 1 week, from 1 week to 1 month and >1 month

2.4. Risk Rating

Risk assessment aims to evaluate and assess the likelihood of industrial hazards using the aforementioned risk analysis. Hazard classes, amounts, frequencies and exposure were rated on a Likert scale from 1 to 3 as follows:

- Hazard classification rating: Low (score = 1), Medium (score = 2), High (score = 3).
- Amount rating: <10 tons (score = 1), 10–30 tons (score = 2), and >30 tons (score = 3);
- Frequency rating: <7 times/month (score = 1), 7–14 times/month (score = 2), >14 times/month (score = 3);
- Impact rating: Environment (score = 1), Environment and Humans (score = 2), Environment, Humans, Plants (score = 3).

The risk rating also referred to risk criteria (Table 2) and the risk matrix of hazardous materials (Figure 2). The level of risk was then determined based on the hazards and exposure criteria using the risk matrix in Figure 2. Figure 4 shows the location map of the sub-district in Balikpapan city, East Kalimantan province, Indonesia and Balikpapan's oil spill that occurred in 2018.



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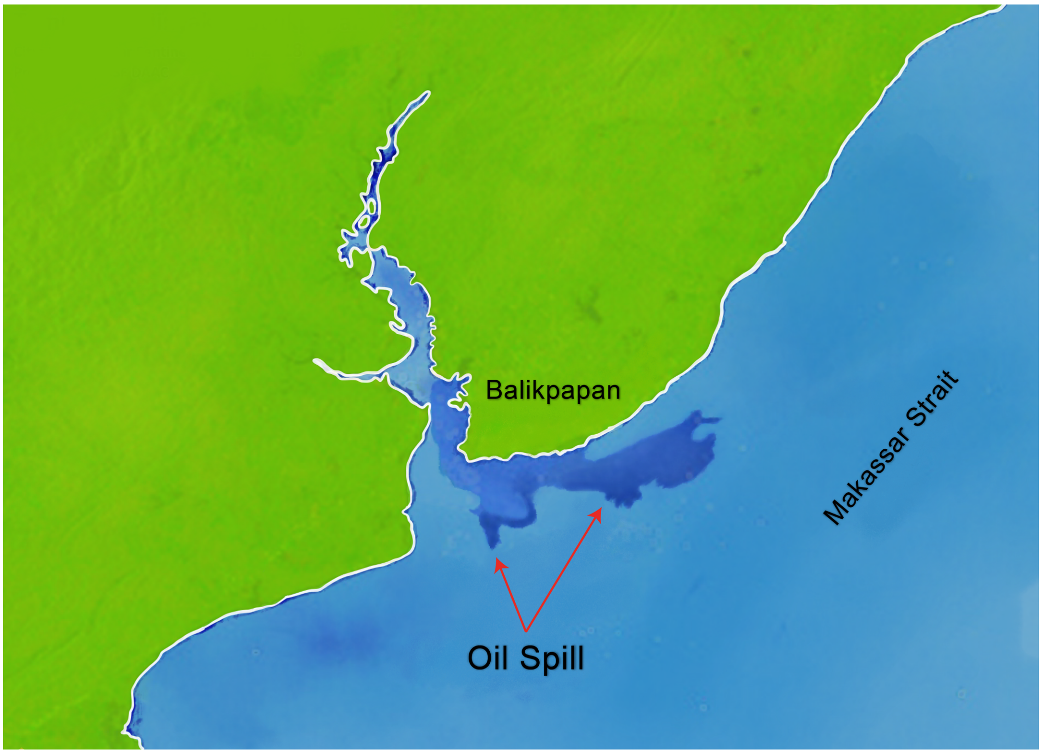

(**b**)

Figure 4. (**a**) Location map of the sub-district in Balikpapan city, East Kalimantan province, Indonesia. (**b**) Balikpapan's oil spill, 2018. Source: Adapted from LAPAN–1 April 2018. Balikpapan's oil spill. Website: https://id.wikipedia.org/wiki/Kebocoran_minyak_Balikpapan_2018. Accessed: 26 March 2023. It can also be accessed through: http://rsgs.lapan.go.id/LAPAN/index.php/subblog/read/2018/671/Tumpahan-minyak-di-Balikpapan/berita, public domain: https://commons.wikimedia.org/w/index.php?curid=68119778.

Table 2. Hazards and exposure criteria.

No.	Component	Code	Potential Hazards	Level of the Potential Hazards		
				Low (Score = 1)	Medium (Score = 2)	High (Score = 3)
1	Hazard	A	Class of Hazards		Hazardous material category 2	Hazardous material category 1
2		B	Quantity	0.1–49% Threshold Quantity	50–90% Threshold Quantity	≥Threshold Quantity
3		C	Hazard Characteristic	Corrosive, irritant and environmental hazards	Toxic	Reactive, flammable and explosive
4		D	Frequency probability of events:			
			Storage	Infrequent: <7 times/month	Medium: 7–14 times/month	Frequent: >15–30 times/month
			Shipment	Infrequent: <4 times/year	Medium: 4–12 times/year	Frequent: >12 times/year
			Processing	Infrequent: <3 times/year	Medium: 3–9 times/year	Frequent: >9 times/year
5		E	Impact on environmental objects	Impact on the environment	Impact on people/ animals and plants	Impact on people/animals, plants and environment
6	Exposure	F	Environmental media	Exposure to one of environmental medium	Exposure to two environ-mental media	Exposure to three environmental media
7		G	Duration	<1 week	1 week–1 month	>1 month

2.5. Data Analysis

The level of risk was determined based on the score obtained from the risk analysis using the risk matrix (Figure 1). If the resulting score was above 60, the level of risk was classified as HIGH; if the score was 30–59, the level of risk was MEDIUM; if the score was below 29, the risk was classified as LOW. The scores obtained from the risk rating were then summed up and divided by the number of samples to obtain the average score of industrial disaster potential. The average risk rating was calculated based on the average total risk level from the summation of the risks reported by all companies. Further analyses were then conducted to determine level of risk at the provincial level. The scores obtained from the risk assessments were then summed and divided by the number of samples to obtain an average industrial hazard probability score.

2.6. Risk Mapping

This research collected two types of data. First, the data for defining the sub-district of Balikpapan City. In this study, the map of the sub-district of Balikpapan City was obtained using the base map. First, the shape files of the Balikpapan polygon were prepared. This polygon represents the Balikpapan City divided into five sub-districts. The second type of data were collected from data analysis of the level of risk. Risk mapping was conducted by using GIS aiming to generate an industrial hazardous risk map of Balikpapan City, East Kalimantan. GIS mapping revealed trends, distribution and areas at the highest risk.

3. Results

3.1. General Description of Balikpapan

Balikpapan is located in the eastern part of Kalimantan Island and is directly adjacent to the Balikpapan Bay and Makassar Strait or between 1.0° and 1.5° South Latitude and 116.5°–117° East Longitude on the earth map. Kalimantan island is also known as Borneo Island. The total area of Balikpapan is 503.3 Km^2 and is divided into six districts, including the East Balikpapan District, the South Balikpapan District, the Kota Balikpapan District, the Central Balikpapan District, the West Balikpapan District and the North Balikpapan District.

According to *Balikpapan dalam Angka* 2021, Balikpapan had 688,318 people with a population density of 1368 people per km^2. The population growth rate was 2.06% per year. Balikpapan has a tropical climate, and it rains all year round. The highest temperature in 2020 was recorded at 34.3 °C, and the lowest was 22.2 °C. The highest rainfall in 2020 was recorded at 545.6 mm, and the lowest at 158.1 mm [6].

3.2. Use of Hazardous Materials in Industries in Balikpapan

The hazardous material data were obtained from 2021 inventory data. The sector of businesses included oil and gas, refineries, clean water providers and energy generators in Balikpapan, which used hazardous materials that were flammable and corrosive, as shown in Table 3. Industrial activities which used hazardous materials included storage, usage, handling and distribution of hazardous materials within Balikpapan City.

Table 3. Characteristics and tonnage of hazardous materials in Balikpapan 2021.

Sector/Industry	Activities	Hazardous Material Characteristics	Quantity (Tons)
Mining for energy and oil and gas	Storage, usage, hazardous materials producers and distributors	Flammable	4,206,929
Clean water providers	Usage	Corrosive	2887
	Total		4,209,816

3.3. Natural Hazard Risk Index in Balikpapan

The natural hazard risk index for Balikpapan City was obtained based on the Indonesian Disaster Risk Index, known as Index Risiko Bencana Indonesia (IRBI), which is published by the Indonesian National Disaster Management Agency, or known as Badan Nasional Penanggulangan Bencana (BNPB). Based on the 2021 BNPB Indonesia Disaster Risk Index (IRBI), Balikpapan was in the medium risk class category, with a score of 108.14, as shown in Table 4. It was necessary to understand the natural hazard risk index of Balikpapan to obtain a more comprehensive multi-hazard risk for Balikpapan city and determine the possibility of Natech (Natural Hazards-triggered technological disaster). It was found that Balikpapan faced a high risk of flooding, forest and land fire and extreme waves and abrasion, while for earthquake, tsunami, landslide, drought and extreme weather, the risk level was medium (Table 4).

Table 4. Natural hazard risk index of Balikpapan, 2021.

No.	Type of Disaster	Score	Risk Level
1	Flooding	23.64	High
2	Earthquake	7.34	Medium
3	Tsunami	10.87	Medium
4	Forest and Land Fire	24.45	High
5	Landslide	8.15	Medium
6	Extreme waves and abrasion	16.41	High
7	Drought	8.15	Medium
8	Extreme weather	9.24	Medium

red = high category; yellow = medium category.

3.4. Results of the Hazards and Risks Identification for Hazardous Materials

Hazard and risk identification was carried out in two industrial sectors in Balikpapan, namely, mining for energy and oil and gas and clean water provision (Table 5).

Table 5. Risk identification for hazardous material.

No.	Sector	Type of Hazardous Materials	Hazards Class	Quantity (Tons)	Risk Score	Risk Level
1	Mining Energy and Oil and Gas	Premium	Category 1	330,980	72	High
		Pertamax	Category 1	117,794	72	High
		Pertadex	Category 1	11,903	39	Medium
		Kerosene	Category 1	103,364	39	Medium
		LPG	Category 1	11,173	30	Medium
		NBF	Category 1	56,146	30	Low
		MFO LS	Category 1	18,640	30	Low
		Avtur	Category 1	101,512	22	Low
		FLUX OIL	Category 1	2976	26	Low
		Miscellaneous	Category 2	123,240	26	Low
		Solar + Biosolar	Category 1	1,887,454	24	Low
		LAWS	Category 1	5502	24	Low
		Naphtha	Category 1	345,521	24	Low
		IDO	Category 1	1965	24	Low
		MGO LS	Category 1	3537	24	Low
		LSWR & LSFO	Category 1	354,729	20	Low
		SFO5	Category 2	5839	18	Low
		HVGO	Category 2	7355	18	Low
2		Pertalite	Category 1	-	78	High
		Reformate	Category 1	-	28	Low
		Marine Gas Oil (MGO)	Category 1	-	24	Low
		Automotive Diesel Oil (ADO)	Category 1	-	22	Low
		Smooth fluid	Category 1	-	20	Low
		Propane	Category 1	-	20	Low
3		Avtur	Category 1	411	22	Low
4		Avtur	Category 1	6168	22	Low
5		LPG	Category 1	50,706	30	Medium
6		Avtur	Category 1	24	20	Low
7		BBM	Category 1	2294	78	High
8		BBM	Category 1	4428	78	High
9		BBM	Category 1	83,360	78	High
10		Calcium carbide	Category 1	387	39	Medium
		Biodiesel	Category 1	547,500	24	Low
11		Coal	Category 1	22,000	65	High
		Hydrazine	Category 1	3.04	39	Medium
		Turbine Lubricants, Transformers, Grease	Category 1	12	22	Low
		Sodium hydroxide	Category 1	1.305	20	Low
		Ammonia	Category 1	0.6	20	Low
		HCl	Category 1	1.755	18	Low
TOTAL Hazardous Materials in Mining for Energy and Oil and Gas				4,206,929	33	Medium
12	Clean Water Provider	Chlorine	Category 1	406	36	Medium
		Sodium hypochlorite	Category 1	165	36	Medium
		Soda ash	Category 1	447	22	Low
		Aluminum sulfate	Category 1	1157	20	Low
		Limestone	Category 2	478	16	Low
		Alum powder	Category 1	234	16	Low
TOTAL Hazardous Materials in the Clean Water Provision				2887	24	Low
TOTAL Hazardous Materials in Balikpapan				4,209,816	32	MEDIUM

red = high category; yellow = medium category; green = low category.

From the results of the risk identification above, it was found that the hazardous materials emergency risk value for the mining for energy and oil and gas companies in Balikpapan was on average 33, indicating a medium risk and was determined mainly by hazardous materials of category 1. This was due to the large number of hazardous materials present and their properties.

Meanwhile, for clean water providers, it was found that the average hazardous materials emergency risk was 24, which means a low risk. In addition, it can also be seen that most of the hazardous materials in this sector was in category 1.

In general, the average risk score for Balikpapan city was 32, indicating a MEDIUM risk level. The types of emergency risk related to hazardous materials derived from flammable and corrosive were fire and explosion, oil and chemical spills, chemical burns, ex human and environmental exposure. In addition, it can be seen that 30 hazardous materials were categorized as low, 8 hazardous materials as medium and 7 hazardous materials were grouped as high category (Figure 5).

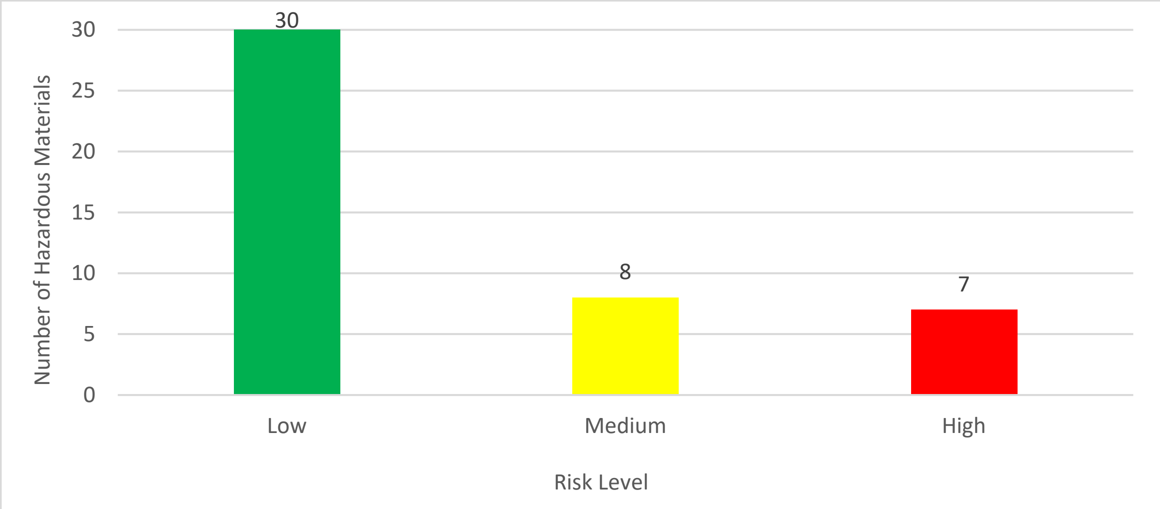

Figure 5. Recapitulation of hazardous materials' risk identification in Balikpapan, 2021.

Considering that most of the hazard materials were in the flammable and corrosive categories and the amounts of hazardous materials for each of these companies were more than 30 tons/year, recommendations have to be made optimally, regarding. For example, emergency response Standard Operational Procedures (SOPs) related to each hazardous material used, fire and explosion as well as spill prevention measures, providing safety equipment and using appropriate Personal Protective Equipment (PPE) for responding to industrial emergency situations. This is necessary to minimize the occurrence of spills, fires, explosions and environmental pollution.

3.5. Hazardous Material Mapping in Balikpapan

The hazardous materials distribution in Balikpapan City is presented in Figure 6. The results from GIS mapping suggested that the locations of the hazardous materials were spread around Balikpapan City, as shown in Figure 6. The industrial sectors included water treatment, mining, energy, oil and gas. The clean water provider industry appeared to be concentrated in one location, while the mining, energy, oil and gas industries appeared to be spread out in several locations. The distribution of hazardous materials based on their amount is shown in Figure 7. Large amounts of hazardous materials were found in Balikpapan Central City and in the central area of Balikpapan City, surrounding the coastal area of Balikpapan City. The risk level mapping distribution of hazardous material in relation to Balikpapan's population and environmental media is presented in Figure 8. The highest risk level was located within Balikpapan Central City and in the central area of Balikpapan. Figures 9 and 10 present the risk level mapping based on the industrial type, i.e., clean water providers, mining, energy, oil and gas industries.

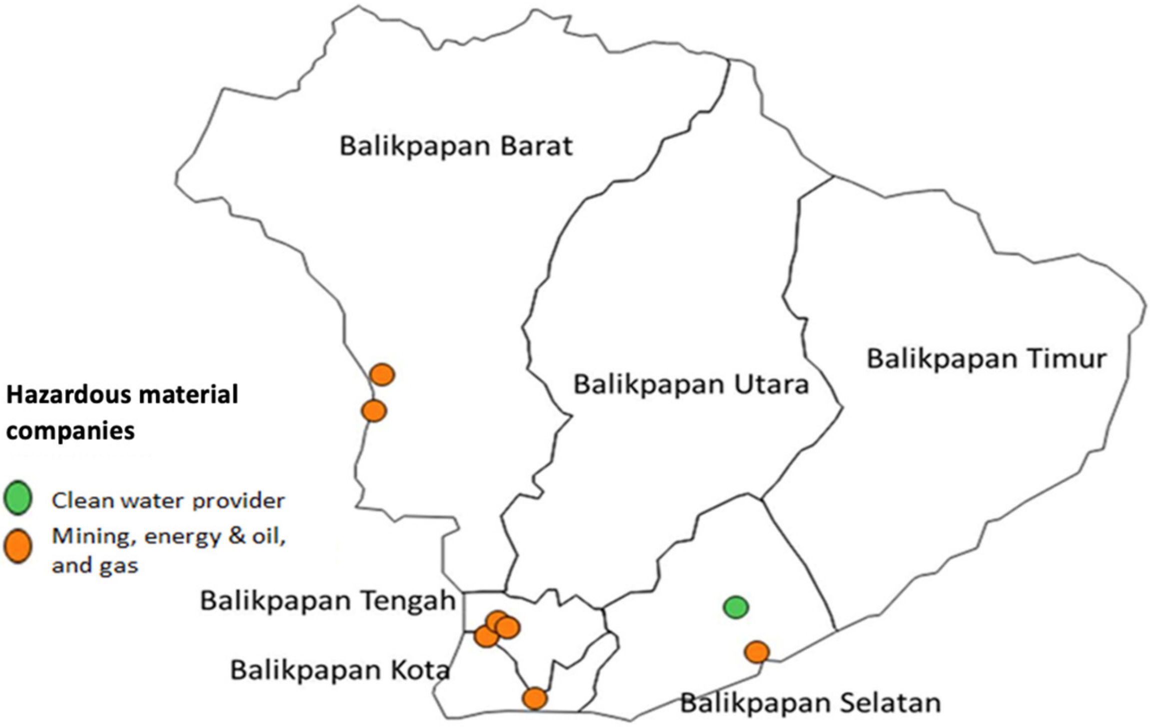

Figure 6. Distribution of hazardous materials-producing companies.

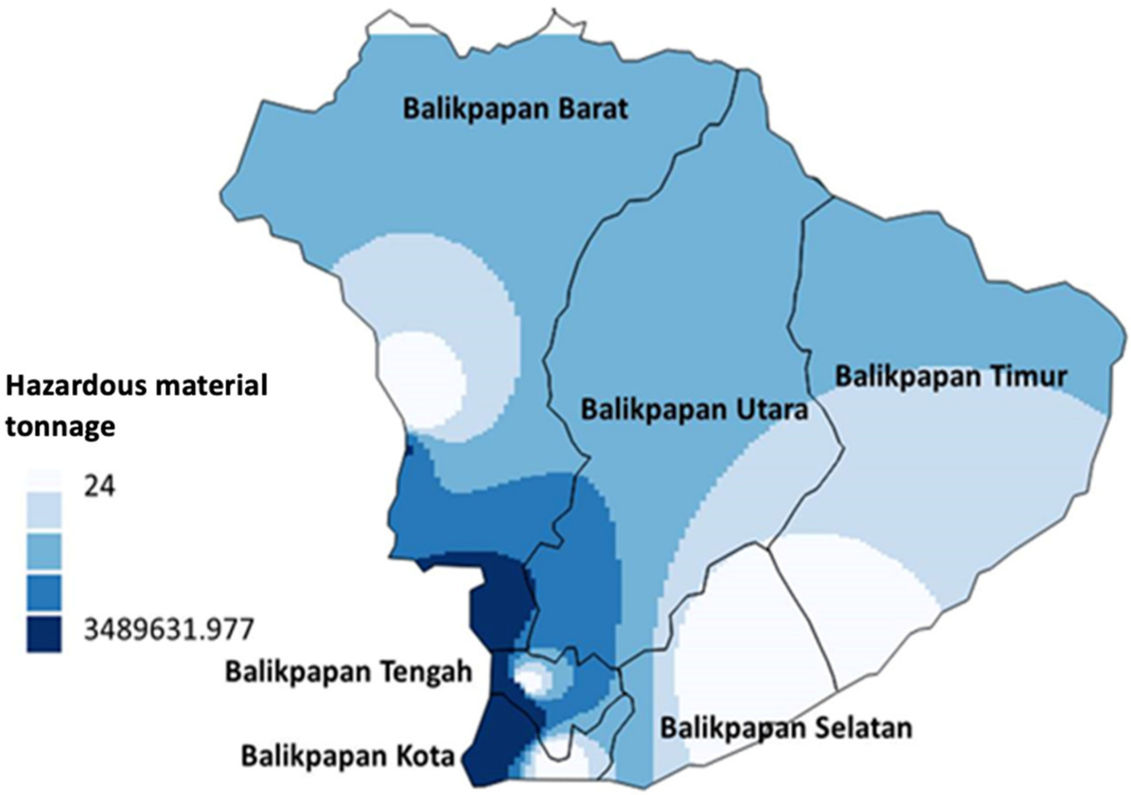

Figure 7. Hazardous materials tonnage distribution (the darker the color, the higher the amount of hazardous materials).

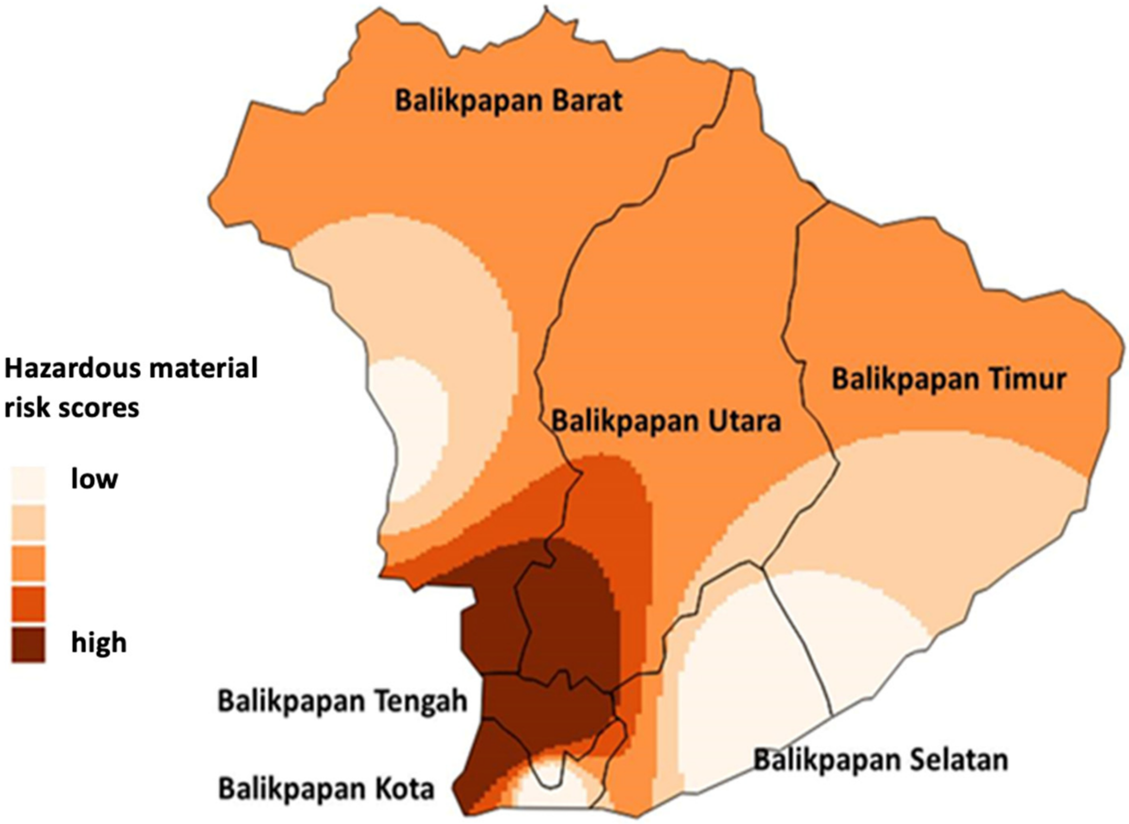

Figure 8. Distribution of the hazardous materials risk scores (the darker the color, the higher the hazardous materials risk scores).

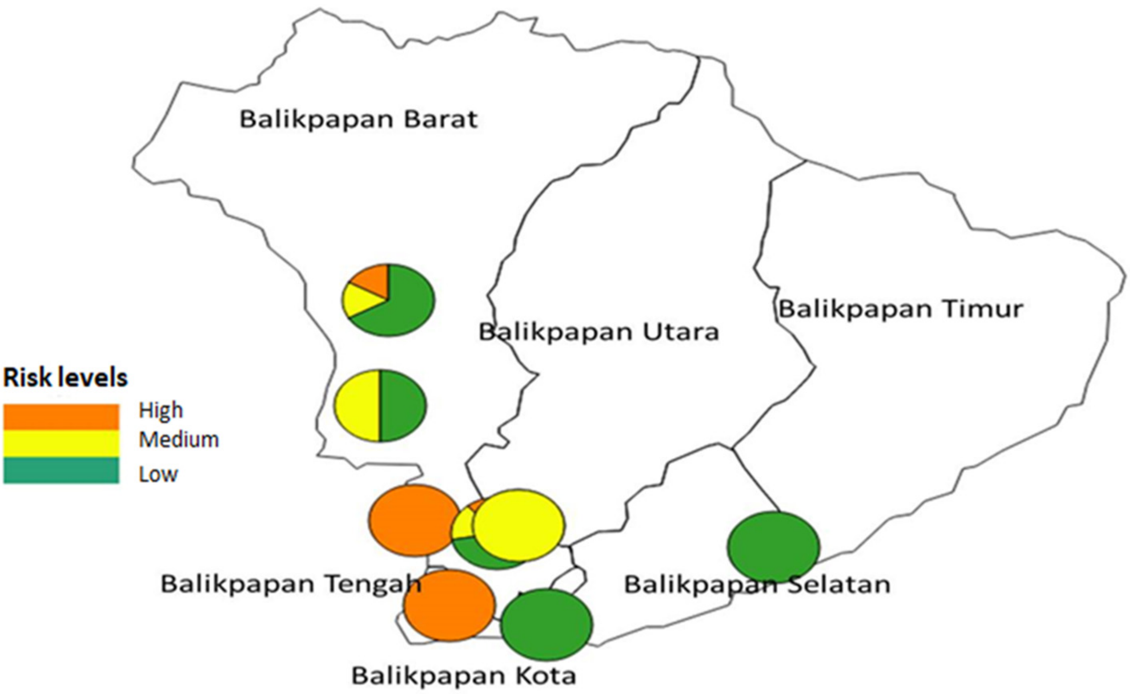

Figure 9. Hazardous materials composition based on the risk level for the mining, energy and oil and gas sector.

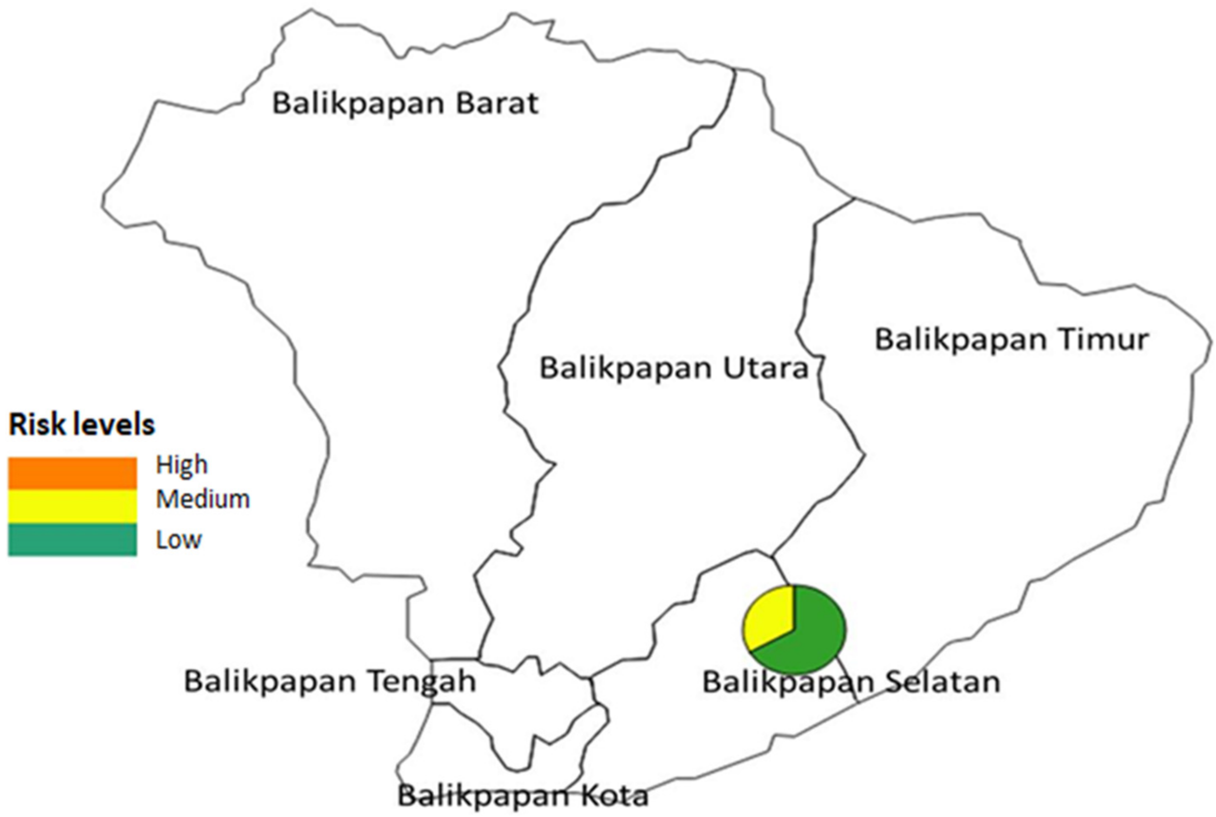

Figure 10. Hazardous materials composition based on the risk level for the clean water provider sector.

4. Discussion

4.1. Industrial and Environmental Disaster Risk for Balikpapan

Balikpapan has experienced a large oil spill during 2018 [26,27]. The oil spill in Balikpapan was located in the coastal region of Balikpapan and covered an area of an estimated 120 square kilometers. It caused the death of five fishermen, public health and economic problems to Balikpapan local communities, as well as danger to environmental wildlife and ecosystems [26,27]. The large impact of the oil spill in Balikpapan bay led to huge sanctions for Indonesia's state-owned industry [25]. The oil spill caused an industrial and environmental disaster, and public health problems for at least 900,000 people in Balikpapan.

4.2. Industrial and Environmental Disaster Risk from Hazardous Material in Balikpapan

Based on our risk assessment result, the average risk score for Balikpapan city was 32 indicating a MEDIUM risk level, with the main hazardous materials classified in category 1. The emergency risk related to hazardous material and derived from flammable and corrosive included fire and explosion, oil and chemical spills, chemical burns, human and environmental exposure. The business sectors in this area included oil and gas companies, refineries, clean water providers and energy generators in Balikpapan which use hazardous materials. The industries in Balikpapan carry out activities such as hazardous materials storage, usage, handling and distribution within Balikpapan City. Furthermore, since Balikpapan has experienced a large oil spill which can be classified as an industrial and environmental disaster, the risk level of MEDIUM should be considered carefully. It is suggested that the industries and government of Balikpapan need to be ready in responding to hazardous materials (hazmat) emergencies, which may escalate to industrial and environmental disasters.

In a more detailed analysis, it was found that the risk level for the mining for energy and oil and gas sectors was 33 (MEDIUM), linked to the flammable hazmat type. The risk of fire and explosion and oil spills is becoming dominant among the risks posed by industries. The risk of environmental disaster may include environmental pollution, damage to wildlife and ecosystems, contamination of air, water and land. Indeed, since this typical hazardous material occurs in large quantities, the possible exposure of local communities, the significant impact on public health, and the possibility to cause both industrial and environmental disasters have to be considered. Furthermore, since in East Kalimantan the risks level for natural hazard, such as floods, forest and land fire, extreme waves and abrasion, is also high, future research is needed to evaluate the risk level according to NaTech descriptions (natural hazards-triggered technological disasters), the potential cascading effects of these hazards [28] and how the community would response to them [29].

Our research suggested that for the industry sector of clean water provision, the average risk level was 24, which means a LOW risk. The hazardous materials type mostly used in this industrial sector is corrosive material, commonly used in its activities, belonging to category 1. The risk of causing industrial or environmental disasters for this industrial sector appeared to be considerably low. However, the industries and the government of Balikpapan are still required to be ready for an emergency situation in case accidents occur. Typical corrosive materials include irritants and chemical spills which may impact public health.

4.3. Hazardous Material Mapping in Balikpapan

The results from the GIS mapping suggested that the hazmat industries are located within several areas of Balikpapan City (Figure 6). A large amount of hazmat is concentrated within Balikpapan City and its coastal area (Figure 7). Similarly, the highest risk level and the highest risk score were found for these areas as well (Figure 8). The types of industrial sectors contributing to the high risk level included the water treatment, mining, energy, oil and gas sectors. The clean water provider industry is concentrated in one location, while the mining, energy, oil and gas industries are spread out in several locations. Indeed, as a result of the GIS mapping, the areas at higher risk are located within Balikpapan City and Balikpapan central and coastal regions. During the Balikpapan's large fire and major oil spill in 2018, the investigation revealed that the root cause was the crude oil that spilled from a fractured pipeline in the Tanjung Penajam. The crude oil pipeline was fractured because an overseas ship's anchor fell on it. In addition, the latest field observations by conservationists from Rare Aquatic Species Indonesia (RASI) confirmed that the spill intrusion progressed deeply into the estuary ecosystem and mangrove forest and, 34 hectares of mangrove forests were impacted [27]. It was estimated that 60 km of beach was affected by the disaster. After the oil spill occurred on 31 March 2018, the local authorities of Balikpapan declared a 15-day state of emergency. Meanwhile, more than 1000 residents complained about nausea and breathing problems due to toxic chemicals [25].

The results from the GIS mapping obtained in this study indicating the risks of hazardous materials in particular coastal areas are comparable with those of previous studies [30]. Coast-originated hazardous material has long been recognized as an ever-increasing problem for the nearby oceans and coastal community. It contaminates both beaches and sea surfaces and is consumed by fish, seabirds and other creatures, even humans. Hazardous material released due to the Dalian New Port oil spill on 16 July 2010 emitted approximately 35,000 tons of crude oil into the coastal water. The potential releases of hazardous material in Balikpapan are also comparable to the Deepwater Horizon Oil Spill in the northern Gulf of Mexico.

This study provides information on particular industries and companies that pose risks linked to hazardous materials to the Balikpapan City, including its coastal areas. This study has several limitations. The information on the hazardous materials should be compared with environmental data presenting and justifying the impact of the presence of those hazardous materials. These variables were not measured in this study, and it is recommended to assess them in the future studies. This study used GIS mapping as a tool to measure and monitor hazardous materials' presence and distribution in particular coastal areas. To obtain and expand the monitoring coverage in the terms of spatial and temporal analyses, it is recommended to use and develop various GIS and remote sensing monitoring tools in the future [31].

5. Conclusions

Industrial and environmental disaster risk evaluation for hazardous material risk mapping is highly important to identify industrial disaster hazards and their consequences. It was reported that Balikpapan City experienced a major fire and a large oil spill which caused an industrial and environmental disaster, due, mainly, to hazmat such as flammables and corrosives. Several industries, such as mining, energy, clean water provision, oil and gas, have a high probability of causing these types of disaster. Our study indicated the highest hazardous material risk for the Balikpapan City coastal areas. In order to reduce the major risks and provide a quick and accurate disaster response, the industries and the government of Balikpapan must be prepared for industrial and environmental disasters. The disaster preparedness would include preparing competent major hazmat responders and a large spills response equipment and ensuring large environmental monitoring and measurement, procedures to deal with major fires and explosions, comprehensive disaster communication and coordination, material management, education of industrial workers and managers and adequate local regulations and legislations. The risk assessment is strongly recommended to be conducted by the involved companies in order to minimize industrial and environmental disaster.

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