Investigating Climate Change Risk of “Oil and Gas” City: Case of Dumai City, Indonesia

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Abstract. Based on Climate Resilient Development Policies on 2020-2045, there are four priority sectors threatened by climate change, namely marine and coastal, water, agriculture, and health. Indonesia still depends on oil and gas energy that will threats to infrastructures that support the sustainability of production that can have an impact on people's lifelines. This study investigates the risk distribution shift of climate change impacts in Dumai, which generally have oil refineries and ports. Risk is calculated by using hazard and vulnerability components. A uniform weighting approach is used to calculate each indicator indices. Using the RCP 8.5 hazard scenario with threats in the form of sea-level rise, moderate flooding, and high-end results in the projection year, this research results in significant differences in affected areas and at risk. The main factors affect the increasing of element at risk are the inundation and the spatial changes. An increase in the risk area means there will be an increase in losses. Moreover, disasters in oil and gas cities have the possibility of collateral hazards and even disruption of the national energy system. The government must take several adaptation steps such as adding eco-buffer zones, walls around refineries, and periodic monitoring of critical infrastructure.

1. Introduction
Climate change is the occurrence of significant changes in global weather patterns [1]. Basically, climate change is identified in various analysis in two different areas, such as mainland e.g., temperature, rainfall, and extreme events, and Ocean e.g., ocean surface climates, El Nino Southern oscillation, sea-level, surface salinity, tidal waves, historically as well as the future. The potential impact of climate change is related to the increasing frequency of threats that add to concerns because it can hinder the achievement of a country's national development plans [2]. Climate change can cause an increase in extreme weather, an increase in the frequency of hydro-meteorological hazard such as landslides, floods, abrasion, and others. In addition, the increase in temperature and changes in rain patterns also change the dry and rainy seasons. These conditions have an impact on household and agricultural activities. Future climate characteristics are very important to study, especially because Indonesia is located on the equator and is between two oceans which has an impact on the dynamics of its climate patterns [3]. As one of the "long-term" evidences of climate changes is sea level rise that is related to human activities (anthropogenic) so that the size of sea level rise is relative. This is caused by one of the variables of sea level rise, namely land subsidence that varies from one place to another. The "global sea level" and “land subsidence” are related to “relative sea level” in certain different places. Coastal cities in the world today are threatened by the real impacts of climate change, especially coastal flooding that can inundate the cities. The result of a study by [4], predicts to cause losses of 3,082 billion USD. They compared the
risk of coastal flooding in 136 cities with the worst climate change scenario, namely RCP 8.5 and high-end (95th percentile) in 2050 [4]. This condition is also experienced by several coastal cities in Indonesia such as Jakarta, Semarang, Pekalongan, Palembang, and others because they have almost the same problem, namely experiencing land subsidence. The rate of land subsidence in Indonesia varies widely start from 1-3 cm/year in Denpasar, and 1-20 cm/year in Semarang [5].

There have been many studies on the real impact of climate change, including in Indonesia, especially sea level rise on the northern coast of Java Island. This is because the island of Java is still the centre of human activity in Indonesia and have the potential to experience significant impacts from climate change. In fact, there are still many other areas in Indonesia that have not been explored in terms of the potential impacts of sea level rise, such as districts/cities located on the east coast of Sumatra Island. Figure 1 shows the distribution of oil and gas working areas in Indonesia and one of the biggest area is located on Sumatra Island. The oil and gas sector, especially industry (including oil refineries) are a vital sector of the state, so districts/cities that grow from this sector need to get more attention, especially those on the coast. Due to the significant role in oil and gas, Sumatra Island has many regions/locations for sea level rise and land subsidence study. One of them is Dumai which has the characteristics of a coastal area with a topography which dominated by lowlands. According to the data, Dumai is one of the cities known as an oil city and contributes greatly to the supply of national fuel needs [6]. It is recorded from the City Spatial Plan document, Dumai has the potential for disasters, namely technological failure (exploding oil refineries), floods, coastal abrasion, tornadoes, and forest and land fires. Several studies have been conducted, for e.g. [7] on sea level rise and coastal flooding in Dumai City [8]. Taking several explanations from the Open-ended Intergovernmental Expert Working Group on Indicators and Terminology to Disaster Risk Reduction (OEIWG) regarding the definition of critical infrastructure, [9] describes that critical infrastructure is the physical structure, facilities, networks and other assets that provide important services for the social and economic functions of the community, including the following: 1) energy (network/power generation including nuclear, oil and gas), 2) health facilities, 3) educational facilities, 4) transportation infrastructure (airports, ports, stations, roads), 5) government facilities, 6) defense and security, 7) telecommunication networks, 8) water and sanitation service networks, 9) financial services, and 10) agricultural infrastructure.

Figure 1. Several oil and gas working areas in Indonesia [16].

In a further context, a natural hazard can have a more detrimental impact while it affects an area that has hazardous industry or critical infrastructure. This is because accidents and even technological disasters can occur with more complex impacts. This condition is known as natech (natural hazards triggering technological disasters). The term natech is commonly used by scholars and official institutions in such as UNDRR [10,11]. The combination of "na" and "tech" was introduced by [12] with a study of the frequency of interactions between natural hazards and technological disasters in the US [11]. These natech risks can be found in both developing and developed countries. In the future, climate change and human development (industrialization and urbanization) can increase the potential of natech [13]. According to the problems mentioned before, this study was conducted to determine the level of risk of climate change impacts, especially coastal flooding in the “oil and gas” city with a case study on Dumai City, Riau Province, Indonesia. The risk assessment is carried out using baseline data for 2019 and projected data for 2039. We decide to use 2039 as the projection year due to the dataset availability.
(especially land use/land cover). We use the Spatial Pattern map in accordance with the Dumai City Regional Regulation Number 15/2019: Dumai City Regional Spatial Plan (RTRW) for 2019-2039 as an approach/proxy to the future land use change dataset. The risk components used in this research are hazard (H) and vulnerability (V). Several indicators on the vulnerability component were adapted from Borbor-Cordova et al., 2020 and Liu et al., 2020, whose studies about vulnerability of coastal flooding respectively in the Guaya River Estuary, Duran City (Ecuador) and Laizhou Bay (China) [14,15].

2. Method

2.1. Study location

The scope of this research covers the administrative area of Dumai City, which is located between 1°23'00"-1°24'23" N and 101° 23'37"-101°28'13" E. Most of the Dumai City area is lowland with an altitude of 0 - 15 masl (figure 3) and with a slope between 0 - 3%, only a small part is a hilly area with a slope between 8 - 15 %. Dumai City is divided into 7 sub-districts and 33 villages (figure 2). Dumai City is located on the southern coast of the Rupat Strait with relatively flat topography, especially in West and East Dumai Districts, while other sub-districts, such as Bukit Kapur, Medang Kampai and Sungai Sembilan, have slightly bumpy topography. The length of the coastline based on Topographic Map of Indonesia (RBI) dataset is 121.3068 km (Geospatial Information Agency/BIG), whereas the coastline depicted on Dumai City Regional Spatial Plan (RTRW) for 2019-2039 is 121.3038 km.

![Figure 2. Dumai City elevation and administrative division.](image)

2.2. Research stages and Analysis method

This research phase adopts the approach developed by Developed by the Ministry of Environment and Forestry (formerly the Ministry of Environment) [17], but with some adjustments, especially in determining the projection of hazards or threats due to the limited availability of datasets. The results of adaptation and simplification of the approach can be seen in figure 3. Based on the research stages in figure 3, variables and indicators (Table 1) are formulated that refer to several references [14,15,17,18]. One of the criteria for selecting indicators for risk analysis is based on data availability [18]. The criteria for each indicator are determined based on the adaptation of [15] and [14] according to the characteristics of the data in each indicator. The number of classes used is 5 (five) namely very low, low, medium, high, and very high. However, for weighting, only uniform weighting is used without using additional analysis such as Principal Component Analysis, Analytical Hierarchical Process, etc. Each indicators index is calculated by using the equation (1) and (2). Specifically for vulnerability components, the index calculations are carried out using equation (3) adapted from Balica, especially in their research on Coastal City Flood Vulnerability Index (CCFVI) [18]. The weighting uses assumptions based on the importance of each indicator and risk component. All analysis were carried out with the help of raster-based spatial analysis in QGIS software.

According to Balica, the vulnerability (V) components are exposure (E), susceptibility or sensitivity (S), and adaptive capacity or resilience (R or AC) [18]. Exposure is the tangible assets located in hazard-prone zone such as housing, infrastructure, even the people [19]. In the coastal context, exposure is...
defined as a “predisposition” of a system that will be disrupted by coastal flooding due to its presence in an area around the coast [18], which one example of such an indicator is the distance from the shoreline [15,18]. The concept of sensitivity has long been developed for example by Penning-Roswell and Chatterton, who stated in 1977 that sensitivity is a condition that affects the level of potential damage, death, or loss of a certain exposed elements [18]. Meanwhile, adaptive capacity is seen as the ability of a system (community, region, or country) to cope with even adapting to threats including climate change [20], for example is the strength of the health system or the economy [15].

\[
\text{Score} = \frac{\text{Class value}}{\text{Max class value}}
\]

\[
\text{Index} = \text{Weight} \times \text{Score}
\]

\[
\text{Vulnerability} = \frac{\text{Sensitivity} \times \text{Exposure}}{\text{Adaptive Capacity}}
\]

**Figure 3.** Research stages.

| Variables | Indicators                                      | Description                                           | Class value: very low (1) to very high (5) | Weight |
|-----------|------------------------------------------------|------------------------------------------------------|------------------------------------------|--------|
| **Hazard** | 2019: Coastal inundation (in meters) (2030 RCP 2.6) / 2039: Coastal inundation (in meters) (2040 RCP 8.5) | The higher the inundation, the higher the danger level | ≤ 0.5 | 1 |
|           |                                                |                                                      | 0.6 – 1 | 2 |
|           |                                                |                                                      | 1.1 – 1.5 | 3 |
|           |                                                |                                                      | 1.6 – 2 | 4 |
|           |                                                |                                                      | > 2 | 5 |
| **Vulnerability** | 2019: Population density (people/ha) / 2039: Projected population density (people/ha) | The denser the population, the more potential of increasing economic losses and affected population | ≤ 50 | 1 |
|           |                                                |                                                      | 51 – 100 | 2 |
|           |                                                |                                                      | 101 – 150 | 3 |
|           |                                                |                                                      | 151 – 200 | 4 |
|           |                                                |                                                      | > 200 | 5 |
| **Exposure** | 2019: Land cover (class and area) / 2039: Spatial pattern of RTRW (class and area). The spatial pattern plan map in the RTRW is assumed to represent future land use landcover. | The differences of land cover affects the exposure value because it depends on the potential loss and the affected population | • Lake, pond, river | 1 |
|           |                                                |                                                      | • Shrub | 2 |
|           |                                                |                                                      | • Forest, Mangrove | 3 |
|           |                                                |                                                      | • Agriculture, farm, garden | 4 |
|           |                                                |                                                      | • Settlement, industrial, transportation, commercial | 5 |
|           |                                                |                                                      | > 2 | 1 |
|           |                                                |                                                      | 1.6 – 2 | 2 |
|           |                                                |                                                      | 1.1 – 1.5 | 3 |
|           |                                                |                                                      | 0.6 – 1 | 4 |
|           |                                                |                                                      | ≤ 0.5 | 5 |

**Table 1.** Risk components.
### Variables

| Indicators                                                                 | Description                                                                 | Class value: very low (1) to very high (5) | Weight |
|---------------------------------------------------------------------------|-----------------------------------------------------------------------------|--------------------------------------------|--------|
| **Variables**                                                             |                                                                             |                                            |        |
| **Class value**                                                           |                                                                             |                                            |        |
| **Slope (°)**                                                             | the more gentle the slope of the land, the drainage system is prone to inundation | > 0.1                                      | 1      |
|                                                                           |                                                                             | 0.1                                        | 2      |
|                                                                           |                                                                             | 0.01                                       | 4      |
|                                                                           |                                                                             | < 0.01                                     | 5      |
| **Distance from coastline (km)**                                          | The closer a body of water is, the more possibility occurring flood and the higher the exposure. | > 2                                         | 1      |
|                                                                           |                                                                             | 1.5                                        | 2      |
|                                                                           |                                                                             | 1                                          | 3      |
|                                                                           |                                                                             | 0.5                                        | 4      |
|                                                                           |                                                                             | < 0.5                                      | 5      |
| **Sensitivity 30%**                                                       | 2019: %Vulnerable ages (0-14 & ≥65 years old) / 2039: %Projected vulnerable ages (0-14 & ≥65 years old) | ≤ 20                                       | 1      |
|                                                                           | Children, especially at that age as elementary school students. Meanwhile, due to decreased body functions, the elderly are more vulnerable. | 21 - 30                                    | 2      |
|                                                                           | Physically, women are generally more vulnerable to coastal flooding than men | 31 - 40                                    | 3      |
|                                                                           | Residents with low economic conditions will find it difficult to face flooding and a complete access so it will increase the vulnerability itself | 41 - 50                                    | 4      |
|                                                                           | > 50                                                                        |                                            | 5      |
| **Adaptive Capacity 30%**                                                 | 2019: The number of healthcare facilities / 2039: The number of projected healthcare facilities | ≤ 2                                        | 1      |
|                                                                           | The more health facilities, the better the capacity                          | 3 - 9                                      | 2      |
|                                                                           | 10 - 15                                                                     |                                            | 3      |
|                                                                           | 16 - 22                                                                     |                                            | 4      |
|                                                                           | > 22                                                                        |                                            | 5      |
| **2019: %GDP**                                                            | Regions with higher %GDP tend to have more public budget spending, so it will increase the adaptability of the regions | ≤ 0.45                                     | 1      |
|                                                                           | 0.46 - 2.07                                                                 |                                            | 2      |
|                                                                           | 2.08 - 3.69                                                                 |                                            | 3      |
|                                                                           | 3.70 - 5.31                                                                 |                                            | 4      |
|                                                                           | > 5.31                                                                     |                                            | 5      |

### 3. Result and Discussion

#### 3.1. Hazard analysis

The coastal inundation model refers to the results obtained from [https://coastal.climatecentral.org/](https://coastal.climatecentral.org/) with the available projection years: 2030, 2040, 2050 and so on in multiples of 10 years. The platform provides an "interactive online analysis" tool that allows users to determine climate change parameters according to the desired scenario. In this study, 2 (two) scenarios were used, namely the coastal inundation model RCP 2.6 in 2030 as a baseline year and RCP 8.5 in 2040 as a projection year of climate change. Therefore, we use 2030 as an approximation to the 2019 baseline, and 2040 as an approximation to the projected year 2039. This is because 2019 to 2039 is the time period for the Dumai City Spatial Plan.
However, one of the challenges to using existing model based on the https://coastal.climatecentral.org/ platform is the limited nature of the output (not public domain). Therefore, to be able to conduct the analysis with other risk components, further processing is needed (figure 4), namely mosaicking, geo-referencing, and classification. The classification method used is the ISODATA cluster. The results of the hazard analysis can be seen in figures 5 and 6 for the baseline and projection, respectively. The results of the analysis are then reclassified using DEMNAS data so that the hazard level is obtained as can be seen in figures 7 and 8 for baseline and projection, respectively. The area of inundation increases by more than 10 times, i.e., from 3,636 to 38,949 hectares. The more gentle the slope, at a lower elevation, and closer to the coastline of an area, will be more likely to be inundated.

3.2. Vulnerability assessment

It can be seen the difference in figures 9 and 10 that the vulnerability is significantly reduced and indicated by the increase in the area in green. This is because the sensitivity indicators, especially poverty, are planned to decrease drastically and their adaptive capacity is also predicted to improve. However, one thing that needs to be studied more deeply is related to the quality of land use/land cover
dataset, both baseline and projection, because it has an anomaly where the exposure in the projection year is lower than the baseline year, even though the population is projected to increase. Baseline land use/land cover has different classification system to projected land use/land cover (i.e. farm/cultivation zone in 2019 refers to production forest zone in 2039). This study assumes that these conditions contribute to a decrease in the level of exposure to land use/land cover indicator. In addition, the sub-district of Dumai Kota and Dumai Timur have significant gap in land area due to the different coastline configurations used in the two land use/land cover datasets (2019 and 2039) especially in the harbour and near oil refinery area (figure 11).

3.3. Risk assessment
The risk delineation automatically follows the coastal inundation hazard area because the analysis principle used is the overlay (intersection between the results) of the hazard and vulnerability analysis. It can be seen in figure 12 and 13. There are significant changes in the distribution of coastal inundation risk and the white circle on the right indicates the location of one of the largest oil refineries in Dumai City (figure 14). While the white circle on the left shows that there is a difference in area due to the different coastline configurations and the risk level is getting higher. Based on the results of the analysis conducted on the risk of flooding in Dumai City, it was found that the risk level of coastal flooding in the baseline and projected years was a significant increase in areas experiencing coastal flooding in Dumai City. Based on the analysis, the risk categories are divided into 5 categories, namely very low, low, moderate, high and very high. Figure 15 shows the changes in the proportion of risk (relative in %) and the form of absolute area (hectares) in each village, so that the risk in the baseline and projection years can be observed specifically. For the baseline year (2019), the largest area of very high risk is located in Basilam Baru village which is around of 44.6 ha, while in the projection year (2039), is located in Tanjung Penyebal sub-district which is around 22.1 ha. This indicates that areas with very high risk experienced significant changes in both the distribution and the area. The indicators of vulnerability and hazard in the previous discussion greatly determine these conditions and at the same time prove that there is a possibility of changes in certain risk areas, thus requiring more attention in preparing for future uncertainties. Inundation coastal flooding itself, has an impact on the destruction of facilities, housing, road networks, and has an impact on mobility where community movements are hampered which sometimes even causes traffic jams where people continue to travel even though there is a flood. In the Dumai city area, there are several oil refineries that need to be considered in the event of a disaster. If
there is a serious increase in flooding, this will affect the effectiveness of the workers of the oil refinery and the potential for damage to the core area of the oil refinery should be prevented. However, based on visual observations, coastal flooding did not inundate most of the Pertamina oil refinery area, this is because the ground height at each refinery is made in such a way that is higher than the road network, as well as the construction of a flood prevention wall around the oil refinery, so that this is what makes the oil refinery low potential for coastal flooding itself. Various mitigation policies have been carried out by the local government where this is stated in the Dumai City Regional Act No/2019 such as the construction of tertiary water canals/channels, normalization of rivers/irrigation canals and the construction of flood retaining embankments.

Indeed, critical infrastructure in the energy sector must be taken seriously, for example through specific climate change adaptation efforts. Many adaptation alternatives for energy infrastructure involve long-term and expensive efforts for example building/strengthening berms, floodwalls, elevating the facilities (substations, pump stations, and control room), expanding wetlands restoration, and relocating some critical facilities to protection them from sea level rise and flooding [21]. Further,
nexus (especially between governments and industries) is needed to enhance system resilience in energy sectors to anticipate climate change impact. The interdependence of each part in critical infrastructure system shows that disruptions to energy services could affect other sectors (finance & banking, communications & information technology, transportation system, etc) [21]. This is in line with research by [22], which underlines that if sea level rise is left untreated, then it can disrupt critical energy infrastructure and the energy systems connected to it. This disruption will have regional and national implications.

4. Conclusion
The coastal inundation event has a physical and non-physical impact. There has been a significant change in the area and distribution of coastal flood risk, for example in some areas of Dumai Kota and Dumai Timur sub-districts where ports and oil refineries are located. This critical infrastructure located in the coastal inundation-prone area, but this has been anticipated by the company by taking various preventive actions such as building flood embankments and drainage around the oil refinery. The existing adaptation scenario only focuses on vegetation-based environmental aspects and infrastructure aspects, namely the drainage and road network sectors due to support policies that have been carried out by the local government. The main concept of the adaptation scenario that must be carried out is to make a study of drainage and coastal inundation-resistant road networks in areas that have a high level of vulnerability so that drainage and road networks are not damaged quickly and are able to minimize the height of inundation that occurs in areas with a high level of vulnerability. An increase in the risk area means there will be an increase in losses. Moreover, disasters in oil and gas cities have the possibility of collateral hazard and even disruption of the national energy system. The government and parties must take several adaptation steps such as adding eco-buffer zones, walls around refineries, and periodic monitoring of critical infrastructure structures. Unfortunately, this research has some limitations which are grouped into 2 (two) categories namely data usage and weighting process. The hazard model used in this study was obtained from several pre-processing stages, namely geo-reference, classification, and vectorization due to limited access to the original format of the coastal inundation model. Furthermore, land use/land cover projection data (2039) is also obtained from secondary sources so that it requires a pre-processing approach as in the hazard model. The implication of the pre-processing approach is the possibility of error propagation which was not considered in this study. Then, the weighting process in this study only adapts from the existing literature by including assumptions without any expert consideration process. Therefore, it is necessary to develop this research, especially in terms of data input and the process of determining the index to improve the results of the risk analysis of climate change impacts, especially coastal inundation.

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