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Disaster risk analysis of technological failure of industrial estate: a case study

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A B S T R A C T

The world has agreed on reducing disaster risks through Sendai Framework for Disaster Risk Reduction (SFDRR) 2015–2030. Efforts to reduce disaster risks are one way to attain Sustainable Development Goals related to "sustainable cities and communities." The first points of disaster risk reduction priorities inscribed in the SFDRR 2015–2030 incorporate disaster risk studies. While studies on natural disaster risks have been widely conducted, non-natural (manmade) disaster risk studies are relatively scant, particularly for technological failure disasters. In this paper, the author investigates the levels of technological failure disaster risks in Gresik Regency, Indonesia, one of the National Strategic Areas in East Java Province. This study employs a disaster risk analysis encompassing aspects of hazard and vulnerability through map overlays with the help of a Geographical Information System (GIS) to identify areas with risks of technological failure. Results illustrate that a high risk is predominantly spread in areas with high hazards, which is 60 m radius of the industrial area. The findings in this study may help shed light on the hazards that may arise due to technological failures that span not only around the source of hazard, i.e., the industrial areas, but also beyond them, and also conclude that the higher the disaster risk is, the higher the vulnerability of an area will be.

1. INTRODUCTION

Disaster risk is the possibility of an event or a series of hazards and exposure levels resulting in a disaster due to urbanization, environmental degradation, socio-economic inequality, and poor urban management that results in substantial loss, such as deaths, damage, economic decline, and physical degradation [1], [2]. The impacts of disasters are often multidimensional, which, in turn, call for integrated and multisector efforts for disaster risk mitigation. As such, disaster risk studies are imperative, as suggested by the Sendai Framework for Disaster Risk Reduction (after this, referred to as SFDRR) 2015–2030, in which the priority action includes understanding disaster risks through conducting studies and disseminating the results.

Understanding disaster risks incorporates policies and practices based on comprehending vulnerability, environmental characteristics, and hazards [3]–[5]. Disaster risk analyses encompass hazard and vulnerability variables that make up the portion of steps in attaining Sustainable Development Goals [6], which is Goal 11, titled "sustainable cities and communities". Through disaster risk studies, we can identify economic, social, physical, cultural, and environmental characteristics, even

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sustainable living aspects, for creating disaster resilience [6]. It highlights the significance of disaster risk studies as the basis for addressing global issues with far-reaching implications. In this paper, the author discusses the disaster risk of technological failures by taking the example of Gresik Regency, Indonesia.

Disasters are generally categorized as a combination of three main sources, which are natural (e.g., earthquakes, volcanic eruptions, tsunamis), non-natural (e.g., technological failure, toxic waste), and social (e.g., family violence, poverty) [7]. Technological failures are disasters due to human errors following technological malfunctions and unpredictable but preventable incidents related to the loss of control over technological cases, thus leading to damage to the natural environment, exposure to toxic materials, and other social impacts [8], [9]. United Nations Office for Disaster Risk Reduction (UNISDR) defines technological failures as dangers emerging from technologies and industries, including accidents, unsafe procedures, infrastructural failures, or certain human activities that may cause loss of lives, injuries, diseases, or other health-related repercussions, property damage, loss of employment and social service, economic disruptions, and environmental deterioration [10].

Gresik Regency is included as one of the National Strategic Areas (KSN) with the potential for industrial development supported by the Presidential Regulation Number 80 of 2019 on Economic Development Acceleration at the Gresik-Bangkalan-Mojokerto-Surabaya-Sidoarjo-Lamongan, the Bromo-Tengger-Semeru Area, and Selingkar Wilis and Lintas Selatan Area; and Government Regulation Number 13 of 2017 on the National Spatial Plan, which includes Gresik Regency as a Centre for Nation-Scale Activities. The central and regional governments have conceived various strategies to promote industrial activities in Gresik Regency, unsurprisingly resulting in the industrial sector flourishing.

Risk preparedness for total accident and incident costs has been undertaken by people working in industries through their HSE (Health, Safety, and Environmental) unit, which ensures workplace safety and minimizes the environmental impacts of industrial activities [11]. Despite industrial activities, especially those of large industries, having been regulated to curb disaster risks, the parties involved, including the people, must still be cautious because 1) the majority of companies in the industry sector tend to focus on internal problems and the relatively-conservative impacts on the area in which the industries operate, 2) the people living near the industrial areas are not actively involved in the efforts of reducing disaster risks due to technology, and 3) people working in industries seldom weigh the possible impacts of technological failures on their surrounding environment, although facts show that the impacts have been extensive and long-lasting.

Analysis on risks of technological failures have been conducted by several researchers, among whom are Supriadi & Oswari [12], Ager *et al.* [13], and Fancello *et al.* [14], where mostly focusing on one type of industry or one company. This study attempts to investigate, within a broader scope, the Gresik Regency, as the extent to which regional autonomy concerns disaster risk mitigation in Indonesia is limited to its administrative boundaries. As evident, disaster risks extend beyond just the industrial area itself, threatening the environment, social lives, economic conditions, and even the psychological well-being of the people outside the industrial area [15]. A spatial analysis of the risks of technological failures has been conducted using hazard and vulnerability [14].

2. RESEARCH METHODS

This study aims to identify the risk level of technological failure in Gresik Regency, Indonesia, especially in its industrial area, by applying a quantitative method and spatial data.

2.1. Study area

Industrial development in Gresik Regency began with the establishment of limited liability company Semen Gresik in 1953 and PT Petrokimia Gresik in 1972. Today, Gresik Regency has several strategic industrial areas, including metal processing, electricity generator, and chemical producing industries. Chemical industries are highly susceptible to technological failures due to the hazardous nature of their operational activities [16]. The raw materials in chemical industries are generally flammable and explosive. The industry sector thrives both in the industrial and non-industrial estates, with an area spanning 16% of the entire Gresik Regency. Prevailing large industrial estates include Gresik Industrial Area, Java Integrated Industrial and Port Estate (JIIPE), and Maspion Industrial Estate. The largest industrial land used is in Manyar District (2,162 ha) and Kebomas District (957 ha). Industrial areas are

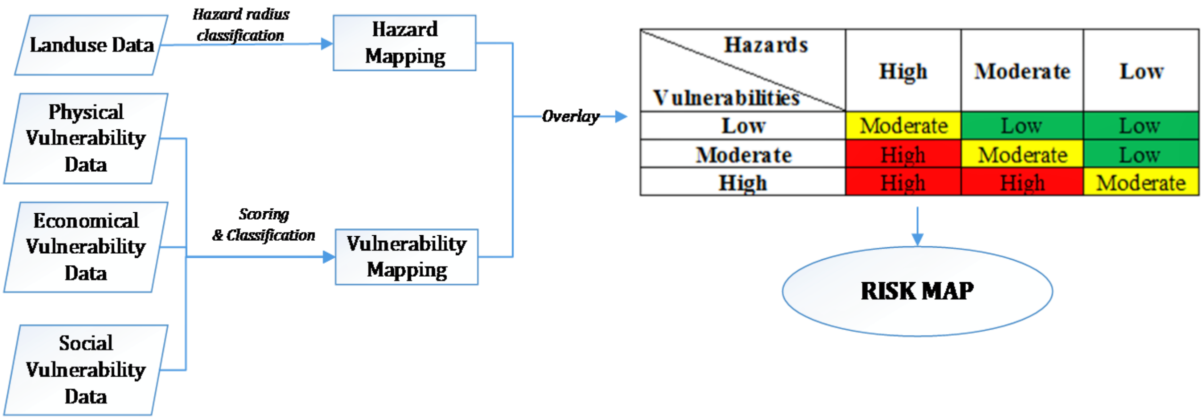

Fig. 1. Stages in mapping technological failure risks

also present in the southern and central parts of Gresik Regency, such as Driyorejo District (745 ha), Menganti District (388 ha), and Wringinanom District (318 ha).

2.2. Disaster risk analysis of technology failure

This study conducted a technology failure disaster risk (R) analysis in which R (risk) = H (hazard) x V (vulnerability) [14]. Primary and secondary data were collected in this study, with the village as the unit of analysis. The stages in analyzing the risk of technological failures in Gresik Regency are hazard assessment, vulnerability assessment and disaster risk assessment of technological failures (Fig. 1).

The Hazard assessment of technological failures employed the land use data based on the municipal spatial plan (RTRW) of Gresik Regency from 2019 to 2039, with results indicating that hazards from technological failure originate from the industrial area. The data were then processed using the GIS software by mapping the impact radius of potentially hazardous incidents from industrial activities, producing a hazard map of technological failures that categorizes regions in the Gresik Regency into high, moderate, and low levels. The radius of the high-hazard area is 0–60 m from the point of origin (the industrial area), while the radius of the moderate-hazard area is 6–120 m from the point of origin, and the radius of the low-hazard area is 120–270 m from the point of origin [17]. Predictions of technological failure hazards ought to be assessed based on the elementary materials used in industries. The elementary materials determine the impacted area/radius of industrial failures [18]. Limited access to information on the types of industrial activities during this research has made it difficult to map the types of industrial activities.

Vulnerability assessment aims to identify the reason(s) for people's decreased resilience due to external factors that may threaten their safety, livelihood, natural resources, infrastructures, economic productivity, and welfare [19]. The aspects of vulnerability are (1) physical vulnerability describes the estimated physical (infrastructure) damage should a certain hazard occur; (2) economic vulnerability measures the loss or damage of economic activities following a hazardous event; and (3) social vulnerability is the susceptibility of a given population to being impacted by a hazardous event [20]. The vulnerability aspect is measured by combining the scoring and weighting of indicators for each type of vulnerability. After the three vulnerability types were identified, they were overlaid using the sum-weighted overlay analysis in the GIS software.

The disaster risk assessment of technological failures combines the hazard and vulnerability maps, which results in the technological disaster risk map with low, moderate, and high-risk levels.

3. RESULTS AND DISCUSSION

3.1. The hazard assessment

Industrial development has positive and negative impacts: 1) air, water, and soil pollution; 2) high rate of urbanization; 3) increased hazards due to technological failures; 4) rampant traffic congestion. Oversight/negligence in ensuring safety design within the technology factories or errors in operating the factory/technology are common threats often left unaddressed [21]. Technological failure disasters can be divided into three categories: industrial (chemical spill,

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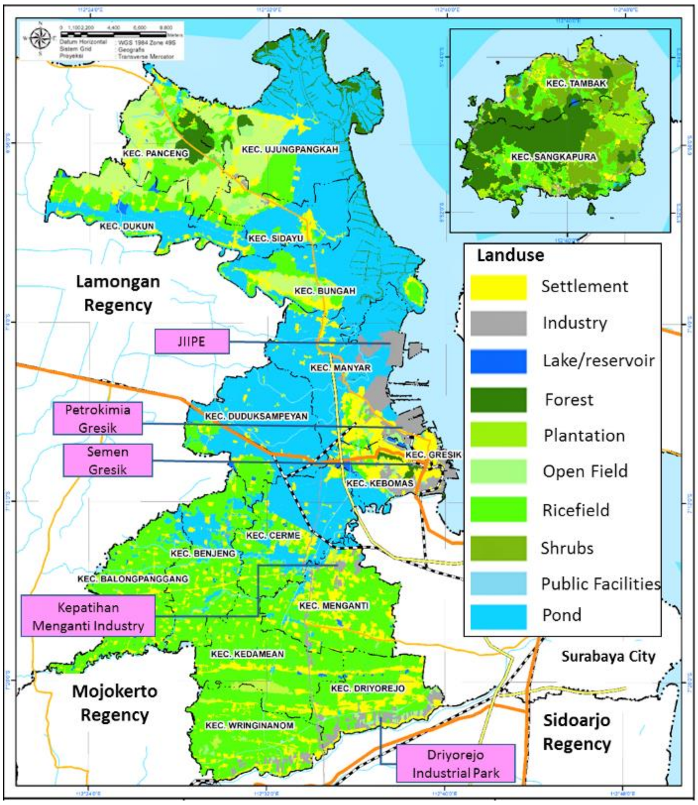

Fig. 2. A land use map in Gresik regency

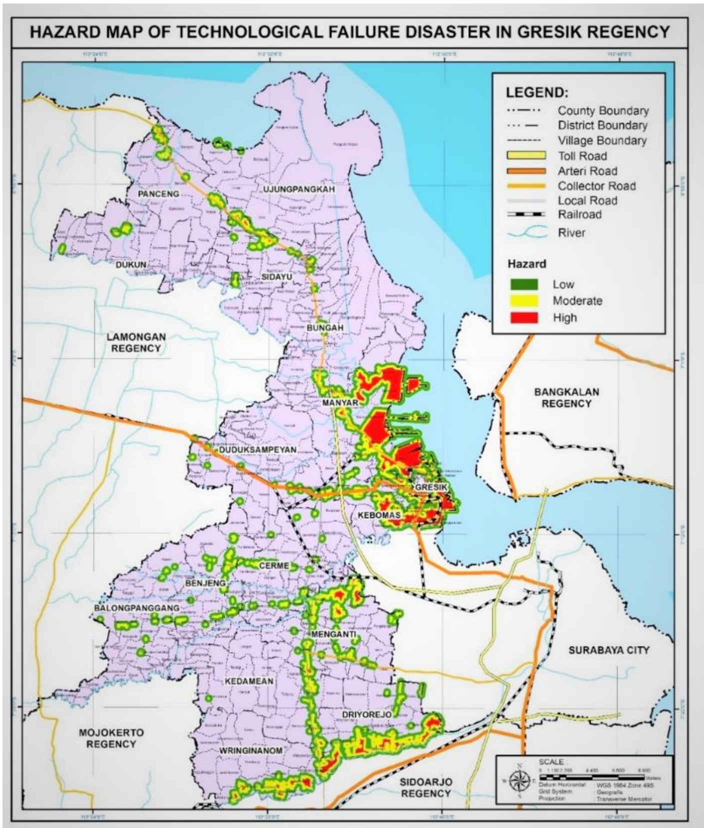

Fig. 3. A technological failure hazards map in Gresik regency

collapse, explosion, fire, gas leak, poisoning, radiation, and others), transport (air, rail, road, and water), and miscellaneous accidents (fire, collapse, (fire, collapse, explosion, and others) [22]. However, this paper focuses on industries.

Some technical failures in Gresik Regency occurred at the oil processing factory PT Primergy Solution in 2011 at the Gresik Industrial Area (KIG). In 2017 (in January–March), there were 41 accidents in the welding [23]; another case was an inferno at the PT Petro Widada Gresik in 2004, resulting in three casualties and 56 wounded; another event was an explosion at one of the factories along the Kapten Darmo Sugondo Road, Gresik Regency, causing five deaths and two factory workers injured [24]. Many technological failures are due to activities related to hot work in tanks, which may include welding, grinding, burning, boiling, and others [25] that may inflict fire and explosion. The industries proliferating in Gresik Regency are mostly carrying out these hot works.

The results of GIS-assisted hazard assessment based on industrial land use data show that all districts in Gresik Regency have at least one region with a high-hazard level related to technological failures (Fig. 2). The industrial areas are home to potential technological failure hazards due to the majority of their production process involving a hot work environment with flammable industry products, such as toxic chemicals, metals, lubricants and oil, paper, foods, and materials that can ignite, causing fire or even setting off an explosion. Four districts with the most hazard-prone area are Manyar District (15 villages/2,587.9 ha), Driyorejo District (15 villages/1,259.4 ha), Kebomas District (21 villages/1,330.62 ha), and Menganti District (20 villages/762.46 ha). Ha [17] pointed out that areas within a radius of 60 m from industrial areas that may pose hazard risks may be significantly affected in the event a technological failure incident inflicts casualties, injuries, and other direct, immediate consequences; areas within 120 m radius from the point of incident experience the impacts, albeit indirectly, which may comprise post-explosion gas odor, smoke, crowd surges following explosion/fire.; areas within a radius of 270 m perceive other indirect impacts, for instance, environmental, air, water, and soil pollution.

Identifying the hazards of technological failures indicate that the locations of all explosion incidents in Gresik Regency in 2004 (PT Petro Widada in Manyar District), in 2011 (PT Primergy Solution in Gresik District), and in 2021 (a factory along the Kapten Darmo Sugondo Road, Gresik District) are classified into high-hazard zones (Fig. 3). Deaths and injuries occur in the high-hazard zone, i.e., within the 60-m radius. Fig. 3 also shows that technological failure hazards are scattered along the main road networks of the Gresik Regency. The reason is that networks of arterial and primary collector roads of both national-and provincial-scale road status have underpinned the development of industrial areas. It suggests that technological failures in Gresik Regency can potentially incapacitate access to the main roads due to static outbursts from the production processes and the transportation of vehicles carrying goods and production outputs. There certainly are hazards due to technological failure along the roads neighbouring the industrial areas in Gresik Regency. Still, there have been no incidents involving the mobilization of industrial goods. The mobilization of flammable and hazardous materials from and to the industrial areas will pass through the distribution channels, potentially inducing explosions along its path if incidents arise. As a result, company HSE units should take heed not only of the industrial area itself and a small fraction of its surroundings but also give more thought to what is beyond, including along the mobilization process of the company's goods and production outputs.

3.2. Vulnerability assessment

3.2.1. *Physical vulnerability*

Studies on physical vulnerability include three main parameters: the number of houses, public facilities, and critical facilities. The number of house parameter identify houses that can potentially experience damage and losses in a disaster-prone area. Public facilities are service-providing public buildings that are likely to be damaged. At the very least, the public facility parameter requires data on education and health facilities [4]. This study defines critical facilities as buildings having essential (critical) roles that may suffer from damage in times of crisis or disaster. According to the Indonesian National Board for Disaster Management (BNPB), critical facilities consist of airports, harbours, and electrical networks. Gresik Regency does not have an airport, and the critical facility parameter is only

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harbours and electrical networks, which, in this case, are electrical substations.

The physical vulnerability level assessed in Gresik Regency mostly comprises low physical vulnerability due to the number of houses, public facilities, and critical facilities spread in each village being categorized as having low vulnerability (a score of 0.33–0.44) (Table 1). High vulnerability (a score of 0.8) can be seen in Sembayat Village and Tebalo Village in Manyar District. The reason is that Manyar District is located in the urban areas of Gresik Regency (Presidential Regulation 80/2019 and Government Regulation 13/2017), focusing on developing industrial activities, residential areas, government, and service and trade. Consequently, it is no surprise that Sembayat and Tebalo Village are characterized by dense residential areas with relatively more abundant public facilities than other villages.

3.2.2. *Social vulnerability*

Studies on social vulnerability in this study employed four parameters: population density, sex ratio (female), age ratio (toddler and elderly population), and poverty headcount ratio. Population density indicates the number of people living in a given district; the higher the density is, the more likely the people will be exposed [25]. The sex ratio (female) contributes to vulnerability because women in Indonesia generally stay at home; therefore, the chance of exposure is higher if a technological failure occurs. The age factor in this study reflects that the older people and toddler population have less capacity to keep themselves safe from danger, resulting in lower odds of survival than the remaining cohorts when disasters strike [19], [20]. Meanwhile, people living in poverty are considered vulnerable due to requiring more efforts to adapt and a longer time to recover from disasters because of their lack of access to financial aid.

Based on the four social vulnerability parameters analysis, a social vulnerability level mapping can then be produced (Table 1). The majority of Gresik Regency shows moderate social vulnerability, though several villages in several districts show high social vulnerability (with a score > 0.66). The districts in question are Balongpanggang District, Benjeng District, Bungah District, Cerme District, Driyorejo District, Dukun District, Gresik District, Kebomas District, Kedamean District, Menganti District, Sidayu District, Wringinanom District. The villages in Gresik District have also displayed high social vulnerability (with a score of 0.82) due to a higher population density than those in other districts. Another reason is that Gresik District is the urban administrative center of Gresik Regency in which the center of residential, government, trade, service, and industrial activities take place.

3.2.3. *Economic vulnerability*

Economic vulnerability calculation looks at a region's GDP through the availability of productive land area, including agriculture, fisheries, industry, mining and trade/services. The land area is assumed that the higher the availability, the higher the contribution to GDP. This assumption refers to the technical guidelines for calculating economic vulnerability issued by Indonesian National Board for Disaster Management (BNPB). GDP cannot refer to secondary data from the Central Statistics Agency (BPS) because the unit of analysis in this study uses villages, while GDP in the secondary data has the smallest scope only at the sub-district level. This vulnerability was measured on productive lands because the damage inflicted by technological disasters through toxic or hazardous refuse may result in the loss of livelihood, affecting income, both individual and, consequently, regional.

The average economic vulnerability of Gresik Regency belongs to the moderate level (0.34–0.66) based on the score of the villages in each district (Table 1). Villages with moderate economic vulnerability can be found in Balongpanggang District, Benjeng District, Bungah District, Driyorejo District, Duduk Sampean District, Dukun District, Gresik District, Kebomas District, Manyar District, Menganti District, Panceng District, Sangkapura District, Sidayu District, Tambak District, Ujungpangkah District, and Wringinanom District. High economic vulnerability is mostly in the Kedamean District, comprising Banyuurip Village, Lampah Village, Mojowuku Village, Sermenlerek Village, and Sidoraharjo Village because more than 70% of their area is productive land (farmlands, orchards, fisheries, and livestock operations), which are highly prone to pollutions from the impacts of technological failures, while also having a GDP score of > 0.6. It indicates that having advantageous economic potentials and facilities, in this case, poses some conundrums, as this may potentially lead to a much greater disadvantage than other less-developed areas [26]. Therefore,

Table 1. The average village vulnerability score for each district

Districts	Physical vulnerability	Economic vulnerability	Social vulnerability	Area vulnerability	Level of area vulnerability
Balongpanggang	0.34	0.60	0.70	0.57	Moderate
Benjeng	0.34	0.59	0.73	0.58	Moderate
Bunga	0.35	0.61	0.64	0.55	Moderate
Cerme	0.35	0.68	0.72	0.60	High
Driyorejo	0.42	0.44	0.77	0.58	Moderate
Duduk Sampean	0.33	0.62	0.62	0.54	Moderate
Dukun	0.34	0.63	0.74	0.60	High
Gresik	0.38	0.39	0.82	0.57	Moderate
Kebomas	0.40	0.45	0.76	0.57	Moderate
Kedamean	0.35	0.67	0.68	0.59	Moderate
Manyar	0.42	0.58	0.66	0.57	Moderate
Menganti	0.40	0.48	0.78	0.59	Moderate
Panceng	0.37	0.65	0.62	0.56	Moderate
Sangkapura	0.36	0.46	0.51	0.46	Low
Sidayu	0.34	0.55	0.68	0.55	Moderate
Tambak	0.36	0.49	0.50	0.46	Low
Ujung Pangkah	0.38	0.61	0.55	0.52	Moderate
Wringinanom	0.36	0.47	0.72	0.55	Moderate
Average	0.36	0.56	0.69	0.56	Moderate

enhancing the capacities of stakeholders using spatial planning is important to reduce disaster risk, avoid technological failure and protect productive land around industrial areas.

3.2.4. *Gresik regency's vulnerability*

The process of overlaying each village's physical, social, and economic vulnerability levels produces the overall vulnerability level (Fig. 4). This study took Indonesian National Disaster Management Board (BNPB) as a reference for calculating vulnerability level and weighting each aspect of vulnerability: 40% for social vulnerability, 30% for physical vulnerability, and 30% for economic vulnerability. Based on the calculations made on area vulnerability (Table 1), the vulnerability of the villages in each district in Gresik Regency, on average, is moderate level (a score of 0.5–0.6). Meanwhile, areas affected by technological failures have a low vulnerability level. The most vulnerable (a score of 0.60) area is the Dukun District due to its high social vulnerability (a score of 0.77). Some underlying factors causing this are the high sex ratio and poverty headcount ratio.

The analysis results indicate that areas with high vulnerability are commonly found in villages with a high number of people living in poverty. Analogous to the previous study results, in times of disaster, including technological failures, people experience a decline in their income. At the same time, the poverty level increases [27], [28]. Financial aid is undoubtedly vital during these challenging times to allow impacted people to recover. In other words, affected by the repercussions of some technological disasters, poverty-stricken residents will only grow destitute and will require even more time to recover due to the lack of access to investments or assets, i.e., a higher poverty headcount ratio will exacerbate the impacts of a disaster. Therefore, the government needs to bridge the gap so that the people around the industrial area can increase their economic level, for example, by providing business skills, directing the company's Corporate Social Responsibility (CSR) program to increase the economic standard of the community, and providing socio-economic guarantees for the impact of the dangers of technological failure (insurance).

High vulnerability can be seen in villages with a higher proportion of women than men. High vulnerability takes place in areas with higher female populations [29]. Women in Indonesia, especially in Gresik, tend to spend more time at home than other house residents because they take care of their children and perform household duties [30]. Therefore, efforts to mitigate disaster

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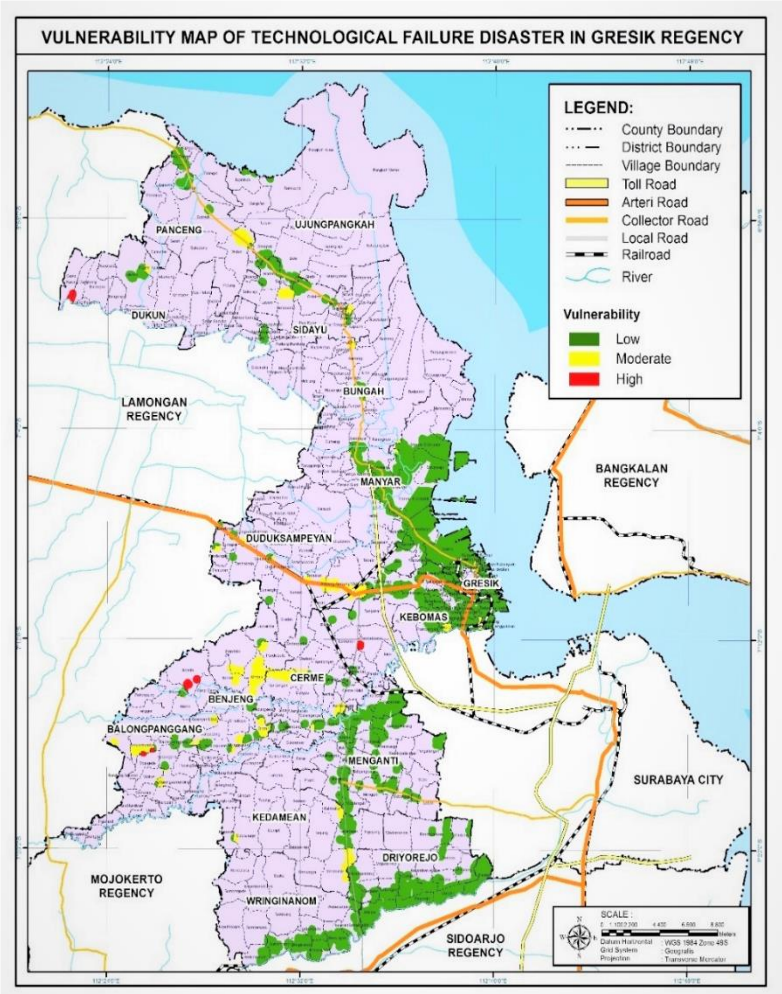

Fig. 4. A vulnerability map of Gresik regency

risks need to be implemented by empowering women and ensuring their education so that they will have the capacity to deal with and minimize the adverse impacts arising from the industries near them. In addition, educating women is an efficient way to educate society because women will pass on their knowledge to other family members, especially their children. That can be done by socializing the dangers of disasters that threaten the location of their settlements (including the danger of technological failure from industrial activities), disaster evacuation rehearsal training, including socialization of emergency assembly points and evacuation points, and it is necessary to make efforts to improve the standard of living of families through creative home business training to reduce economic vulnerability, That steps can be carried out with synergy between the government and industrial actors through Corporate Social Responsibility (CSR) programs.

3.3. Disaster risks

According to the technological failures risk map (Fig. 5), most villages in Gresik Regency have a low technological-failure risk despite some demonstrating moderate and high risk. This study measured the area of each risk category in Gresik Regency, which comprises low risk (8,238.39 ha), moderate risk (7,968.63), and high risk (617.70 ha). A high-risk level of technological failure disaster can be observed in villages (Table 2). This high risk is primarily caused by the many industrial areas in these districts' villages, along with their accompanying physical, social, and economic vulnerability.

Almost all villages with a high-hazard level show a moderate-risk level. The reason is that most villages neighbouring the industrial areas have a low vulnerability level. In line with previous research [14], the lower the vulnerability, the lower the disaster risk of an area, and vice versa, and it is remarked that areas with low

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vulnerability face no risk at all from technological failures. In this study, even for the areas with low vulnerability, the classification of disaster risk still depends on the hazard level. Areas with low vulnerability may experience low and even high risk, depending on the hazards that may arise [5], [19], i.e., an area with low vulnerability with a high-hazard level will still have a high-risk level. Some of the examples are Ngimboh Village, Banyuurip Village, Sembayat Village, Manyarejo Village, Banyuwangi Village, Sukomulyo Village, Pongahan Village, and Peganden Village in Manyar District, all of which have a low vulnerability but indicate a moderate- to high-risk level.

High-risk villages are observed in Dukun District, Balongpanggang District, Duduk Sampeyan District, Kedamean District, and Banjeng District (Table 2 and Fig. 5). High-risk villages have moderate-to-high hazard and moderate-to-high vulnerability levels—the number of high-risk

Table 2. Areas at risk for technological failure disaster for each district in Gresik regency

Districts	Area of low risk (ha)	Area of moderate risk (ha)	Area of high risk (ha)
Balongpanggang	261.07	125.20	63.74
Benjeng	527.00	161.78	132.64
Bungah	104.06	45.39	7.13
Cerme	612.70	195.50	108.60
Driyorejo	1,040.19	1,259.41	0
Duduk Sampean	357.04	90.10	97.65
Dukun	167.81	81.83	22.05
Gresik	224.49	346.56	1.88
Kebomas	838.96	1,271.62	61.46
Kedamean	262.11	128.47	42.51
Manyar	1,149.51	2,588.28	0.11
Menganti	1,308.99	762.46	0
Panceng	288.27	137.46	48.42
Sidayu	364.59	169.44	31.52
Ujung Pangkah	154.72	63.58	0
Wringinanom	576.89	541.57	0
Total	8,238.39	7,968.63	617.70

Table 3. The average area of villages facing technological failure disaster risks in each district of Gresik regency

Average of Villages' Area to Their District	Average area (ha)		
	Low	Moderate	High
Balongpanggang District	17.40	10.43	9.11
Benjeng District	25.10	12.44	16.58
Bungah District	8.67	5.04	1.78
Cerme District	18.57	9.77	12.07
Driyorejo District	34.67	83.96	0
Duduk Sampeyan District	18.79	8.19	19.53
Dukun District	13.98	11.69	4.41
Gresik District	6.24	20.39	1.88
Kebomas District	22.08	63.58	30.73
Kedamean District	37.44	32.12	14.17
Manyar District	39.64	172.55	0.11
Menganti District	32.72	38.12	0
Panceng District	20.59	22.91	48.42
Sidayu District	17.36	18.83	10.51
Ujung Pangkah District	17.19	12.72	0
Wringinanom District	32.05	60.17	0
The average for the entire regency	23.27	41.50	12.61

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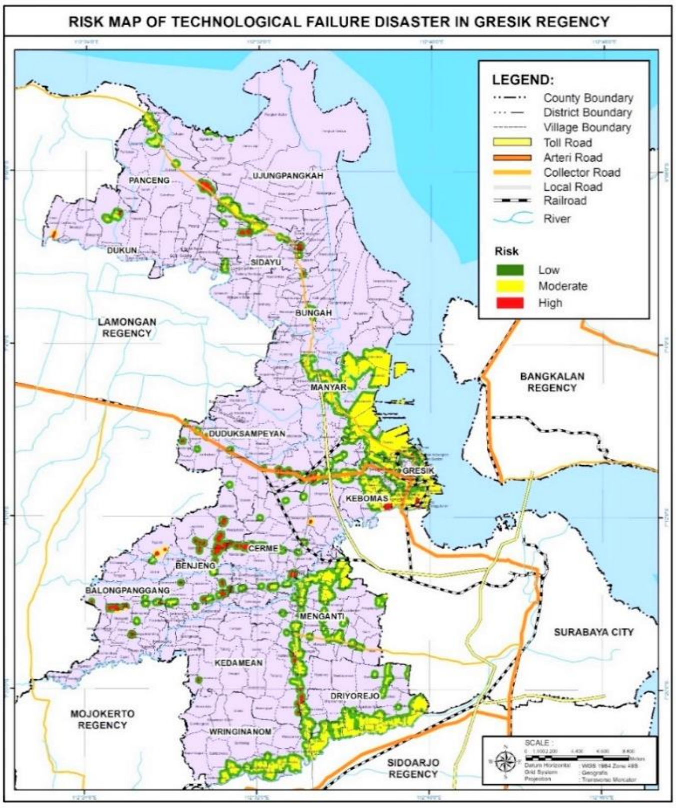

Fig. 5. A technological failure disaster risk map in Gresik regency

villages in 43 villages. Table 3 illustrates that only the villages in Dukun District and Ngasin Village in Balongpanggang District have a high vulnerability, thus, high risk, which requires efforts to alleviate their vulnerability, particularly social and economic vulnerability. Companies and the government must ensure synergy in education and assistance to improve the people's economy in those villages and reduce disaster risk.

PT Petro Widada (Roomo Village, Manyar District), PT Primergy Solution (Tlogopojok Village, Gresik District), and the industrial area along the Kapten Darmo Sugondo Road (Sidorukun District, Gresik District) once experienced technological failures in the past in 2004, 2011, and 2021, respectively, and have moderate risk level. It means that the industrial activities taking place at an industrial estate, i.e., factories along the Kapten Darmo Sugondo Road, PT Primergy Solution, and PT Petro Widada that is located at the Gresik Industrial Area (KIG), despite posing a high hazard, have a moderate-risk level. In contrast, areas beyond the 60-m radius of these factories have a low-risk level. The explosion incidents in 2004, 2011, and 2021 only had a direct impact within a radius of 60 m from the explosion source, which left the people living near the area mostly unharmed. It serves as a reminder that industrial activities should only occur in areas designated for those activities, i.e., industrial areas. Industrial activities should not be close to residential areas, such as those around the villages in Cerme District, Benjeng District, Panceng District, and Balongpanggang District, at high risk. To assign these activities only in areas appropriate for such cases will minimize risks of technological failure impacts because industrial areas impose certain standards to reduce workplace risks, such as delegating a specific function to each block to separate high-hazard levels from the moderate- and low-hazard levels; providing hydrants that are following the calculations made based on the standard of hydrants needed in an industrial area; accommodating integrated wastewater processing installations within an area to mitigate spillover effect of technological failures; ensuring the availability of a medical facility in the area for any possible workplace accidents that may need further care than the one provided in factories; and integrating the firefighter system in the planned industrial area with the already available regional- or municipal-scale system.

4. CONCLUSION

The research aims to develop a mapping of technological failure risk in Gresik Regency, which consists of industrial areas operating in an industrial estate or industries outside of the industrial areas. The result of the disaster risk analysis regarding technological failure in industries in Gresik Regency suggests that hazards following technological failures grow higher the closer it is to the source, which lies within the 60-m radius of the industrial area. High-risk villages (which are observed in Balongpanggang District, Banjeng District, Bungah District, Cerme District, Duduk Sampeyan District, Dukun District, Gresik District, Kebomas District, Kedamean District, Manyar Panceng District, and Sidayu District) have moderate- to high-hazard levels and also moderate- to high-vulnerability levels. Driyorejo District, Menganti District, Ujung Pangkah District, and Wringinanom District are identified as not having high-risk areas despite having a high potential for technological failure hazards due to having low vulnerability regardless of the high hazards.

These risks have not considered in detail the hazards arising from each type of Hazardous and Toxic Waste (LB3) in the event of an explosion in industrial activity. Future research can map the risk of LB3 distribution based explicitly on the type of LB3 to estimate the risk level of technology failure.

REFERENCES

[1] R. Shaw, J. M. Pulhin, and J. Jacqueline Pereira, 'Chapter 1 Climate change adaptation and disaster risk reduction: overview of issues and challenges', in *Climate change adaptation and disaster risk reduction: Issues and challenges*, vol. 4, Emerald Group Publishing Limited, 2010, pp. 1–19, doi: 10.1108/S2040-7262(2010)0000004007.

[2] K. Rajeev, S. Soman, V. R. Renjith, and P. George, 'Human vulnerability mapping of chemical accidents in major industrial units in Kerala, India for better disaster mitigation', *Int. J. Disaster Risk Reduct.*, vol. 39, p. 101247, 2019, doi: 10.1016/j.ijdrr.2019.101247.

[3] United Nations for Disaster Risk Reduction, '*Sendai framework for disaster risk reduction 2015–2030*', 2015. [Online]. Available: www.undrr.org/publication/sendai-framework-disaster-risk-reduction-2015-2030.

[4] T. A. Rachmawati, D. Rahmawati, and A. Rachmansyah, 'Disaster risk analysis of Mount Bromo eruption after the 2015 eruption in Sukapura District', *MATEC Web Conf.*, vol. 229, p. 01015, Nov. 2018, doi: 10.1051/matecconf/201822901015.

[5] N. A. Akhirianto, 'Regional Planning and Development Based on Disaster Risk Reduction in Banten Province', *J. Sains dan Teknol. Mitigasi Bencana*, vol. 15, no. 2, pp. 74–86, Dec. 2020, doi: 10.29122/jstmb.v15i2.4502.

[6] N. Etinay, C. Egbu, and V. Murray, 'Building Urban Resilience for Disaster Risk Management and Disaster Risk Reduction', *Procedia Eng.*, vol. 212, pp. 575–582, 2018, doi: 10.1016/j.proeng.2018.01.074.

[7] S. E. Atmojo, 'Natural Disaster Mitigation on Elementary School Teachers: Knowledge, Attitude, and Practices', *JPI (Jurnal Pendidik. Indones.*, vol. 10, no. 1, pp. 12–22, Mar. 2021, doi: 10.23887/jpi-undiksha.v10i1.25060.

[8] D. A. Gill and L. A. Ritchie, '*Contributions of Technological and Natech Disaster Research to the Social Science Disaster Paradigm BT - Handbook of Disaster Research*', H. Rodríguez, W. Donner, and J. E. Trainor, Eds. Cham: Springer International Publishing, 2018, pp. 39–60, doi: 10.1007/978-3-319-63254-4_3.

[9] United Nations Economic Commission for Europe, *Implementation Guide for Manmade and Technological Hazards Words into Action Guidelines*. United Nations for Disaster Risk Reduction, 2018. [Online]. Available: https://unece.org/DAM/env/documents/2018/TEIA/Words.

[10] International Strategy for Disaster Reduction, '*Disaster risk reduction', United Nations International Strategy for Disaster Reduction*, 2019. [Online]. Available: https://www.undrr.org/publication/2009-unisdr-terminology-disaster-risk-

 http://dx.doi.org/10.30656/jsmi.v7i1.4673

reduction.

[11] T. Acheampong and A. G. Kemp, 'Health, safety and environmental (HSE) regulation and outcomes in the offshore oil and gas industry: Performance review of trends in the United Kingdom Continental Shelf', *Saf. Sci.*, vol. 148, p. 105634, 2022, doi: 10.1016/j.ssci.2021.105634.

[12] A. Supriadi and T. Oswari, 'Analysis of Geographical Information System (GIS) design aplication in the Fire Department of Depok City', *Tech. Soc. Sci. J.*, vol. 8, pp. 1–7, May 2020, doi: 10.47577/tssj.v8i1.181.

[13] A. A. Ager *et al.*, 'The wildfire problem in areas contaminated by the Chernobyl disaster', *Sci. Total Environ.*, vol. 696, p. 133954, 2019, doi: 10.1016/j.scitotenv.2019.133954.

[14] G. Fancello, S. Mancini, C. Pani, and P. Fadda, 'An emergency vehicles allocation model for major industrial disasters', *Transp. Res. Procedia*, vol. 25, pp. 1164–1179, 2017, doi: 10.1016/j.trpro.2017.05.134.

[15] H. Zhang, C. Dolan, S. M. Jing, J. Uyimleshi, and P. Dodd, 'Bounce Forward: Economic Recovery in Post-Disaster Fukushima', *Sustainability*, vol. 11, no. 23. 2019, doi: 10.3390/su11236736.

[16] A. B. Arjuna and S. Hasibuan, 'Fire Risk Analysis in The Chemical Industry using The Hazard Identification and Risk Assessment Method', in *Proceedings of the 3rd Asia Pacific Conference on Research in Industrial and Systems Engineering 2020*, Jun. 2020, pp. 225–229, doi: 10.1145/3400934.3400976.

[17] K. C. Ha, 'Case Study on the Analysis of Disaster Vulnerabilities (Focused on the Fire & Explosion in the N-Industrial Complex)', *J. Korean Soc. Saf.*, vol. 36, no. 2, pp. 94–100, 2021, [Online]. Available: http://www.koreascience.or.kr/article/JAKO202122558915284.page.

[18] J. Leukel, J. González, and M. Riekert, 'Adoption of machine learning technology for failure prediction in industrial maintenance: A systematic review', *J. Manuf. Syst.*, vol. 61, pp. 87–96, 2021, doi: 10.1016/j.jmsy.2021.08.012.

[19] L. Chakraborty, J. Thistlethwaite, D. Scott, D. Henstra, A. Minano, and H. Rus, 'Assessing social vulnerability and identifying spatial hotspots of flood risk to inform socially just flood management policy', *Risk Anal.*, vol. 43, no. 5, pp. 1058–1078, May 2023, doi: 10.1111/risa.13978.

[20] K. Mason *et al.*, 'Social Vulnerability Indicators for Flooding in Aotearoa New Zealand', *International Journal of Environmental Research and Public Health*, vol. 18, no. 8. 2021, doi: 10.3390/ijerph18083952.

[21] I. Mohamed Shaluf, 'Technological disaster stages and management', *Disaster Prev. Manag. An Int. J.*, vol. 17, no. 1, pp. 114–126, Jan. 2008, doi: 10.1108/09653560810855928.

[22] N. Zhang and H. Huang, 'Resilience Analysis of Countries under Disasters Based on Multisource Data', *Risk Anal.*, vol. 38, no. 1, pp. 31–42, Jan. 2018, doi: 10.1111/risa.12807.

[23] N. Fitri, A. R. Thursina, and E. Dwiyanti, 'Analysis of Risk Management At Welding in Gresik Steel Fabrication Company', *Malaysian J. Med. Heal. Sci.*, vol. 3, no. 15, pp. 11–14, 2018, [Online]. Available: http://medic.upm.edu.my/upload/dokumen/20190826155031VOL_15_SUPP3_AUGUST_2019.pdf#page=14.

[24] H. Handayani, 'Implementation Occupational Health And Safety Communication In The Petrochemical Industry Of Kujang Fertilizer', *Asian J. Manag. Entrep. Soc. Sci.*, vol. 3, no. 02, pp. 521–536, 2023, [Online]. Available: http://www.ajmesc.com/index.php/ajmesc/article/view/351.

[25] Y. Y. Parente and C. F. Szlafsztein, 'Analysis of the level of municipal exposure to technological hazards in the Amazon region of Brazil', *Int. J. Disaster Risk Reduct.*, vol. 70, p. 102782, 2022, doi: 10.1016/j.ijdrr.2022.102782.

[26] H. Onuma, K. J. Shin, and S. Managi, 'Reduction of future disaster damages by

learning from disaster experiences', *Nat. Hazards*, vol. 87, no. 3, pp. 1435–1452, 2017, doi: 10.1007/s11069-017-2825-3.

[27] M. de O. Soares *et al.*, 'Oil spill in South Atlantic (Brazil): Environmental and governmental disaster', *Mar. Policy*, vol. 115, p. 103879, 2020, doi: 10.1016/j.marpol.2020.103879.

[28] R. M. Iqbal, A. Nugroho, Fajri, H. I. Martiastuti, L. Nonita, and K. Fadhiela, 'Financial performance and impacts of village fund on post disaster rural economic development in Pidie Jaya-Indonesia', *IOP Conf. Ser. Earth Environ. Sci.*, vol. 708, no. 1, p. 12070, 2021, doi: 10.1088/1755-1315/708/1/012070.

[29] X. Bao, F. Zhang, X. Deng, and D. Xu, 'Can Trust Motivate Farmers to Purchase Natural Disaster Insurance? Evidence from Earthquake-Stricken Areas of Sichuan, China', *Agriculture*, vol. 11, no. 8. 2021, doi: 10.3390/agriculture11080783.

[30] R. S. Oktari, S. Kamaruzzaman, F. Fatimahsyam, S. Sofia, and D. K. Sari, 'Gender mainstreaming in a Disaster-Resilient Village Programme in Aceh Province, Indonesia: Towards disaster preparedness enhancement via an equal opportunity policy', *Int. J. Disaster Risk Reduct.*, vol. 52, p. 101974, 2021, doi: 10.1016/j.ijdrr.2020.101974.

 http://dx.doi.org/10.30656/jsmi.v7i1.4673