Monitoring and analysis of a small port expansion based on multi-source and multi-temporal high-resolution imagery: A case study of Ajmr Port, Davao City, Philippines

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Monitoring and Analysis of a Small Port Expansion Based on Multi-source and Multi-temporal High-resolution Imagery: A Case Study of Ajmr Port, Davao City, Philippines

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Abstract

Port construction not only impacts ecological environments of the surrounding regions, but also affects local economic development. Therefore, monitoring the port should consist of two aspects. The construction progress of the port can be monitored visually through remote sensing imagery, and the impact of port construction on the surrounding ecological environment and economic development should be monitored through related data, such as green space, buildings and lighting. This paper uses multi-source and multi-temporal remote sensing imagery to monitor the expansion of the Ajmr Port. It analyzes the land use and the fractional vegetation cover (VFC) of the port to determine the impact of port construction on the local ecology. Meanwhile, the construction progress and economic impact of the port are both monitored through a comparison of the roads, buildings and lighting changes before and after the expansion. The results show that the expansion of small ports will not cause significant

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Introduction

Ports are categorized by size as extra-large, large, medium-sized and small. The annual throughput of extra-large ports is generally more than 30 million tons; for large ports it is between 10 million and 30 million tons; for medium-sized ports it is between 10 and 1 million tons; and for small ports it is below 1 million tons. The expansion of large and medium-sized ports have a profound impact on regional land use structures and can even cause significant ecological and environmental problems. For example, natural land on the coast becomes heavily invaded, the stability of the ecological structures is destroyed, and the marine environment is polluted or disturbed (Gupta et al., 2005; Peng et al 2014).

Since changes in land use types can directly reflect both the expansion of ports and the progress of land occupation while also impacting the ecological environment, most domestic and foreign researchers have performed remote sensing to monitor changes in land use as a result of port construction. Glory O. Enaruvbe et al. considered changes in land use patterns and processes through remote sensing and geographic information systems in Port Harcourt, Nigeria’s second largest port, and detected an increased speed of cultivated land from mangroves, wetlands, and water bodies as well as a reduced speed for the secondary vegetation and natural forests (Enaruvbe & Ige-Olumide, 2014). Liu Baoxiao et al. analyzed spatio-temporal patterns for the long-term sequence of land use in Tianjin Port, the largest comprehensive port in northern China, and quantitatively analyzed the direction, extent, spatial and temporal pattern differences, and expansion modes for the land use type conversion in the Tianjin Port area from 1987 to 2010 by establishing four land use change index models (Liu et al., 2012). Liu Fang used the normal cloud model to establish an ecological port comprehensive evaluation index system and evaluated the top ten major ports in China's coastal areas to provide a basis for port ecological development (Liu, 2014). Zhao Yuzhe and others used the quantitative R clustering method and the coefficient of variation combined with the qualitative approach of expert experience to study 17 major ports, including Shanghai Port and Ningbo-Zhoushan Port, to prove the rationality of the ecological port evaluation index system (Zhao & Liu, 2015). Li Jing constructed a high-resolution remote sensing classification system for land use, and studied both the development of Dongdu Port, Haicang Port and Yuyu Port from 2004-2014 and the evolution of the land use structure (Li et al., 2016). Based on the dynamic monitoring of remote sensing images, Huang Pei collected long-term observations of important ports in the Beibu Gulf, extracted their ranges of change, and combined the information with other topics and statistical data to analyze the development behavior of port construction and its impact for terminal berth, cargo throughput, etc. (Huang & Liao, 2017). Ge Wei et al. used multi-temporal high spatial resolution remote sensing images to monitor the infrastructure construction for the ports in Colombo and Hambantota from 2010 to 2017, to track the progress of the port construction, and to predict that the annual port throughputs will be further increased through potential water storages (Ge et al., 2018). Li Xuchun et al. used five typical ports in the Bohai Sea as examples to establish an object-oriented remote sensing monitoring technology process for port spatial patterns, and constructed an index for each feature to quantitatively describe the port space composition and performance (Li et al., 2019).

Most of these studies were taking large and medium-sized ports as research objects, while research on small ports has mostly been based on the study of regional ports or large ports. Such information includes monitoring the port ecology, construction progress and land use types without much direct comprehensive monitoring or analysis. The impact of port construction on a region is more objective and comprehensive as it considers both ecological and economic aspects. In response to this problem, this paper considers the Ajmr Port in Davao City, Philippines as an example of performing comprehensive monitoring and analysis of small ports. The specific objectives include the use of remote sensing imagery to 1) observe the progress and changes from port expansions; 2) study the impact of port construction on the local ecology; and 3) study the impact of port construction on local and peripheral economic development.

Study Area and Data Processing

Study area

The port of Ajmr is located along the northwestern shore of Davao Bay, which is southeast of Mindanao, in the eastern part of Davao City, 21 km from Davao City(*Figure 1*). Davao City is located approximately 946 km southeast of Mindanao and covers a total area of 2,443.61 square kilometers. It is the largest city in the Philippines and is at the center of the Philippines' third most populous metropolitan area. There are several corporate terminals along the coast of Davao City, including Texaco, Legazpi, National Warehouse, and the Philippines Shell Oil Terminal.

As the port of Ajmr is mainly used to import and export goods for the Sumifru Company, it is also known as Sumifru Port and is part of the Philippine commercial port. Sumifru Company is a large-scale international enterprise that integrates the planting, research and development, and import and export of tropical fruit products, including pineapple, banana and mango, with banana production accounting for three-quarters of the company's total fruit cultivation. Davao has a tropical rainforest climate with little seasonal variation in temperature. Thus, the monthly average temperature is always relatively high with an average monthly rainfall of over 77 mm. The country's bananas are abundant in the mountains at elevations of 600 meters or more. Sumifru Company currently has 12,010 hectares of banana plantations in 5 different regions of Davao City, Philippines. The total output and export volume of bananas ranks second among the Philippines-related industries, and its fruits are exported to China, Japan, South Korea, Iran and many other countries.

Image data and pre-processing

This paper studies the expansion process for the port of Ajmr, which has been under construction since 2002. However, nearly no expansion occurred from 2002 to 2009, so only images from 2009 to 2018 were selected for preprocessing.

A wide range of images from the port during both 2009 and 2018 from the Landsat dataset were selected to monitor the vegetation cover before and after the port expansion. Images from Landsat7 and Landsat8 were downloaded for 2009 and 2018, respectively. However, as a result of the failure of a Landsat 7 sensor in 2003, a large number of bands appeared in the image. This stripe was repaired by downloading the Landsat_gapfilter.sav plug-in, and pretreating the images in ENVI, which included geometric corrections, image clipping, and atmospheric and radiation corrections. A square image centered on the port with a side length of 15 km was obtained after the correction.

High-definition images were selected for the port area from 2009 to 2018 to classify the land use. Since the expansion lasted for 9 years, there were obvious changes seen over this entire duration. This paper presents monitoring from every three years with images from 2009, 2012, 2015 and 2018. These high-resolution images were obtained from Google Earth and have an accuracy of 1 m. The images were corrected using the ENVI software so that the points were evenly distributed throughout the image, and the images were registered using the image to map method. The corrected imagery is convenient when performing dynamic change analyses.

Nighttime lighting time series imagery data were downloaded from 2009 to 2018. Since the lighting image requires extensive observation of the surrounding areas of the port, the region of interest was the night light data centered on the port with a side length of 40 km. The night lighting data from 2009 to 2013 came from the DMSP/OLS (operational line scanning system of the Defense Meteorological Satellite Program) and from the VIIRS/DNB (visible infrared imaging radiometer kit day/night band) for 2013 to 2018. Compared with the OLS data, the VIIRS has the advantages of a finer space-time resolution, stronger data comparability over different years and no data saturation. Since the data comes from two observation platforms and involves multiple sensors, the downloaded imagery needs to be pre-processed(Zou et al., 2014; Shi et al., 2014; Cao et al., 2015; Zhang et al., 2017; Wu et al., 2018). First, the same size image was intercepted, and the VIIRS data was resampled so that the spatial resolutions for all the images were the same. Then, a model algorithm was established and corrected the errors for the different sensors. Finally, the error of the existence between different images is corrected. The calibration process primarily used the map algebra from the Arcgis software to calculate and obtain the required light data.

Survey methodology

On the one hand, the Landsat imagery was used to remotely monitor the expansion of the Ajmr Port and analyze the dynamic changes in the land use time series and vegetation growth time sequences to monitor the ecological environment. On the other hand, the high-resolution imagery was used to check the progress of port roads and building construction to obtain port transportation and housing density. Finally, the light data obtained through the remote sensing images was to comprehensively analyze the impact of small port construction on the local economy.

Port ecological environment remote sensing monitoring analysis

Land use monitoring

After pre-processing the high-resolution images from 2009, 2012, 2015 and 2018 for Ajmr Port, the visual interpretation method was used to analyze the spatio-temporal dynamic changes in the land. The port identifiable land classification segmented features as either roads, buildings, waters, pier, container yard, bare land, supporting facilities, green areas, residential areas and construction areas. The roads were divided into either dirt roads, cement roads or internal roads, and the area where the port is located was marked. In the visual interpretation process, the 2009 image was first interpreted, and then based on the comparison of the two images, the first image is modified to create the next image land use map which is the land use map for 2012. The land use maps for 2015 and 2018 were derived in an analogous manner. By comparing these images, changes in the land use before and after the construction were observed.

Vegetation growth sequence monitoring

Using the 2009 pre-processed Landsat imagery of Ajmr Port, the normalized difference vegetation index (NDVI) for 2009 was calculated to estimate VFC in the area. The NDVI maximum image for the year was synthesized using the calculated NDVI data. Based on the obtained image, VFC was calculated using the following empirical equations.

$$NDVI = (P_{nir} - P_{red}) / (P_{nir} + P_{red})$$

In the formula, P_{nir} is the reflectance of the near-infrared band and P_{red} is the reflectance of the red band.

$$VFC = (NDVI - NDVI_{\min}) / (NDVI_{\mathrm{man}} - NDVI_{\min})$$

In the formula, the $\mathrm{NDVI}_{\max}$ and $\mathrm{NDVI}_{\min}$ are the maximum and minimum NDVI values in the region, respectively.

Due to the inevitable presence of noise, the $\mathrm{NDVI}_{\max}$ and $\mathrm{NDVI}_{\min}$ are generally the maximum and minimum values within a certain confidence interval. The 5% DN value was selected in this paper for the $\mathrm{NDVI}_{\min}$ and the 95% DN value was taken for the $\mathrm{NDVI}_{\max}$. This same approach was used for the 2018 vegetation cover map. Comparing the two images shows the changes in the vegetation cover before and after the port construction.

Social and economic remote sensing monitoring analysis

Comparison changes in roads and buildings

Roads are an important factor in the development of a regional economy. The amount of road traffic reflects the situation of the regional economy to a certain extent. The accessibility and convenience of roads greatly promotes economic development (Wang, 2014; Li, 2014; Yuan, 2018). This study mainly detected changes in the roads inside the port region and divided into three grades according to the road construction status: dirt, cement and the roads within the port. The roads were extracted from the high-resolution images. By comparing the changes before and after the expansion project, it is possible to visualize the traffic changes in the area, the density of the road network, the estimated traffic volume and level of development for the port city.

Changes in the architecture allow the economic prosperity of the area to be estimated by comparing the changes in the buildings before and after the port construction primarily by monitoring the buildings inside the port. By counting the number of buildings, one can better understand the economic prosperity of the port area and the area occupied by the buildings as a visualization for the progress of the port construction.

Analysis of light changes

Nighttime lights are a more objective reflection of the production and living activities of human society (Dolores, 2013; Xu et al., 2015; Wang & Huang, 2018;Li et al., 2018). The lighting data are used to study the development and population activities of the area by comparing the bright and dark regions in the imagery. There is a positive correlation between the strength of the lighting data and socio-economic factors. Using this quantitative relationship can provide estimates for social and economic development. This article used the DMSP/OLS 2009 and VIIRS/DNB 2018 nighttime lighting data to compare and view changes in the study area's lighting data to estimate demographic changes and economic development.

Results and analysis

Land use status of the study area

Through the 1-meter high-resolution imagery, it was found that the expansion of the port of Ajmr mainly began in 2009. At the time of construction, the port covered a small area of 12.94 hectares. It began to expand year after year starting in 2009 to 23.5 hectares in 2012, 31.83 hectares in 2015 and 41.15 hectares in 2018 (*see Figure 2, Port area*).

The land use statuses of the study areas in 2009, 2012, 2015 and 2018 are shown in turn by the four pictures given in *Figure 2-A, B, C&D*. During the expansion of the port, there was a large change in land cover in the study area. Specifically, the port increased by a total of 28.21 hectares during the expansion period, mainly through land reclamation that occupied large regions of water. From 2009 to 2018, the port expansion area gradually expanded from the central to the southern coastal region, mainly occupying the green. The more obvious features during the expansion period are the buildings, construction area, bare land, waters, supporting facilities, container yard, roads and green area. Among these, there was a significant increase in buildings, construction areas, bare land, supporting facilities, container yards and roads, with increases of 10.05, 8.58, 5.1, 4.43, 8.68 and 4.06 hectares, respectively. Meanwhile, there was a significant reduction in the waters and green space, with reductions of 12.02 and 29.95 hectares, respectively.

The specific coverages for various types of land in the study area from 2009 to 2018 are shown in Table 1. Compared with the landforms in 2009, there was a significant expansion in the northern part of the port area in 2012 (*Figure 2 A&B*). After the original green area, bare land

and waters were rebuilt and expanded and became container yards, construction areas, roads and supporting facilities. There was a large increase in these construction areas by 6.71 hectares. From 2012 to 2015 (*Figure 2 B&C*), the northern port region added a 104-meter-long and 23-meter-wide pier and ship landing infrastructure and expanded the port area in the southern part. The original 2.57 hectares of green space and construction areas were converted into port land, which had a significant increase in the bare land by 9.6 hectares. In from 2015 to 2018 (*Figure 2 C&D*), the port reclaimed 2.81 hectares in the eastern part, which was mainly expanded into a container yard and construction area. The original construction area in the western part of the port was converted to buildings covering an area of 3.79 hectares. In addition, the container yard had an obvious increase of 5.42 hectares.

Vegetation coverage change monitoring

The green space in the port region before the expansion covered an area of 87.3 hectares, compared with 57.35 hectares after the expansion, giving a total reduction of 29.95 hectares. Over the duration of the expansion, the vegetation coverage decreased by 34.31%, so the expansion of the port had a certain impact on the ecological environment for small regions around the port (*Table 1*).

The large-scale vegetation coverage around the port is shown in *Figure 3*.The left panel shows a vegetation coverage of 15 km around the port in 2009*(Fig. 3A*). It can be clearly seen that there is a distinct boundary between the water area and the vegetation. Of this region, the vegetation coverage in the range of 0.2 to 0.6 accounted for 7.78%; the coverage in the range from 0.8 to 1 accounted for 44.01%; and the coverage between 0.6 and 1 accounted for the most at 56.94% and covered an area of 131.45 square kilometers.

The picture on the right shows a vegetation coverage of 15 km around the port in 2018(*Fig. 3B*). The vegetation coverage in the range of 0.2 to 0.6 accounted for 9.1%; the coverage in the range 0.8 to 1 accounted for 47.83%, which is more than the 44.01% in 2009; and the coverage in the range of 0.6 to 1 accounted for 56.31%, covering an area of 129.94 square kilometers, which is close to the vegetation coverage in 2009. Vegetation coverage is an important indicator to evaluate the quality of the ecological environment in a region (Alo & Pontius, 2008; Xin et al., 2008; Amarsaikhan et al., 2009;Chen & Wang, 2009; Zhang et al., 2010; Lu et al., 2017; Li et al., 2019). After nine years of comparison, it can be seen that the expansion of the port has not greatly affected the large-scale ecological situation of the region.

Analysis of changes in the port roads and buildings

During the nine-year expansion of the port, roads and buildings showed significant increases, as indicated in *Figure 4*. The left panel shows the distribution of roads and buildings in 2009(*Fig. 4A*), and the right panel shows the distribution of ports and buildings in 2018(*Fig. 4B*). Among these roads, there were 13 new dirt roads outside the port, covering an area of 1.09 hectares. These were mainly concentrated in the vicinity of residential areas and distributed on the west side of the port, indicating that the road network density in this area is relatively large and densely populated. There were 7 new roads in the port covering an area of 2.97 hectares, which were mainly concentrated in the northeastern part of the port. Due to the newly added land area of reclamation, a large number of container areas were added, and the transportation channels for goods correspondingly increased. The road area after the expansion increased by 4.06 hectares. Before the expansion, the roads were mainly dirt roads, while after the expansion, both new dirt roads and cement roads were added. However, the road grade was low, indicating that the city's economic activity in the region was also low, resulting in a relatively slow economic development.

After the expansion, changes to the buildings were more obvious, mainly due to the increased number of buildings in the central and southern regions of the port. There were 26 new buildings with an area of 9.7 hectares after the expansion. The expansion area of the port was large and mainly occupied green space and waters. Compared with the total development, new roads and buildings accounted for 1.57% and 3.75% of the total area, which is a relatively small proportion. The port area consisted of a total of 12.94 hectares before the expansion, and after the expansion, it occupied an area of 41.15 hectares. The newly added 28.21 hectares accounted for 10.92% of the total research area. The increase in the construction area reflects increased internal populations around the port and the expansion of the construction scale. In addition, the continual occupation of the green space has a certain impact on the environment around the construction area.

Port Light Change Analysis

The port is adjacent to Panabo City to the north and Davao City to the south. Davao City is the only independent city in the Davao District of Northern Mindanao and is the most populous city, while the city of Panabo is a small city in the north of Davao. The time-series dynamic lighting monitoring for a large 40 km area around the port of Ajmr provided lighting data from 2009 to 2018 (*Figure 5*). Comparing the port lighting data with the adjacent cities, it can be seen that the port had a significant increase in lighting, especially since the beginning of 2011 and 2015. During this time, the port's lighting data was close to that of Davao and had a grown significantly. The nine-year lighting data of the cities of Panabo and Davao also showed an increasing trend, but at a relatively slow growth.

Differences between the 2009 and 2018 lighting images were calculated to obtain the 9-year lighting growth rate around the port, as shown in *Figure 6*. The growth of the light data from the northeast to the southwest in the figure is very obvious, forming a red curve.From the high-definition image, it can be seen that the red curve is just in the southeast coast of Mindanao in the southern Philippines. The growth rate of the lighting data along the coastline was mostly between 100 to 150 or more. Among them, Panabo City and Davao City had a growth rate between 100 and 150 and are both located along the coast. Before the expansion of Ajmr Port, the port's economic development level was low. However, after nine years of continuous expansion, the region's economic development became relatively fast, indicating that the port's construction promoted the local economic development. Ajmr port, Panabo City and Davao City jointly formed the economic belt on the southeast coast of Mindanao, which promoted the comprehensive economic development along the coast.

There are large areas on the east side of the port that had a growth rate of 0 to 50, indicating small increases in lighting data. From the high-resolution imagery, this slow-growth area is northwest of Davao Bay and Samal Island. The growth of lighting data in the sea is mainly due to ships. The large number of vessels in the water indicates the frequent maritime transport trade in the region. According to relevant associated information, Ajmr Port has a large export volume and many trading partners. In 2015, the Sumifru Company began exporting South American bananas to China. The company relies on China's Dalian, Tianjin, Shanghai, Shenzhen and other coastal ports for trade. It has established large processing, storage and sales organizations in these major port cities in China to provide fresh fruits to the Chinese mainland. The continuous cooperation between China and the Philippines has benefited from the "21st Century Maritime Silk Road" (Zhai et al., 2016). Through the continuous strengthening of trade at sea, China has now become the largest export market for bananas in the Philippines.

Conclusions

(1) The expansion of the port of Ajmr occupies a certain amount of land and water, which changed the land use structure of the area and had a certain impact on the local environment. However, from the perspective of large-scale vegetation coverage, the vegetation coverage rate in the range of 0.6 to 1 was maintained at around 56%, and the overall coverage rate was high. This indicates that the port construction did not have a significant impact on the ecology of the area.

(2) By analyzing the increase in roads and buildings, it can be seen that the population of the area increased significantly, the scale of construction expanded, and the economic prosperity

increased. The lighting data of the area from the northeast to southwest is obvious and located along the coastline, indicating that the economic development of the coastal zone was faster than the other regions. In addition, the newly developed coastal areas promoted the economic development of the inland regions.

(3) Ajmr Port has a small footprint compared to large ports and is mainly used for exporting goods. The impact on the local ecological environment during the construction was relatively small, and it was not expected to cause many ecological or environmental problems. The expansion of the port of Ajmr has played a significant role in promoting the development of agriculture in the Philippines, so relatively backward areas can promote the sustainable economic development of the region through the expansion of small ports.

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Figure 1

Location of the study area.

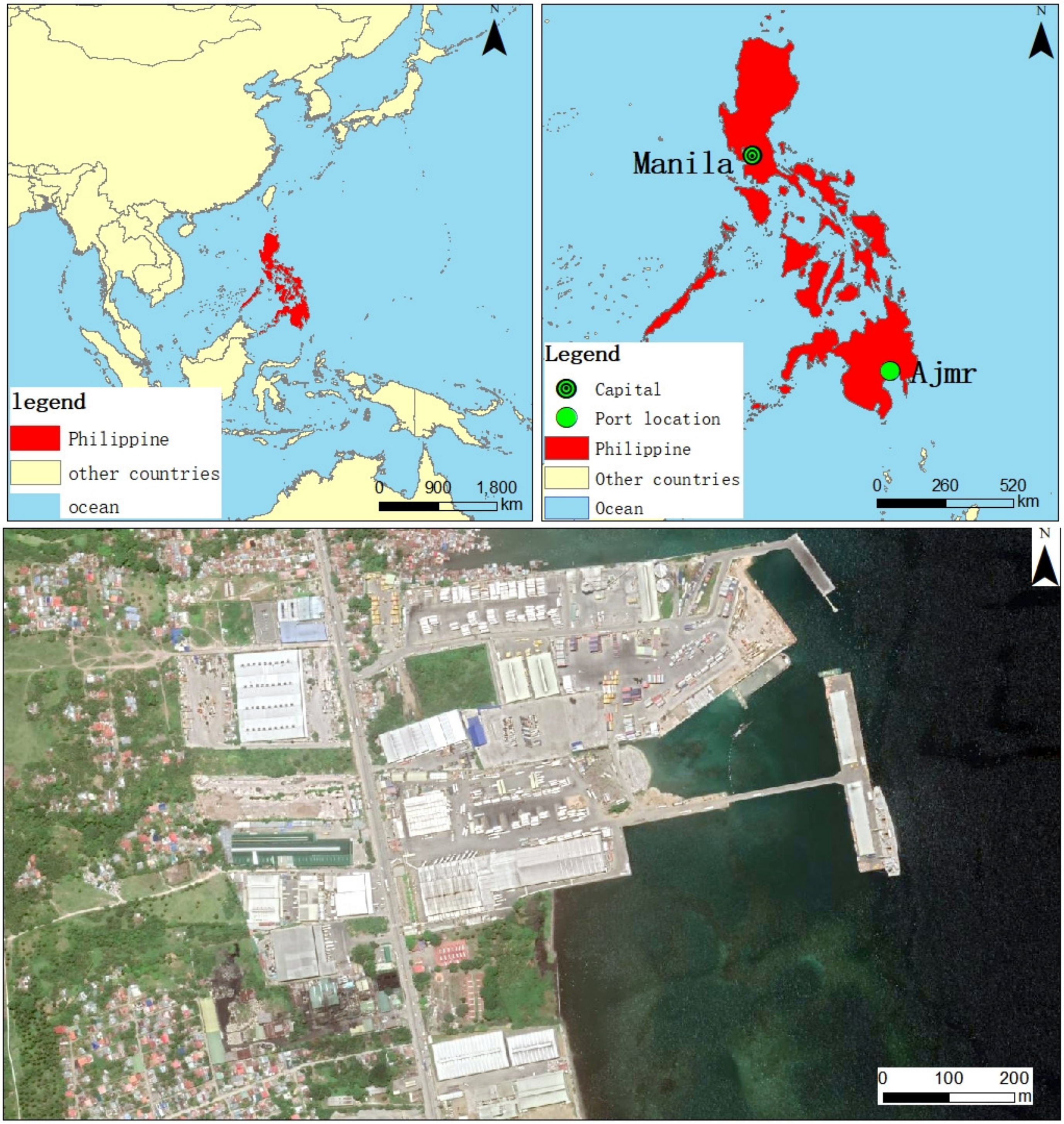

Figure 2

Land use map of Ajmr Port from 2009(A), 2012(B), 2015(C) and 2018(D).

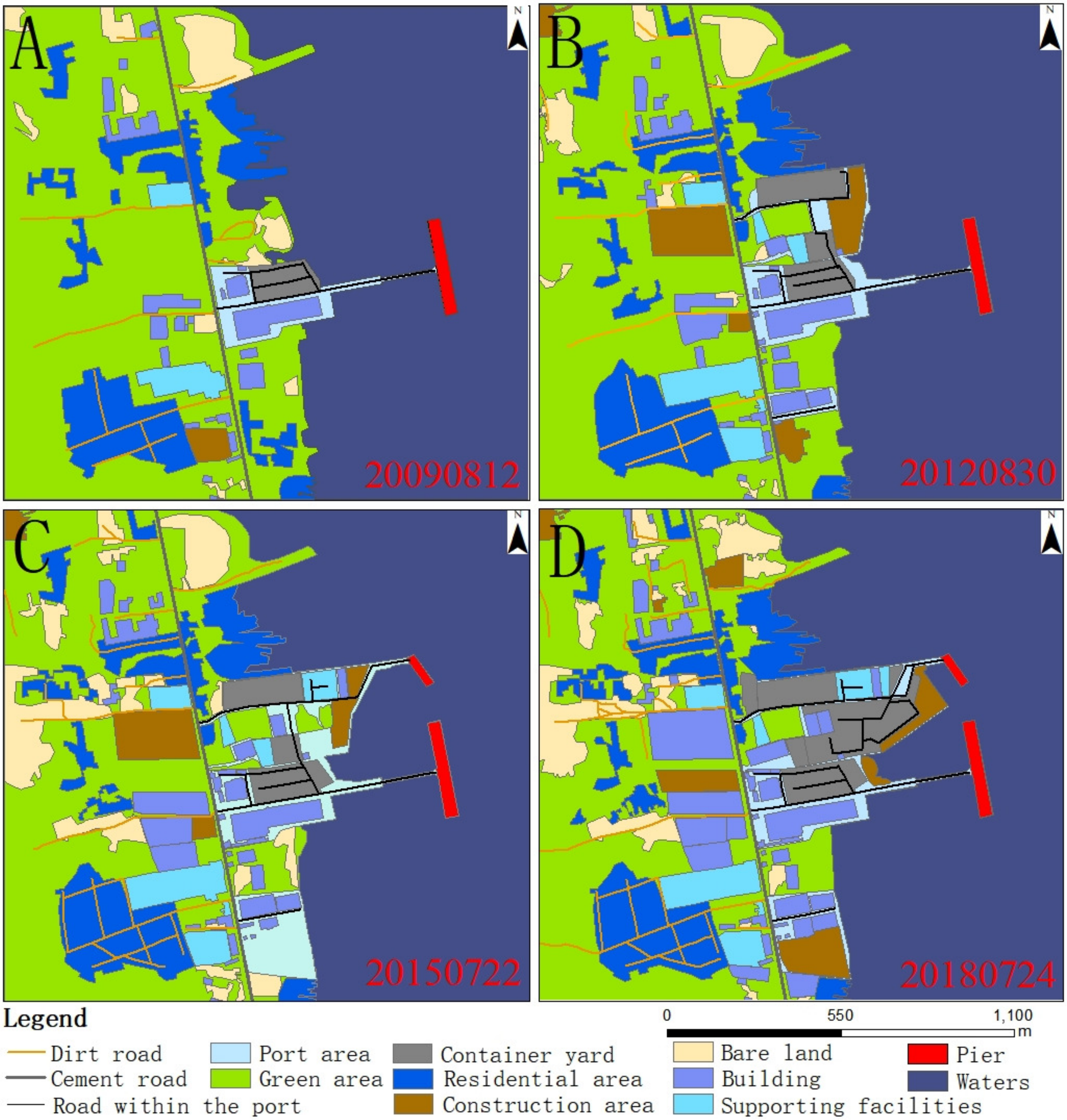

Figure 3

Vegetation coverage map around the Ajmr Port in 2009 (A) and 2018 (B) .

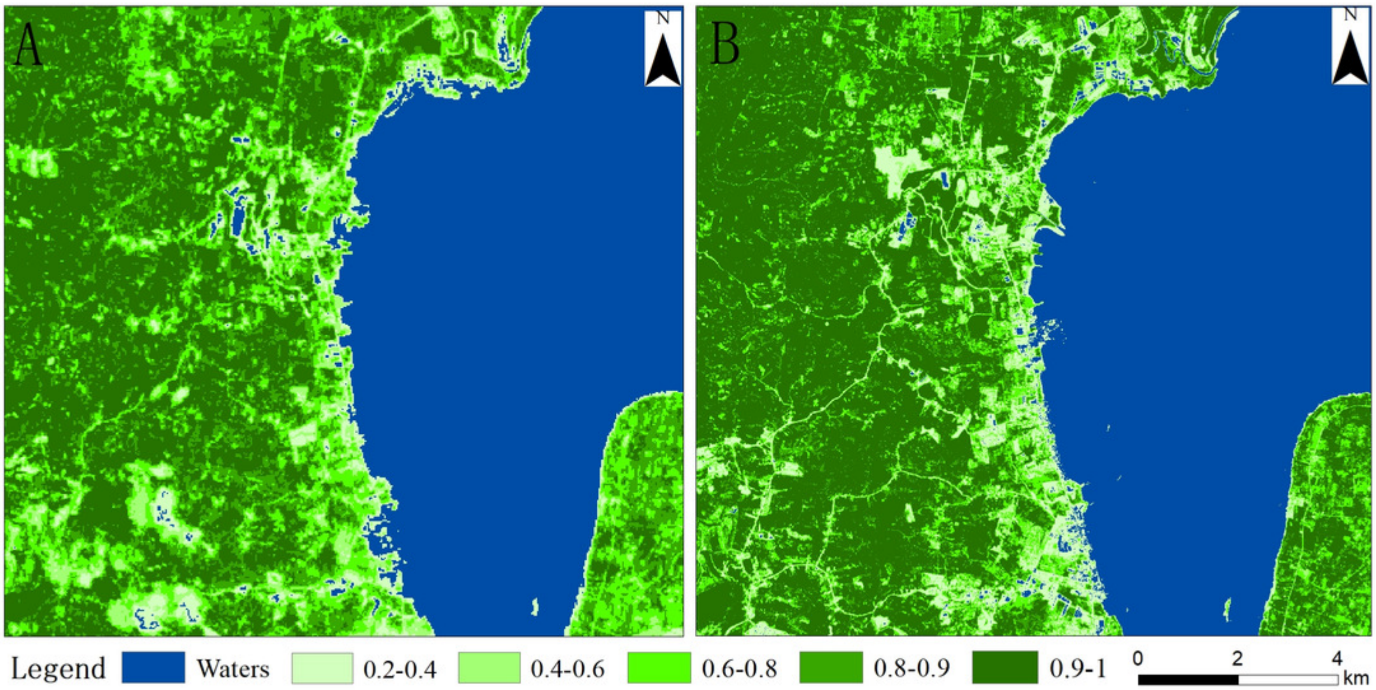

Figure 4

Changes in the port roads and buildings from 2009 (A) and 2018 (B).

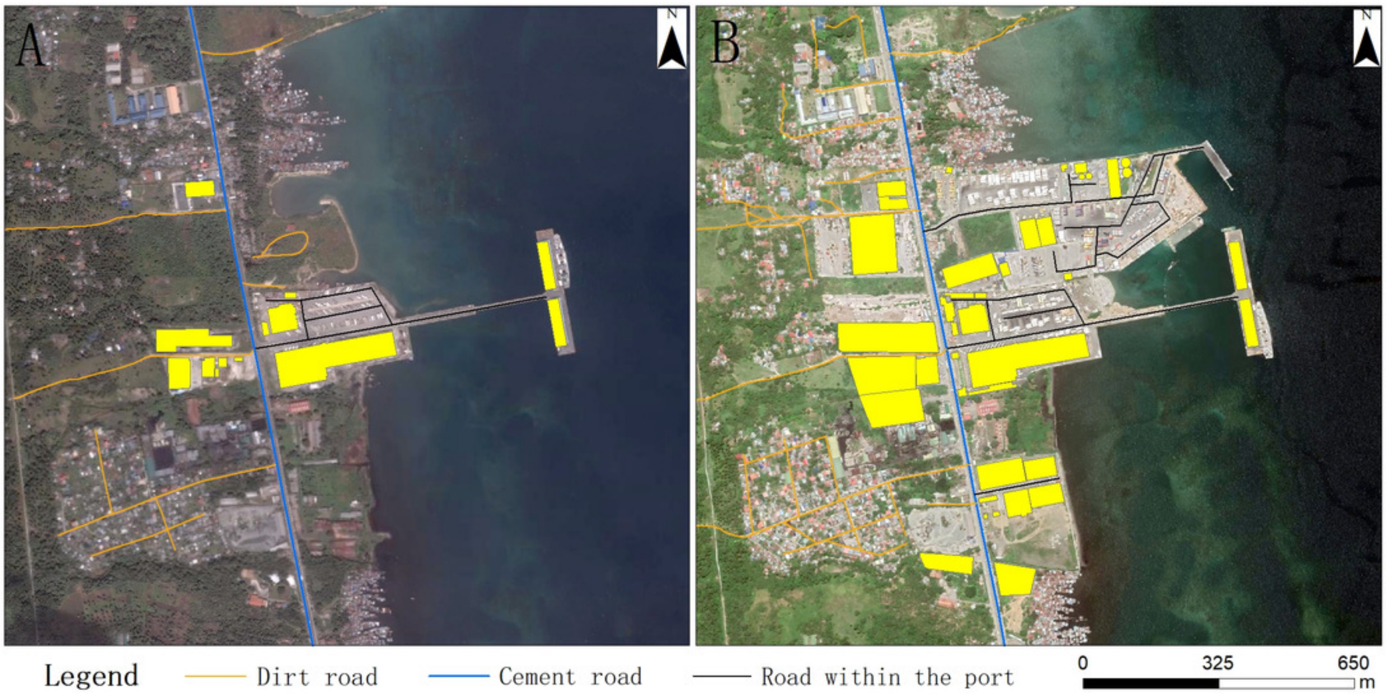

Figure 5

Changes in the lighting curves for the port, Panabo City and Davao City from 2009 to 2018.

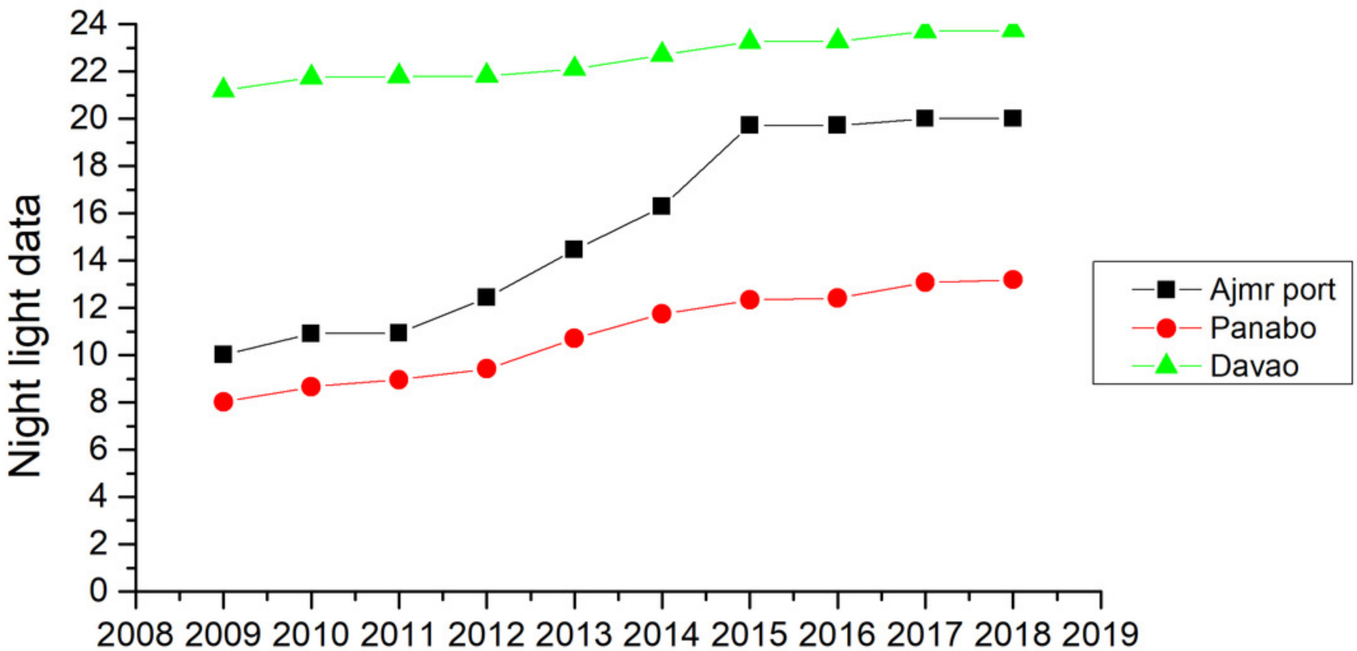

Figure 6

Growth chart of the lighting data surrounding the port region from 2009 to 2018.

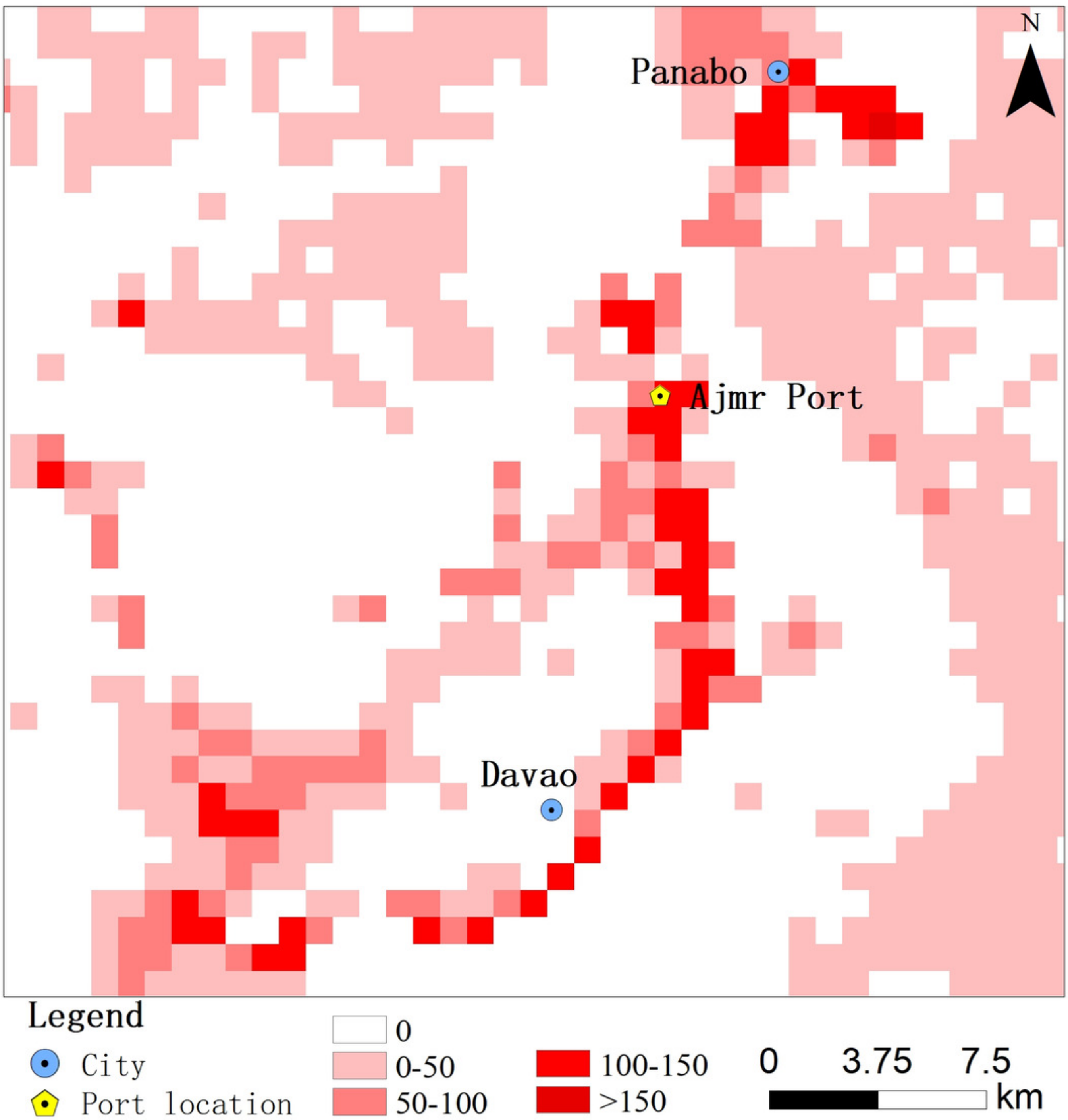

Table 1(on next page)

Areas for various types of land in the study area (hectares).

Feature category	August 2009	August 2012	July 2015	July 2018
Building	6.87	9.37	12.21	16.92
Waters	118.53	112.55	109.28	106.51
Pier	1.27	1.27	1.57	1.57
Bare land	8.07	6.42	16.02	13.17
Road	6.65	7.65	9.12	10.71
Green space	87.3	78.34	66.59	57.35
Construction area	1.27	7.98	10.01	9.85
Residential area	23.02	23.23	23.23	23.79
Supporting facilities	3.22	6.29	6.32	7.65
Container yard	2.23	5.33	5.49	10.91

Table 2(on next page)

Statistics of the vegetation coverage around the port of Ajmr in 2009 and 2018.

Years	Vegetation coverage	0-0.2	0.2-0.4	0.4-0.6	0.6-0.8	0.8-0.9	0.9-1	Total
2009	area (km^2)	81.45	6.74	11.23	29.85	38.67	62.93	230.87
	Proportion (%)	35.28	2.92	4.86	12.93	16.75	27.26	100
2018	area (km^2)	79.82	11.05	9.92	19.56	24.63	85.75	230.73
	Proportion (%)	34.59	4.79	4.31	8.48	10.67	37.16	100