Modelling Industrial Growth in The Coastal Area of Semarang Metropolitan Region Using GeOBIA

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Abstract. Central Java Province has the manufacturing industry sector as the largest economic contributor. This manufacturing industry sector growth is mainly supported by the strategic location and infrastructures on the northern coast of Central Java Province (Kendal-Semarang-Demak). However, the high increase of industrial built-up area in the coastal area of Semarang Metropolitan Region has an impact on the conversion of coastal land if the growth cannot be controlled through the spatial plan implementation. This study identified the direction and trends of industrial growth in the coastal area of Semarang Metropolitan Region in 2015-2020 and the industrial growth prediction in 2030 for assessing the industrial zones in spatial plan 2011-2031. This research consists the estimation of industrial built-up area growth using the combination of GeOBIA method and manual interpretation of high-resolution satellite imagery (Sentinel-2A) from 2015 to 2020 and assessment of industrial zones in spatial plan based on the industrial growth prediction model in 2030 using the Cellular Automata Markov (CA-Markov). Industrial built-up area tends to grow towards the western and eastern part of the coastal area of Semarang Metropolitan Region based on map distribution and area growth. The results showed more than 20 % of industrial land is not suitable with the spatial plan in 2020 and it predicted will be increased in 2030, it is necessary to increase the efforts to control the spatial use.

Keywords: Industrial Growth; Coastal Area; GeOBIA; CA-Markov; Semarang Metropolitan Region

1. Introduction

Globally, many manufacturing industries agglomerated in the coastal region with proliferation of Special Economic Zones (SEZs) to attract export oriented industries [1–3]. Coastal areas often experience high industrial growth for obvious reasons of topography, access to infrastructure, supply, high market demand, and waste disposal into the sea [4]. In the other side, the dynamics of industrial growth in the coastal area have a significant impact on environmental conditions such as the loss of blue carbon storage, pollution, and coastal ecosystem conversion into built-up area [4–7]. Industrial growth also has an impact on urbanization and stimulates the development of coastal cities [8]. Coastal populations have rapidly increased over the past 100 years [9]. China, India, Bangladesh, Indonesia and Viet Nam represent the five countries with the largest share of population in the low-elevation coastal zone worldwide [10]. Indonesia as the maritime country covering about 95,181 km of coastline and
17,504 islands (12,000 inhabited) has the coastal population prediction of 61.9 million in 2030 with the highest density in Java Island [10,11]. Rapid economic growth in Indonesia has in turn rapidly increased the demand for industrial land, notably since the late 1980s, when the government permitted private companies to manage industrial estates [12–15]. In 2020, there are 108 industrial estates in Indonesia [16], with total area of 50,795.12 hectares of which 70 % are located in Java (36 % in Jakarta Metropolitan Region; 15 % in Surabaya Metropolitan Region; 6 % in Semarang Metropolitan Region). Industrialization occurred in the northern coastal region of Java such as Jakarta Metropolitan Region and Surabaya Metropolitan Region [12,17].

Industrialization also exist in the coastal areas of Java, especially in the Semarang Metropolitan Region (SMR), the capital of the Central Java Province. Central Java Province has manufacturing industry as the base sector with a contribution to GRDP of 34.42 % with a growth rate of 5.19 % [18]. The high contribution of the industrial sector to the GRDP has a positive effect on the growth of industrial estate [19]. The Coastal Area of Semarang Metropolitan Region having a role as the Central Region for Industrial Growth (WPPI) in Central Java Province based on the 2015-2035 National Industrial Development Master Plan (RIPIN). The high industrial growth in the northern coast of Central Java is mainly supported by the infrastructures such as National Road (Northern Coast Road), Trans Java Toll Road, Tanjung Mas Port and Ahmad Yani International Airport which supports industrial export and import activities. The coastal area of Semarang Metropolitan Region located between Jakarta and Surabaya corridor makes this region highly strategic with strong flow of urbanization and industrialization [20]. Industrial growth in the coastal area of Semarang Metropolitan Region has an impact on the reduction of coastal blue carbon stocks more than 20 % since the adoption of industrial policies in 2015 [6]. Industrial growth in Semarang Metropolitan Region, especially in the north, east, and south, has a significant impact on land-use changes and increasing the built-up area[21].

Rapid urbanization and industrialization, conversion of cropland to built-up area, are the main factor of land use land cover changes in the future [22,23]. However, the majority of the studies on industrial land focus on enterprises choice of location and land-use patterns of economic activities, rather than the amount of land that is actually used [24,25]. Based on these phenomena and problems, this research needs to be done to determine the direction and trends of industrial growth as evaluation during the implementation of industrialization policies that started in 2015 and whether the industrial zones in the spatial plan has accommodated the industrial growth based on the results of industrial growth predictions in 2030. This evaluation is important to be done because based on Government Regulation of the Republic of Indonesia Number 142 of 2015 that every industry must be located at the industrial zones in accordance with the regional spatial plan. Controlling the industrial growth through the development of industrial estates and industrial zones in the regional spatial plan were adopted by the government as stated on the 2015-2035 National Industrial Development Master Plan (RIPIN). The market-oriented policy aim to accelerating economic growth by promoting domestic and foreign private participation in finance and industries, which later boosted the real estate industry as well as FDI in manufacturing [12,26].

This research is also needed because the more precise estimation of industrial growth has not been accommodated in various previous studies[27] then it needs to be supported by a new method of Geographic Object-Based Image Analysis (GeOBIA) combined with manual interpretation to estimate the growth of industrial-built up area and predict the industrial growth in 2030 using CA-Markov. The GeOBIA method is superior for use in spatial planning because land cover classification is done by considering spatial aspects, not just spectral aspect so the classification result is more detailed than pixel-based classification [28]. This is in accordance with the research conducted by [29], that the Geographic Object-Based Image Analysis (GeOBIA) has a higher kappa index than the results of detection using other methods. Measurement of the temporal-spatial pattern of urban growth is important for a better understanding the effects of spatial distribution both qualitatively and quantitatively. Understanding the relationship between land-use change and industrial spatial distribution and
their co-transforming processes can help urban planners and decision-makers develop a more sustainable and livable city [27,30].

2. Data and Methods

2.1 Study Area

The study areas in this study belong to the Coastal Area of Semarang Metropolitan Region, which borders the Java Sea and belongs to the administrative regions of Kendal Regency, Semarang City, and Demak Regency (the coastal area of Semarang Metropolitan Region). The total area of observation is 37,793.48 ha (or 377.93 km$^2$). The administrative area includes 4 districts in Kendal Regency, 10 districts in Semarang City, and 4 districts in Demak Regency. The Coastal Area of Semarang Metropolitan Region having a total population of around 1.7 million. The scope of the area is displayed in the form of a map in Figure 1. The contribution of the industrial sector by 34.42% in the GRDP of Central Java Province was mainly supported by the growth of industrial zones located in the coastal area of Semarang Metropolitan Region (Kendal-Semarang-Demak). High investment in the growth of industrial estates on the north coast of Central Java is supported by the availability of supporting infrastructures such as National Road (Northern Coast Road), Trans Java Toll Road, Tanjung Mas Port, and Ahmad Yani International Airport which supports industrial export and import activities.

![Figure 1. Map of Research Area](image)

2.2 Research Data

This study uses secondary data in the form of Sentinel-2A Imagery in 2015 and 2020. The research years used are 2015 and 2020 because there is a 2015-2019 National Industrial Policy that supports industrial growth through the development of industrial zones in spatial plan. Primary data in this study were used to validate the results of the classification result and validate the industrial growth prediction models. Secondary and primary data used in this study are included in Table 1. The image classification uses a multi-index composite NDTI band (built-up area classification), NDVIre (vegetation classification), and MNDWI (water bodies classification) with a spatial resolution of 20 m. The multi-index composite band (NDTI, NDVI, MNDWI) with a spatial resolution of 20 m has a much higher level of accuracy compared to using a natural band composite (B4, B3, B2) with a spatial resolution of 10 m which has a weakness in distinguishing the type of built-up land cover class with agricultural land and vacant land [31].
### Table 1. Research Data (2020)

| No. | Data                      | Year         | Source                                         |
|-----|---------------------------|--------------|------------------------------------------------|
| 1   | Sentinel-2A               | 2015, 2020   | ESA (European Space Agency)                    |
| 2   | Landsat 5TM               | 2010         | USGS (United States Geological Survey)         |
| 3   | Base Map                  | 2020         | Geospatial Information Agency of Indonesia     |
| 4   | Coastal Population        | 2015, 2020   | Central Bureau of Statistics                   |
| 5   | Gross Regional Domestic Product | 2015, 2020 | Central Bureau of Statistics                   |
| 6   | Land Price in Coastal Area | 2020         | Ministry of Agrarian Affairs and Spatial Planning |
| 7   | Industrial Estates        | 2020         | Ministry of Industry                           |
| 8   | Observation Data          | 2020         | Primary Survey                                 |
| 9   | Industrial Labor          | 2015, 2020   | Central Bureau of Statistics                   |
| 10  | Agricultural Labor        | 2015, 2020   | Central Bureau of Statistics                   |

**Image Classification using GeOBIA and Manual Interpretation**

GeOBIA starts with image segmentation by grouping pixels into objects. The GeOBIA method considers spectral, texture, context, and shape with an algorithm for groups of pixels [32]. The GeOBIA method consists of 2 main processes namely the object segmentation process and the object classification process. In this study, image segmentation is done through the Orfeo Toolbox Plugin in QGIS using Sentinel-2A imagery with multi-index composite bands NDTI, NDVIRE, and MNDWI with a resolution of 20 m to obtain more accurate segmentation results in distinguishing identification of agricultural land cover and vacant land with built-up land and industry compared using natural band composites [31]. Orfeo Toolbox is an open-source plugin that is used to process high-resolution and multispectral images. In this study, there are 5 classes of objects namely the water body, vegetation, agricultural land, and vacant land, built-up area, and industry. Industrial class types are distinguished from built-up area through the rooftop contained in industrial buildings and non-industrial buildings. Most of the industrial building rooftops are made of aluminum and concentrated materials, while other (non-industrial) building rooftops are made of materials other than aluminum [31]. This study uses a classification based on sampling (sample-based).

There are industrial classes that are classified as non-industrial built-up areas based on the results using the GeOBIA Method. This study adopts a combined GeOBIA method and manual interpretation to obtain the classification result more closely with the existing conditions. Manual interpretation uses the results of segmentation and classification produced by the GeOBIA Method, then edit the attribute tables on thematic vector data based on the overlay between the GeOBIA classification results and high-resolution satellite imagery. This method is able to improve the industrial class accuracy (industrial class kappa index increased from 0.63 to 0.87), but the weakness of the method used in this study is the limited human ability to interpret at the large scope that required high effort and time. As compared with the previous method of image interpretation using manual delineation which requires more time, this method is much more efficient and requires shorter time because it uses the results of segmentation and classification based on GeOBIA and only uses the manual interpretation for edit the attribute table to obtain the classification results that more closely with the existing conditions. The synergistic combination between manual interpretation and automatic classification based on GeOBIA is more effective to reduce the misclassifications of objects with similar features [33].
Industrial Growth Prediction using CA-Markov

CA-Markov model is used in this study to predict the extent and distribution of industrial growth in the coastal area of Semarang Metropolitan Region of 2030 based on the results of 2015 and 2020 Sentinel-2A image classification. CA-Markov model is a process that analyzes the possibility of changes in land cover and land use conditions at a location at time t2 predicted based on conditions at time t1 [34]. This method is widely used to identify changes in land cover and land use, forest land cover, urban sprawl, wetland landscape, vegetation growth, optimum location selection, coastal zone management, and others [35]. Prediction of future conditions using the CA-Markov Model is generally done through analysis of land cover classification and land use at different times [36]. This study used the CA-Markov model from MOLUSCE (open source) plugin in the QGIS 2.8 application used in this study. The MOLUSCE plugin is used to analyze changes in land use and vegetation cover and to simulate land cover predictions. Land price and transportation networks are considered as one of the determinants that influence the site selection of industrial factories [27,37]. This research attempts to develop an industrial growth prediction model by considering the land price and distance to the arterial road as the spatial variables.

Existing Industrial Cluster in The Coastal Area of Semarang Metropolitan Region

The Coastal Area of Semarang Metropolitan Region has a strategic location and important role of development in Central Java Province and Indonesia broadly. Based on the Regional Regulation of Central Java Province for 2017-2037, the development of the industrial sector in Central Java refers to the 2015-2035 National Industrial Development Master Plan. Based on the Regional Regulation of Central Java Province for 2017-2037, the existing industrial estate includes Wijayakusuma Industrial Estate, Candi Industrial Estate, Terboyo Industrial Park, Bugangan Baru Small-Scale Industrial Area, Tanjung Emas Export Processing Zone, and Kendal Industrial Park. The distribution of existing industrial clusters in the coastal area of Semarang Metropolitan Region is shown in Figure 2.

![Figure 2. Map of Industrial Cluster in The Coastal Area of Semarang Metropolitan Region (2020)](image-url)
Industrial Zones in Spatial Plan of 2011-2031

The industrial zones plan on the coastal area of Semarang Metropolitan Region, which covers the northern part of Kendal Regency, Semarang City, and Demak Regency, is contained in the spatial plan of 2011-2031. The industrial zones plan has an area of 5,075.08 ha with a large percentage of the total zoning area, which is 11.70%. In 2020, the existing industrial zones consisted of 60% of wetlands, 14% of agriculture, 0.84% of vegetation, 9.35% of settlements, and 16.39% of industry. Industrial Zones is contained in the spatial pattern plan in the form of a plan for developing an activity center system as follows:

a. Kedungsepur National Activity Center (Kendal, Demak, Ungaran, Semarang, and Purwodadi) has a service center for strategic economic areas and industrial estates.

b. Based on the Kendal Regency Spatial Plan for 2011 – 2031, large and medium scale industrial zones are located in Kaliwungu District with a total area of 1,200 ha, including Kendal Industrial Park. Kendal Industrial Park is a Special Economic Zone (SEZ) based on Government Regulation No. 85, 2019.

c. Based on the Semarang City Spatial Plan for 2011 - 2031, the development of industrial zones are located in BWK IV (Genuk District) and BWK X (Ngaliyan District and Tugu District).

d. Based on the Demak Regency Spatial Plan of 2011 – 2031, large industrial zones include Sayung District, Karangtengah District, Mranggen District, and Karangawen District.

Figure 3. Spatial Pattern Plan Map of The Coastal Area of Semarang Metropolitan Region for 2011-2031

3. Results and Discussion

3.1 Land Cover Change in 2015-2020

Industrial growth in the coastal area of Semarang Metropolitan Region was identified based on the results of industrial land cover classification in 2015 and 2020 using combination of Geographic Object-Based Image Analysis method (GeOBIA) and manual interpretation. The results of the land cover classification show an increase in the area of industrial land by 294.16 ha in the coastal area of Semarang Metropolitan Region within a period of 5 years as shown in
Table 2. In 2015, industrial built-up area in the coastal area of Semarang Metropolitan Region has an area of 1,102.12 ha (2.92% of the total area of the coastal area of Semarang Metropolitan Region). In 2020, the industrial built-up area in the coastal area of Semarang Metropolitan Region increased to 1,396.28 ha (3.69%) with the distribution shown in Figure 4. The industrial growth in the coastal area of Semarang Metropolitan Region was influenced by the National Industrial Policy that adopted since 2015 through the development of industrial estates and industrial zones.

**Figure 4.** Land Cover Map of The Coastal Area of Semarang Metropolitan Region in 2015 and 2020

| No | Land Cover                  | Area (ha)  | Area Changes (ha) | Percentage  | % Area Changes |
|----|-----------------------------|------------|-------------------|-------------|----------------|
| 1  | Water Body                 | 19,186.00  | 19,756.64         | +570.64     | 50.76          | 52.28          | +1.51          |
| 2  | Vegetation                 | 1,051.04   | 953.4             | -97.64      | 2.78           | 2.52           | -0.26          |
| 3  | Crop and Vacant Land       | 9,265.76   | 8,347.28          | -918.48     | 24.52          | 22.09          | -2.43          |
| 4  | Built Up Area (Non-Industry)| 7,188.56   | 7,339.88          | +151.32     | 19.02          | 19.42          | +0.40          |
| 5  | Industry                   | 1,102.12   | 1,396.28          | +294.16     | 2.92           | 3.69           | +0.78          |

Table 2. Land Cover Classification Results (ha)

Within a period of 5 years, an increase in the area of built-up area amounted to 151.32 hectares. Therefore, there was a decrease in the area of agricultural land and vacant land by 918.48 hectares and vegetation class by 97.64 hectares. This process caused crop and vacant land on the eastern and western part of the coastal area of Semarang Metropolitan Region converted to built-up areas including industrial, and non-industrial built-up areas such as settlements, commercial, and infrastructure construction. This result is in line with the research conducted by [21] that the growth of industrial estates in Semarang Metropolitan Region, especially in the northern, eastern, and southern parts, has a significant impact on land-use.
change and increase in built-up area. Industrial growth and industrial agglomeration are the main factors causing changes and expansion of built-up area found in the urban areas [38].

Based on the transition matrix on Table 3, it can be seen that most of the largest land cover area transitions are found in the vegetation land cover class, agricultural and vacant land that transformed into built-up area and industry. This pattern indicates the possibility of urbanization that can continue in the next 5 to 10 years and indicates the dynamic growth in the coastal area of Semarang Metropolitan Region. Industrial growth and industrial agglomeration are the main factors causing changes and expansion of built-up area [38]. The urbanization basically occurs because of the process of industrial growth and economic development which causes agglomeration of population density in the urban environment [39]. Industrial growth in the coastal area of Semarang Metropolitan Region in 2015-2020 came from the conversion of agricultural land and vacant land based on the transition matrix. This result is in accordance with the research conducted by [40] that industrial estates around the city center impacting the conversion of agricultural land. Therefore, there was a change in vegetation land cover to industrial built-up area in 2015-2020 in the coastal area of Semarang Metropolitan Region.

### Table 3. Transition Matrix of the Coastal Area of Semarang Metropolitan Region
Land Cover in 2015-2020

| From | Water Body | Vegetation | Crop and Vacant Land | Built Up Area | Industry |
|------|------------|------------|----------------------|---------------|----------|
| Water Body | 0.96       | 0.00       | 0.02                 | 0.00          | 0.00     |
| Vegetation | 0.08       | 0.61       | 0.12                 | 0.17          | 0.01     |
| Crop and Vacant Land | 0.11       | 0.01       | 0.79                 | 0.07          | 0.03     |
| Built Up Area | 0.02       | 0.01       | 0.06                 | 0.87          | 0.00     |
| Industry | 0.00       | 0.00       | 0.01                 | 0.04          | 0.93     |

### 3.2 Industrial Growth in 2015-2020

Industrial growth in 2015-2020 has a direction to the eastern and western parts of Semarang Metropolitan Region as shown in Figure 5. Within a period of 5 years, there was an increase of industrial built-up area by 294.16 ha (26.69%). This increase was influenced by strategic location of the coastal area of Semarang Metropolitan Region (in the corridor of Jakarta and Surabaya) and supporting infrastructures such as the Tanjung Emas Port, Ahmad Yani International Airport, and the National Arterial Road. In 2016, there was Semarang-Batang Toll Road construction project (part of the Trans Java Toll Road) which began operating in 2018 and the Semarang-Solo Toll Road. Based on the results of industrial growth in the coastal area of Semarang Metropolitan Region in 2015-2020, the largest increase of industrial built area was found in Wijayakusuma Industrial Estate with total area growth of 50.04 ha and in Terboyo Industrial Park with total area growth of 39.71 ha (Table 4 and Figure 6). Industrial Growth also found in Kendal Regency, especially with the development of Kendal Industrial Park (KIP) as a National Strategic Project and Special Economic Zones (SEZ) with an area of industry that has been built by 29.02 hectares in 2020. This finding shows that in 2015-2020, the industrial growth appeared in the western and eastern part of the coastal area of Semarang Metropolitan Region.
Figure 5. Map of Industrial Growth in The Coastal Area of Semarang Metropolitan Region in 2015-2020

Table 4. Industrial Growth in The Coastal Area of Semarang Metropolitan Region in 2015-2020

| No | Industrial Clusters                     | Industrial Land (ha) | Industrial Growth (ha) |
|----|----------------------------------------|----------------------|------------------------|
| 1  | Kendal Industrial Park (KIP)            | 6.72                 | 22.30                  |
| 2  | Kayu Lapis Indonesia                    | 36.46                | 18.22                  |
| 3  | Mangkang                                | 10.61                | 4.84                   |
| 4  | Wonsari                                 | 35.82                | 12.29                  |
| 5  | Wijayakusuma Industrial Estate          | 151.22               | 50.04                  |
| 6  | Tambak Aji                              | 47.03                | 13.33                  |
| 7  | Candi Industrial Estate (Northern Part) | 37.55                | 11.80                  |
| 8  | Krapyak                                 | 2.72                 | 13.13                  |
| 9  | Madukoro                                | 24.82                | 20.41                  |
| 10 | Sinar Sentra Cipta                      | 81.18                | 8.28                   |
| 11 | Bandarharjo                             | 14.01                | 29.82                  |
| 12 | Pertamina’s Fuel Oil Terminal           | 13.53                | 4.96                   |
| 13 | Lamicitra Nusantara Industrial Estate   | 158.11               | 1.84                   |
| 14 | Muktiharjo                              | 2.96                 | 2.00                   |
| 15 | Bugangan Baru Small Industrial Area     | 99.47                | 8.61                   |
| 16 | Terboyo Industrial Park                 | 242.41               | 39.71                  |
| 17 | Sayung                                  | 137.50               | 32.58                  |
The Coastal Area of Semarang Metropolitan Region experienced the growth of industrial land by 26.69% with an increase of industrial sector contribution on GRDP of 42.10% and an increase of population by 5.99% in 5 years as shown in Table 5. Industrial growth on the coastal area of Semarang Metropolitan Region having an impact with a significant increase of industrial labor by 70.22% and decreasing agricultural labor of 4.01%. This result is in line with research conducted by [41] that the existence of an industrial estate causes a large increase in the number of the manufacturing workforce and triggers restructuring of the local economy from the agricultural to non-agricultural sectors. The highest growth percentage found on Kendal Regency of 93.84%, especially because of Kendal Industrial Park development that begins since 2015 as National Strategic Project.

Table 5. Growth Percent in The Coastal Area of Semarang Metropolitan Region in 2015-2020

| City/Regency          | Industrial Land | Manufacture Industries Contribution on GRDP | Coastal Population | Industrial Labor | Agricultural Labor |
|-----------------------|-----------------|---------------------------------------------|--------------------|-----------------|--------------------|
| Kendal                | +93.84          | +39.10                                      | +6.62              | +56.01          | -14.40             |
| Semarang              | +23.99          | +42.50                                      | +6.95              | +87.95          | +30.82             |
| Demak                 | +23.69          | +46.38                                      | +2.57              | +2.48           | +1.68              |
| The Coastal Area of   |                 |                                             |                    |                 |                    |
| Semarang Metropolitan |                 |                                             |                    |                 |                    |
| Region                | +26.69          | +42.10                                      | +5.99              | +70.22          | -4.01              |

3.3 Assessment of Industrial Zones in Spatial Plan based on Industrial Growth Model

Based on the identification result of industrial land in 2020, it is known that 78.98% of the industrial land is suitable with industrial zones in spatial plan. However, there is industrial land that not suitable with spatial plan of 21.02% found in the northern part of the Kayu Lapis Indonesia, industries in Madukoro, the southern part of Terboyo Industrial Park, and the southern part of industrial land in Sayung as shown in Figure 7. The industrial location that not
suitable with spatial plan is influenced by various factors considered by the firms in setting up their factories such as lower land prices and maintaining access to infrastructure [4]. The industrial location that not suitable with spatial plan needs to be followed up with an increase in spatial use control efforts because unplanned industrial spatial distribution can cause various undesirable consequences such as high energy consumption, high consolidation of agricultural land, high levels of congestion, and decreased the environmental quality [42,43].

The industrial zones in the 2011-2031 spatial plan has an area of 5,075.08 ha with a large percentage of the total zoning area, which is 11.70 %. In 2020, the existing industrial zones consisted of 60 % of wetlands, 14 % of agriculture, 0.84 % of vegetation, 9.35 % of settlements, and 16.39 % of industry. In 2020 there are 293.54 hectares of industry in the coastal area of Semarang Metropolitan Region that not suitable with spatial plan with 115.20 ha (38.90 %) located in the residential zones. In 2015-2020 there was an industrial growth of 115.69 ha (39.32 %) in the coastal area of Semarang Metropolitan Region that not suitable with industrial zones in spatial plan. This indicates that the industrial zones in spatial plan is not yet optimal for controlling industrial growth in the coastal area of Semarang Metropolitan Region in 2015-2020. Uncontrolled development can reduce the availability of land in the future, and lead to more effort and costs needed in mitigation and adaptation efforts (Dawson et al., 2018). Therefore, it is necessary to re-evaluate the industrial zones in spatial plan because 60 % are located in wetlands, some of those areas consist of mangrove ecosystems and tidal flood-prone areas. This causes a high possibility of the conversion of coastal ecosystems into industrial built-up area as well increase the risk of abrasion and tidal floods with high-value assets including urban infrastructure and settlements [44,45].

3.4 Industrial Growth Prediction Model of 2020-2030

The prediction of industrial built-up area growth in 2030 shows the direction of industrial growth in the western and eastern parts of the coastal area of Semarang Metropolitan Region as shown in Figure 7. This growth prediction considers the driving factor that affects the growth of industrial locations such as distance to the arterial road network, and land prices. The spatial variable in the prediction model includes distance to the arterial road and land prices have a Pearson correlation coefficient of 0.58 (high correlation). Industrial built-up area growth patterns in 2015-2020 and spatial variables are used to simulate predictions of industrial growth in 2030. The industrial built-up area is predicted to increase from 1,396.28 hectares in 2020 to 1,908.90 hectares in 2030 (industrial area growth prediction of 512.62 ha). This growth prediction has a kappa index of 0.821. The highest growth is found in Terboyo Industrial Park by 63.97 ha and Industries in Sayung by 43.15 ha (see Table 6 and Figure 8). Terboyo Industrial Park and Industries in Sayung are located close to main arterial roads (Northern Coast Road) and Tanjung Mas Port which is used together as a product export facility and import of raw materials and having lower land prices which cause the industry to experience the high growth and agglomerated. This is in accordance with the research conducted by [46] that supporting special infrastructures such as arterial road, port facilities, and railways will stimulate industrial agglomeration. In the western part of Semarang Metropolitan Coast, it is predicted that there...
will be an increase of industrial built-up areas in Kendal Industrial Park (KIP) and Wijayakusuma Industrial Estate in 2030.

![Figure 8. Suitability Map of Industrial Land with Spatial Plan in 2020](image)

### 3.5 Industrial Growth Prediction Model of 2020-2030

The prediction of industrial built-up area growth in 2030 shows the direction of industrial growth in the western and eastern parts of the coastal area of Semarang Metropolitan Region as shown in Figure 9. This growth prediction considers the driving factor that affects the growth of industrial locations such as distance to the arterial road network, and land prices. The spatial variable in the prediction model includes distance to the arterial road and land prices have a Pearson correlation coefficient of 0.58 (high correlation). Industrial built-up area growth patterns in 2015-2020 and spatial variables are used to simulate predictions of industrial growth in 2030. The industrial built-up area is predicted to increase from 1,396.28 hectares in 2020 to 1,908.90 hectares in 2030 (industrial area growth prediction of 512.62 ha). This growth prediction has a kappa index of 0.821. The highest growth is found in Terboyo Industrial Park by 63.97 ha and Industries in Sayung by 43.15 ha (Table 6 and Figure 10). Terboyo Industrial Park and Industries in Sayung are located close to main arterial roads (Northern Coast Road) and Tanjung Mas Port which is used together as a product export facility and import of raw materials and having lower land prices which cause the industry to experience the high growth and agglomerated. This is in accordance with the research conducted by [46] that supporting special infrastructures such as arterial road, port facilities, and railways will stimulate industrial agglomeration. In the western part of Semarang Metropolitan Coast, it is predicted that there will be an increase of industrial built-up areas in Kendal Industrial Park (KIP) and Wijayakusuma Industrial Estate in 2030.
Figure 9. Map of Industrial Growth Prediction in The Coastal Area of Semarang Metropolitan Region of 2030

Table 6. Industrial Growth Prediction in The Coastal Area of Semarang Metropolitan Region in 2020-2030

| No | Industrial Clusters                      | Industrial Built Up Area (ha) | Industrial Growth Prediction (ha) |
|----|------------------------------------------|-------------------------------|----------------------------------|
|    |                                          | 2020                          | 2030                            | 2020-2030                        |
| 1  | Kendal Industrial Park (KIP)             | 29.02                         | 49.19                           | 20.17                            |
| 2  | Kayu Lapis Indonesia                     | 54.68                         | 74.17                           | 19.49                            |
| 3  | Mangkang                                 | 15.45                         | 25.54                           | 10.09                            |
| 4  | Wonosari                                 | 48.11                         | 65.72                           | 17.61                            |
| 5  | Wijayakusuma Industrial Estate           | 201.26                        | 298.07                          | 96.81                            |
| 6  | Tambak Aji                               | 60.36                         | 91.62                           | 31.26                            |
| 7  | Candi Industrial Estate (Northern Part)  | 49.35                         | 74.73                           | 25.38                            |
| 8  | Krapyak                                  | 15.85                         | 32.26                           | 16.41                            |
| 9  | Madukoro                                 | 45.23                         | 78.73                           | 33.50                            |
| 10 | Sinar Sentra Cipta                       | 89.46                         | 137.26                          | 47.80                            |
| 11 | Bandarharjo                              | 43.83                         | 74.61                           | 30.78                            |
| 12 | Pertamina’s Fuel Oil Terminal            | 18.49                         | 31.10                           | 12.61                            |
| 13 | Lamicitra Nusantara Industrial Estate    | 159.95                        | 175.88                          | 15.93                            |
| 14 | Muktiharjo                               | 4.96                          | 10.37                           | 5.41                             |
| 15 | Bugangan Baru Small Industrial Area      | 108.08                        | 130.33                          | 22.25                            |
| 16 | Terboyo Industrial Park                  | 282.12                        | 346.09                          | 63.97                            |
| 17 | Sayung                                   | 170.08                        | 213.23                          | 43.15                            |
3.6 Assessment of Industrial Zones in Spatial Plan based on Industrial Growth Prediction

In 2030, it is predicted there will be industrial growth that not suitable with spatial plan of 28.34% with the highest area located in the western part of the coastal area of Semarang Metropolitan Region, in Genuk and Sayung District, at the southern of Terboyo Industrial Park and Industrial Areas in Sayung as shown in Figure 8 and Figure 9. Besides, it is predicted that there will be an increase in industrial built-up area at the industrial location close with the Semarang-Batang Toll Road Exit, the efforts to implement the spatial use control, and higher monitoring are needed. It is necessary to intensify the industrial land efficiently as an anticipatory strategy so the industry will not be located outside the industrial zones plan. The efficient use of industrial land is one strategy to reduce the impact of expansive, uncontrolled development. The efficient use of industrial land can increase intensive city development and avoid uncontrolled urbanization [19]. The intensification of industrial land also reduces land-use change and over-exploitation of land [47].

Figure 10. Industrial Land in The Coastal Area of SMR in 2020 and Prediction in 2030

Figure 11. Suitability Map of Industrial Growth Prediction in 2030 and Spatial Plan 2011-2031
4. Conclusion

This research estimated the area and distribution of industrial growth using a combination of GeOBIA method and manual interpretation of high-resolution image data (Sentinel-2A) from 2015 to 2020 and the assessment of industrial zones in spatial plan based on the results of the industrial growth prediction model in 2030 using Cellular Automata Markov (CA-Markov). The combined method was adopted in this study because the accuracy of the industrial class in the GeOBIA Method is lower than the accuracy of the industrial class produced by combination of the GeOBIA Method and manual interpretation. The industrial growth model in 2015-2020 shows an increase in industrial areas of 294.16 ha in the coastal area of Semarang Metropolitan Region within a period of 5 years. In 2020, the largest increase of industrial growth was found in the Wijayakusuma Industrial Estate, Terboyo Industrial Park, and Industrial Areas in Sayung. The growth of industrial built-up area in the coastal area of Semarang Metropolitan Region also had an influence on the increase of non-industrial built-up area of 151.32 ha within a period of 5 years. Besides, there was a decrease in the area of agricultural land and vacant land by 918.48 hectares and vegetation class by 97.64 hectares.

The prediction results show industrial built-up area of 1,908.90 ha in 2030 with a kappa index of 0.821. The highest area of industrial growth in 2030 is predicted will be occurred in the western and eastern part of the coastal area of Semarang Metropolitan Region at Wijayakusuma Industrial Estates with an area increase of 96.81 hectares and Terboyo Industrial Park with an area increase of 63.97 hectares. Industrial areas that not suitable with spatial plan increased from 177.85 ha (16.12 %) in 2015 to 293.54 ha (21.02 %) in 2020. This indicates that the spatial plan is not yet optimal for controlling the industrial growth in the coastal area of Semarang Metropolitan Region at 2015-2020. Intensification of industrial land and strengthen the monitoring policy implementation is needed to be adopted as the strategy to control the industrial growth in the coastal area of Semarang Metropolitan Region and reduce the expansive and uncontrolled growth that impacting the coastal land-use changes. This research has succeeded in estimating the extent and distribution of industrial growth in the coastal area of Semarang Metropolitan Region. Therefore, the weakness of this study is the prediction model that only uses driving variables that affect the growth of industrial locations including land prices and distance to the arterial road network, it is recommended for further studies related with the industrial growth prediction scenario to consider industrial location criteria from the Indonesian government policy to be included as spatial variables in the scenario of the industrial growth prediction model.

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