Monitoring and analysis of the expansion of the Ajmr Port, Davao City, Philippines using multi-source remote sensing data

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Ports have been built or expanded in a number of countries to cater to increasing maritime trade in the 21st century. Port expansion is associated with economic and environmental impacts on the local and regional scales, and these impacts can be studied using remote sensing. The present study presents new results from multi-source remote sensing monitoring of the Ajmr Port expansion. An analysis of land use and vegetation coverage at the port is used to monitor the impact of port construction on the local ecology, while changes in roads, buildings, and lights are used to monitor the economic impact. The results show that: (1) the Ajmr Port expansion has changed the structure of land use and the area occupied by sea in the area. However, 44.25% of the land has vegetation coverage between 0.6 and 1 that this level is considered to be good, and that indicates port construction has not had a major impact on the ecology of the area; (2) the area occupied by roads and buildings has increased with port construction. The light data show increases in lighting along the coast from the northeast to the southwest, indicating that economic development in the coastal zone is more rapid than in the other regions, and that development in the coastal areas has driven economic development in the inland areas; (3)The expansion of Ajmr Port has increased the efficiency of import and export of agricultural products in the region and promoted agricultural development in the Philippines, indicating that less developed areas can contribute to sustainable economic development within a region through the expansion of small ports.

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Abstract

Ports have been built or expanded in a number of countries to cater to increasing maritime trade in the 21st century. Port expansion is associated with economic and environmental impacts on the local and regional scales, and these impacts can be studied using remote sensing. The present study presents new results from multi-source remote sensing monitoring of the Ajmr Port expansion. An analysis of land use and vegetation coverage at the port is used to monitor the impact of port construction on the local ecology, while changes in roads, buildings, and lights are used to monitor the economic impact. The results show that: (1) the Ajmr Port expansion has changed the structure of land use and the area occupied by sea in the area. However, 44.25% of the land has vegetation coverage between 0.6 and 1 that this level is considered to be good, and that indicates port construction has not had a major impact on the ecology of the area; (2) the area occupied by roads and buildings has increased with port construction. The light data show increases in lighting along the coast from the northeast to the southwest, indicating that economic development in the coastal zone is more rapid than in the other regions, and that development in the coastal areas has driven economic development in the inland areas; (3)The expansion of Ajmr Port has increased the efficiency of import and export of agricultural products in the region and promoted agricultural development in the Philippines, indicating that less

34 developed areas can contribute to sustainable economic development within a region through the
35 expansion of small ports.

Introduction

38 The "21st Century Maritime Silk Road" (MSR) is a major China-based initiative focused on
39 domestic development, with benefits for international development throughout the region. The
40 Port is a key component of the strategic infrastructure that supports the MSR transportation
41 corridor. Additionally, port will attract new resources into area, and become an important node
42 that will promote new opportunities for the country and strengthen international trade. Port
43 development will increase gross domestic product, improve national income, provide more
44 employment, and it plays an important role in regional and urban economic development.
45 However, construction of infrastructure at the port has had profound impacts on regional land
46 use. These impacts include ecological and environmental problems, such as erosion in the coastal
47 zone and pollution and disturbance of the marine environment (Gupta et al., 2005; Peng et al
48 2014). Increases in maritime trade have driven an increase in the number of ports internationally,
49 and remote sensing has been used to monitor and analyze the impacts of port construction on the
50 regional ecology. Previous work has focused on the effects that the expansion of large and
51 medium-sized ports have had on the temporal and spatial evolution of the natural environment.
52 However, the number of small port expansions is increasing rapidly, so the impact of these
53 smaller developments must also be investigated.

54

55 The methods used for port monitoring, and the results, are diverse. For example, Cowell and
56 coworkers used measurements of the abundance of intertidal species near a dock in Valdez Port,
57 Alaska, USA, to develop ecological for a rock bank baselines in the area (Cowell & Monk,
58 1981). Gulbin and coworkers used a survey of benthic communities in Wrangel Bay, Peter Dam,
59 Sea of Japan, to reveal the environmental impacts of port operations in the area (Gulbin et al.,
60 2003). A three-stage SPOT image was used to study changes in land use in the vicinity of the
61 lower reaches of the Thi Vai River in Ho Chi Minh City and Vung Tau City, southern Vietnam
62 (Rutten et al., 2005). Smith and coworkers used baseline data that represented water quality,
63 sediment quality, and benthic diversity to assess the ecological status of coastal resources in the
64 Gulf of Mexico (Smith et al., 2007). Chen and coworkers used a combination of the
65 comprehensive index method and the decision tree classification method to study changes in land
66 used for construction in Qinzhou Port over an eight-year period (Chen & Luo, 2009). Kidd
67 explored the relationship between the historic public policy of Houston, Texas, and the
68 development and expansion of the Houston port system and the impact of port expansion on the
69 socioeconomic status of surrounding communities (Kidd, 2010). Portman and co-workers used
70 parcel-level data and geographic information system (GIS) tools to study the interactions
71 between fisheries and changing land use for two New England ports (Portman et al., 2011). Zhu
72 and co-workers used a comprehensive analysis of land use in the coastal areas surrounding Bohai
73 Bay to study the evolution of land use dynamics and spatial differentiation (Zhu et al., 2012). Liu
74 and co-workers established four land use change index models, and used them to analyze the
75 orientation and extent of spatial–temporal patterns and expansion patterns associated with
76 changes in land use type in and around the Tianjin Port Area between 1987 and 2010 (Liu et al.,

77 2012). Chen used remote sensing data to simulate the process of changing land use for the port
78 cities of Dalian, China. The results were used to support decisions that promoted sustainable
79 development in port cities (Chen & Nuo, 2013). Bezerra and co-workers discussed the economic
80 development of the Port of Pecém and Industrial Complex in Ceara, Brazil, and its impact on
81 employment, environment, and health (Bezerra et al., 2014). Felsenstein and co-workers used
82 microscopic simulation models and statistical estimates to determine the relationship between
83 expansion of the Haifa Port and expected future land use (Felsenstein et al., 2014). Glory and co-
84 workers used remote sensing and GIS to analyze the patterns and processes of changing land use
85 around Port Harcourt, which is Nigeria's second largest port. These researchers monitored an
86 increased rate of conversion from mangroves, wetlands, and water bodies to cultivated land, and
87 a reduced rate of growth of the area of secondary vegetation and natural forests (Enaruvbe & Ige-
88 Olumide, 2014). Liu used the normal cloud model to establish a comprehensive set of ecological
89 indices for ports, and evaluated the ten largest Chinese ports, providing a basis for future port
90 ecological development (Liu, 2014). Sany and co-workers developed biological indicators based
91 on large benthic communities, and used the indicators to assess the ecological status of the
92 marine environment (Sany et al., 2015). Zhao and Liu used the quantitative method of R
93 clustering and coefficient of variation, combined with the qualitative method of expert
94 experience, to study the 17 major ports such as Shanghai Port and Ningbo-Zhoushan Port, that
95 proved the rationality of the ecological port evaluation index system. (Zhao & Liu, 2015). Li and
96 co-workers established a more detailed and applicable classification system, using multi-source
97 and multi-resolution images to monitor and analyze land use changes in and around three typical
98 ports in the vicinity of Xiamen Port (Li et al., 2016). Hassan and co-workers used remote sensing
99 and GIS to monitor changes in land use and land cover in the southern part of the province that
100 hosts Port Said in Egypt, and to assess the impact of the port on climate change (Hassan &
101 Omran, 2017). Huang and Liao used dynamic monitoring of remote sensing images and long-
102 term observations to determine variation range at important ports in the Beibu Gulf. The results
103 were combined with other data, including statistical data, to produce an analysis of the
104 development of port construction and its impact on parameters such as terminal berths and cargo
105 throughput (Huang & Liao, 2017). Ge and co-workers used multi-temporal high spatial
106 resolution remote sensing images to monitor infrastructure construction at the ports of Colombo
107 and Hambantota between 2010 and 2017; the results were used to track the progress of the port
108 construction, and to predict increases in annual port throughput through potential water storage
109 (Ge et al., 2018). Li and co-workers used the five typical ports in the Bohai Sea as an example to
110 establish a remote sensing monitoring technology process for the port space pattern, and
111 constructed an index of various objects to quantitatively describe the port space composition and
112 performance (Li et al., 2019). Zhong and co-workers constructed a mangrove wetland ecosystem
113 health evaluation index based on Google Earth images, and explored the spatial and temporal
114 differentiation of the health of the mangrove wetland ecosystem in the Zhangjiang Estuary, and
115 the factors that influenced the wetlands (Zhong et al., 2019).

116

117 These previous studies have focused on the ecological and economic aspects of ports or coastal
118 areas, including ecological aspects such as water quality, sediment quality, species diversity,
119 cultivated land change, vegetation cover, mangrove status, wetland changes, and land use.
120 Economic aspects considered in the studies include rates of construction progress, construction
121 land use, level of industrial development, number of berths, port throughput, and public policies.

122 Research has generally focused on ecological or economic aspects; few remote sensing
123 monitoring analyses have focused on both. To address this, we use a comprehensive analysis of
124 remote sensing images to investigate ecological and economic consequences of the expansion of
125 Ajmr Port, Davao City, in the Philippines. The results are used to monitor the impact of port
126 expansion on the surrounding region. The research involved two stages: (1) Landsat images and
127 Google Earth High Definition images were used to monitor the expansion of Ajmr Port and
128 analyze the spatial and temporal dynamics of land use and vegetation growth. These data were
129 used to determine the impact of port construction on the ecological environment; (2) Google
130 Earth High Definition images were used to determine the status of port roads and building
131 construction, and measure port traffic and housing density. These data were combined with
132 lighting data and analyzed to assess the impact of small port construction on the local economy.

133

Study Area and Data Processing

Study area

136 Ajmr Port located in the northern part of Davao City, Philippines, 15 km from Davao City. The
137 city of Davao is located on the land about 946 km southeast of Manila(*Figure 1*). The city covers
138 a total area of 2,443.61 square kilometers and is the largest city in the Philippines and the third
139 most populous metropolitan area in the Philippines.There are several corporate terminals along
140 the coast of Davao City, including Texaco, Legazpi, National Warehouse, and the Philippines
141 Shell Oil Terminal.

142

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

155

Image data and pre-processing

157 High-definition images that record the early stages of port construction are available from 2008,
158 2009, 2010, and 2012. This paper describes the process of the expansion of Ajmr Port. The high-
159 definition images show that the port of Ajmr changed significantly in 2012, indicating that the
160 port began to expand after 2010. Images from 2009 to 2018 were selected for analysis (*Figure*
161 *2*).

162

163 Landsat images of the port taken between 2009 and 2018 were selected to monitor the vegetation
164 cover before and after the port expansion. Images from Landsat7 and Landsat8 were downloaded
165 for 2009 and 2018, respectively. However, as a result of the failure of a Landsat 7 sensor in
166 2003, a large number of bands appeared in the image. These artefacts were repaired using the
167 Landsat_gapfilter.sav plug-in, and by pre-treating the images in ENVI; processing included
168 geometric corrections, image clipping, and atmospheric and radiation corrections. A square
169 image centered on the port, with a side length of five kilometers, was obtained after the
170 correction.

171

172 High-definition images were selected for the port area from 2009 to 2018 and used to classify the
173 land use. The expansion lasted for nine years, and changes were continuous throughout this
174 period. Monitoring for the present study, used images taken at three-year intervals, with images
175 from 2009, 2012, 2015, and 2018. These high-resolution images were obtained from Google
176 Earth; the accuracy is 1 m. The images were corrected using the ENVI software so that the
177 sample points were evenly distributed throughout the image, and the images were registered
178 using the image to map method. The corrected images are amenable to dynamic change analysis.

179

180 Time-series nighttime images from 2009 to 2018 were downloaded. Processing of the lighting
181 images required extensive observation of the surrounding areas of the port, so the region of
182 interest used for the study of night light data was a 40 km × 40 km, centered on the port. The
183 night lighting data from 2009 to 2013 was taken from DMSP/OLS (operational line scanning
184 system of the Defense Meteorological Satellite Program) and from VIIRS/DNB (visible infrared
185 imaging radiometer kit day/night band) for 2013 to 2018. Compared with the OLS data, the
186 VIIRS benefits from a finer space–time resolution, better data comparability between different
187 years, and no data saturation. The acquisition of data from two different observation platforms
188 using multiple sensors means that the downloaded images have to be pre-processed (Zou et al.,
189 2014; Shi et al., 2014; Cao et al., 2015; Zhang et al., 2017; Wu et al., 2018). First, the images
190 were cropped so they covered the same area. Then, the image was re-sampled so that all images
191 had the same spatial resolution. A quadratic regression model was established to correct for
192 differences between the sensors.

193 $$DN_c = a \times DN^2 + b \times DN + c, \qquad (1)$$

194 where DN and DN_C are the grayscale values before and after correction, and a, b, and c are
195 regression parameters. Then, the DN values of the two sensor stable bright value pixel images in
196 the same year are corrected.

197 $$DN_{(n,i)\_c} = \frac{DN^{\alpha}_{(n,i)} + DN^{\beta}_{(n,i)}}{2}, \qquad (2)$$

198   where $DN_{(n,i)}^{\alpha}$ and $DN_{(n,i)}^{\beta}$ are the uncorrected DN values of pixel i acquired by sensors α and β for

199   year n, and $DN_{(n,i)\_c}$ is the corrected DN value of pixel i in year n. Finally, the DN value

200   correction of the multi-sensor multi-year bright value pixel image is performed according to the

201   change rule of the night light image. In cases where the DN value of a pixel in the DMSP/OLS

202   light image for a particular year was less than the DN value for that pixel in the previous year,

203   then the DN value should be corrected.

204
$$DN_{(n,i)} = \begin{cases} DN_{(n-1,i)}, DN_{(n-1,i)} > DN_{(n,i)} \\ DN_{(n,i)}, \text{others} \end{cases} , \qquad (3)$$

205   where $DN_{(n-1,i)}$ and $DN_{(n,i)}$ represent the DN values of pixel i on the DMSP/OLS nighttime light

206   image in years n-1 and n, respectively.

207

Methods

209   The Google Earth High Definition images were used to produce maps of the type of land use and

210   to establish the timing of changes in land use. The Landsat images were used to create vegetation

211   coverage maps and processed to assess changes in vegetation growth during port expansion;

212   these data were used to monitor the ecological environment. The Google Earth High Definition

213   images were used to monitor the progress of port roads and building construction, and measure

214   the density of port transportation infrastructure and housing density. These data were combined

215   with the light images to calculate the annual brightness value of the port, plot the rate of change

216   of light around the port, and to analyze the impact of small port construction on the local

217   economy.

218

Port ecological environment remote sensing monitoring analysis

Land use monitoring

221   After pre-processing of the 2009, 2012, 2015, and 2018 high-resolution images from Ajmr Port,

222   visual interpretation was used to analyze spatio-temporal dynamic changes. The scheme for the

223   port classified features as roads, buildings, water, pier, container yard, bare land, other facilities,

224   green areas, residential areas, or construction areas. The roads were classified as

225   dirt roads, cement roads, or internal roads, and the area where the port is located was marked.

226   The criteria used to classify the interpreted features are provided (*Table 1 & Figure 3*).

227

228   The 2009 image was interpreted first. The interpreted image was compared with the next image

229   (2012), and modified to create the 2012 land use map. The land use maps for 2015 and 2018

230   were derived in an analogous manner. Changes in the land use related to construction were

231   determined by comparing the images.

232

233 **Vegetation growth sequence monitoring**

234 The normalized difference vegetation index (NDVI) for 2009 was calculated, based on the 2009
235 pre-processed Landsat imagery, and used to estimate the fractional vegetation cover (VFC) in the
236 Ajmr Port region. First, the NDVI of the Landsat remote sensing image in 2009 was calculated,
237 and then the maximum NDVI of the year was synthesized. Based on this image, the VFC was
238 calculated using empirical equations.

239
$$NDVI = (P_{nir} - P_{red})/(P_{nir} + P_{red}) \quad , \qquad (4)$$

240 where P_{nir} is the reflectance of the near-infrared band and P_{red} is the reflectance of the red band,
241 and

242
$$VFC = (NDVI - NDVI_{min})/(NDVI_{max} - NDVI_{min}) \quad , \quad (5)$$

243 where $NDVI_{max}$ and $NDVI_{min}$ are the maximum and minimum NDVI values in the region,
244 respectively.

245

246 To account for the inevitable noise in the images, $NDVI_{max}$ was set to the 95th percentile of the
247 DN data, and $NDVI_{min}$ was set to the 5th percentile of the DN data; this strategy minimized noise-
248 related artefacts in the image. The same approach was used for the 2018 vegetation cover map. A
249 comparison of the two images was used to determine changes in vegetation cover before and
250 after port construction.

251

252 **Social and economic remote sensing monitoring analysis**

253 **Comparison changes in roads and buildings**

254 Roads are an important factor in the development of a regional economy, and the volume of road
255 traffic reflects the regional economy to some extent. The accessibility and convenience of roads
256 promotes economic development (Wang, 2014; Li, 2014; Yuan, 2018). In this study, changes to
257 the roads inside the port region were determined, and divided into three grades according to the
258 road construction status: dirt, cement, and the roads within the port. The roads were extracted
259 from the high-resolution images. A comparison of images taken before and after the expansion
260 project enabled visualization of traffic changes in the area, the density of the road network, the
261 estimated traffic volume, and the extent of development of the port city.

262

263 The economic prosperity of the area can be estimated using a comparison of buildings in the port
264 area before and after port construction. The number of buildings was counted, and the data used
265 to calculate the area occupied by buildings and visualize the progress of port construction.

266

267 **Analysis of light changes**

268 Nighttime light is an objective measure of the productivity and activity of human society
269 (Dolores, 2013; Xu et al., 2015; Wang & Huang, 2018; Li et al., 2018). The lighting data were
270 used to study development and activity in the port area, using a comparison of the bright and
271 dark regions in the images. There is a positive correlation between the intensity of lighting and
272 socio-economic factors. This paper used nighttime lighting data from 2009 to 2018 to determine
273 changes to lighting in the port area. Comparisons of the lighting data over the nine-year period
274 were used to identify areas where light changed in the study area, and to infer changes in
275 demographic and the status of economic development.

276

277 **Results and analysis**

278 **The status of land use in the study area**

279 It was not possible to conduct field verification of features measured in the older images, because
280 of changes to the port in recent years. Instead, the high-precision 0.3-m-resolution high-
281 definition image was used to verify the accuracy and revise the results where necessary. The
282 accuracy of the corrected data is better than 90%, which is considered to be satisfactory for the
283 purposes of the study. At the time of construction, the area covered by the port was 9.46
284 hectares. The port expanded to 19.96 hectares in 2012, 26.95 hectares in 2015, and 31.14
285 hectares in 2018 (*Figure 4*).

286

287 Maps of land use type for 2009, 2012, 2015, and 2018 were constructed (*Figure 5*). There were
288 large changes in land use type in the study area during port construction. The area occupied by
289 the port increased by a total of 21.68 hectares during the expansion period, mainly through the
290 addition of land previously occupied by water. From 2009 to 2018, port expansion gradually
291 shifted from the central to the southern coastal region, mainly at the expense of green space. The
292 most obvious features that changed during the expansion period are the areas of buildings,
293 construction, bare land, water, other facilities, container yards, roads, and green space. Among
294 these, there was a significant increase in the area occupied by buildings, construction, bare land,
295 other facilities, container yards, and roads, with increases of 10.05, 8.58, 5.1, 4.43, 8.68 and 4.06
296 hectares, respectively. These increases were accommodated by a reduction in area occupied by
297 water and green space, with reductions of 12.02 and 29.95 hectares, respectively.

298

299 The areas of different land use types in the study area from 2009 to 2018 are shown in Table 2.
300 There was significant expansion in the northern part of the port area in 2012, relative to 2009
301 (*Figure 5A & B*). Green areas, bare land, and water in the 2009 image were built on and
302 expanded to become container yards, construction areas, roads, and other facilities in the later
303 images. The area of these construction-related land use types increased by 6.71 hectares.
304 Between 2012 and 2015, a 104-m-long, 23-m-wide, pier and ship-landing infrastructure was
305 added to the northern port region, and the southern parts of the port area expanded (*Figure 5 B &*
306 *C*). A total of 2.57 hectares originally classified as green space and construction area was

307 converted into port land, with an associated 9.6-hectare increase in the area classified as bare
308 land. Between 2015 and 2018, the port produces 2.81 hectares of land through occupied waters,
309 mostly in the eastern parts of the study area, to provide a container yard and construction area.
310 The original construction area in the western part of the port was converted to buildings that
311 covered an area of 3.79 hectares. Container yards increased by 5.42 hectares compared to 2015.

312

Monitoring of changes to vegetation coverage

314 Five areas within the study area were randomly selected for accuracy verification using the 0.3-
315 m-resolution high-definition image. The accuracy calculated for the five sample areas in 2009
316 was 82.5%, 88.1%, 94.6%, 91.3%, 87.5%, and the average accuracy was 88.8%. The accuracy of
317 the five sample areas in 2018 was 81.2% 86.4%, 93.5%, 92.7%, and 87.2%, with an average
318 accuracy of 88.2% (*Figure 6*). These data were more than 80% accurate and meet the
319 experimental requirements.
320
321 The fractional vegetation cover map of 5 km around the port was mapped (*Figure 7*). In 2009,
322 the boundary between the water and the vegetation is clearly defined (*Fig. 7A*). Within this
323 region, 11.34% of the vegetation ranged from 0.2 to 0.6, 10.83% of vegetation ranged from 0.6
324 to 0.8, and 32.88% of the vegetation ranged from 0.8 to 1. A total of 43.71% of the vegetation,
325 which covered an area of 10.94 km^2, was between 0.6 and 1.
326
327 In 2018, 14.62% of the vegetation ranged from 0.2 to 0.6, 8.35% of the vegetation ranged from
328 0.6 to 0.8, and 33.9% of the vegetation ranged from 0.8 to 1 (*Fig. 7B*). The proportion of the
329 vegetation between 0.8 and 1 was higher in 2018 (33.9%) than it was in 2009 (32.88%). A total
330 of 44.25% of the vegetation, which covered an area of 10.58 km^2, was between 0.6 and 1; these
331 values are similar to those calculated for 2009 (*Table 3*). Vegetation coverage is an important
332 indicator of the quality of the ecological environment in a region (Alo & Pontius, 2008; Xin et
333 al., 2008; Amarsaikhan et al., 2009; Chen & Wang, 2009; Zhang et al., 2010; Lu et al., 2017; Li
334 et al., 2019). Thus, the comparison of the two images shows that the port expansion has not had a
335 significant impact on the ecological status of the area, reflecting the higher overall greening level
336 in the area.
337

Analysis of changes in the port roads and buildings

339 The accuracy of road and building data on the revised 0.3-m-resolution high-definition image is
340 better than 90%. During the nine-year expansion of the port, there were significant increases in
341 the areas occupied by roads and buildings (*Figure 8*). Seven new roads covering an area of 2.97
342 hectares appeared in the port; the new roads were mainly concentrated in the northeastern part of
343 the port. A large number of container areas were added on the newly reclaimed land, so the
344 number of transportation pathways for goods increased accordingly.

345

346   Changes to buildings after the expansion included an increased number of buildings in the
347   central and southern regions of the port. Expansion involved the addition of 22 new buildings
348   with an area of 3.87 hectares. This large area of the port was converted at the expense of green
349   space and water. The new roads and buildings accounted for 9.54% and 12.43% of the total area
350   of the port, respectively, which is a relatively small proportion. The increase in the construction
351   area reflects an increase in the population around the port, and the expansion of construction
352   scale.

353

Port Light Change Analysis

355   The port is adjacent to Panabo City to the north and Davao City to the south. Davao City is the
356   only independent city in the Davao District of Northern Mindanao and is the most populous city,
357   while the city of Panabo is a small city in the north of Davao. The time-series dynamic lighting
358   monitoring of the 40 km × 40 km area around the port of Ajmr provided lighting data from 2009
359   to 2018 (*Figure 9*). A comparison of the port lighting data with that of the adjacent cities showed
360   that there was a significant increase in lighting at the port, especially in 2011 to 2015. During
361   this time, the port's lighting data was close to that of Davao, so grew significantly. The nine-year
362   lighting dataset from the cities of Panabo and Davao also showed increases in lighting, but the
363   rate of growth was slower than at the port.

364

365   Differences between the 2009 and 2018 lighting images were calculated to obtain the nine-year
366   lighting growth rate around the port (*Figure 10*). The expansion of lighting from the northeast to
367   the southwest is clear, highlighted by the red curve. From the high-definition image, it can be
368   seen that the red curve passes over the coast southeast of Mindanao in the southern Philippines.
369   The rate of growth of lighting along the coastline was commonly between 100 to 150, or greater.
370   Panabo City and Davao City also had lighting growth rates between 100 and 150, and both are
371   located on the coast. Before the expansion of Ajmr Port, the port's economic development level
372   was low. However, after nine years of continuous expansion, the rate of economic development
373   in the region increased, indicating that construction at the port promoted local economic
374   development. Ajmr Port, Panabo City, and Davao City form an economic belt on the southeast
375   coast of Mindanao, which has promoted economic development on the coast.
376
377   The lighting in large areas on the east side of the port grew at relatively low rates, between 0 and
378   50. The high-resolution images show that this slow-growth area is northwest of Davao Bay and
379   Samal Island. The growth of lighting data in the sea areas is mainly due to ships. The large
380   number of vessels in the water indicates the frequency of maritime transport trade in the region.
381   The relevant data show that export volumes from Ajmr Port are large, and that there are
382   numerous trading partners (Ahmad & Chua, 2013; Dhang & Partho, 2015; Zhai et al., 2016). In
383   2015, the Sumifru Company began to export South American bananas to China. This company
384   relies on China's Dalian, Tianjin, Shanghai, Shenzhen, and other coastal ports for trade. It has
385   established large processing, storage, and sales organizations in the major port cities of China
386   that provide fresh fruit to the Chinese mainland. Relationships between China and the
387   Philippines have benefited from this "21st Century Maritime Silk Road" (Zhai et al., 2016).

388 Through the continuous increase in sea-based trade, China has become the largest export market
389 for bananas from the Philippines.
390

Discussion

392 This paper describes an analysis of remote sensing monitoring data to quantify five aspects of
393 economic development and the ecological environment (land use structure, vegetation coverage,
394 road and building changes, and lighting growth) at the port of Ajmr in the Philippines between
395 2009 and 2018. The research focuses on this port, and provides, for the first time a
396 comprehensive evaluation of port construction. However, only changes in land use and
397 vegetation coverage were used to assess the impacts on the ecological environment, and only
398 changes in roads, buildings and lighting, were used to assess the magnitude of economic growth.
399 We acknowledge that these five parameters may not provide a complete representation of either
400 the ecological or economic impacts of the port expansion. Additional parameters that could be
401 used to assess the impacts of the port on the ecological environment include studies of water
402 quality, sediment quality, benthic diversity, the area of cultivated land, and mangrove status.
403 Additional parameters that could be used to quantify the economic impacts include statistical
404 analyses of the population, gross domestic product, employment status, and public policy.
405 Inclusion of a targeted statistical analysis in any further work would also prove beneficial.

406

Conclusions

408 (1)The expansion of the port of Ajmr occupied a certain amount of land and water, changing the
409 land use structure of the area. However, the extent of vegetation coverage in the range between
410 0.6 and 1 was maintained at around 44.25%, and the overall coverage remained high. These data
411 indicate that port construction did not have a significant impact on the ecology of the area.

412

413 (2)An analysis of changes in the areas occupied by roads and buildings suggest that the
414 population of the area increased significantly, the scale of construction expanded, and the
415 economic prosperity increased. An increase in lighting in a coastal area oriented northeast–
416 southwest indicates that economic development of the coastal zone was faster than in other
417 regions. In addition, the new development in the coastal areas promoted economic development
418 of the inland regions.

419

420 (3) Ajmr Port has a small footprint compared to large ports and is mainly used for exporting
421 goods. The impact on the local ecological environment during the construction was relatively
422 small, and is not expected to have caused many ecological or environmental problems. The
423 expansion of Ajmr Port has promoted the development of agriculture in the Philippines. This
424 shows that the expansion of small ports in less developed areas can promote sustainable
425 economic development of the region.

426

427

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434

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618

Figure 1

Research area location

"Google Earth High Definition imagery"

Legend   ◎ Capital   ■ Philippine   ■ Ocean
          ● Port location   ■ Other countries

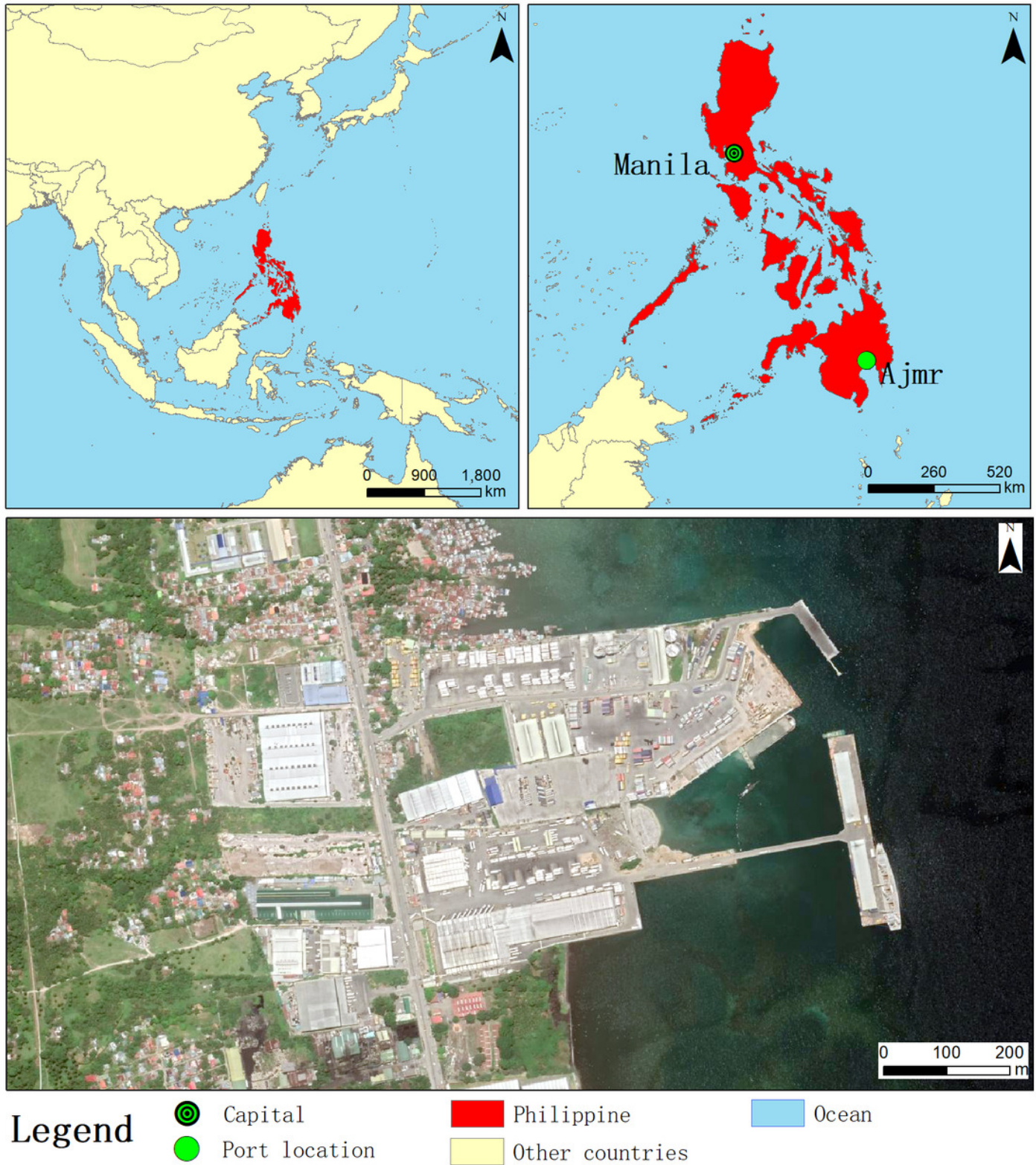
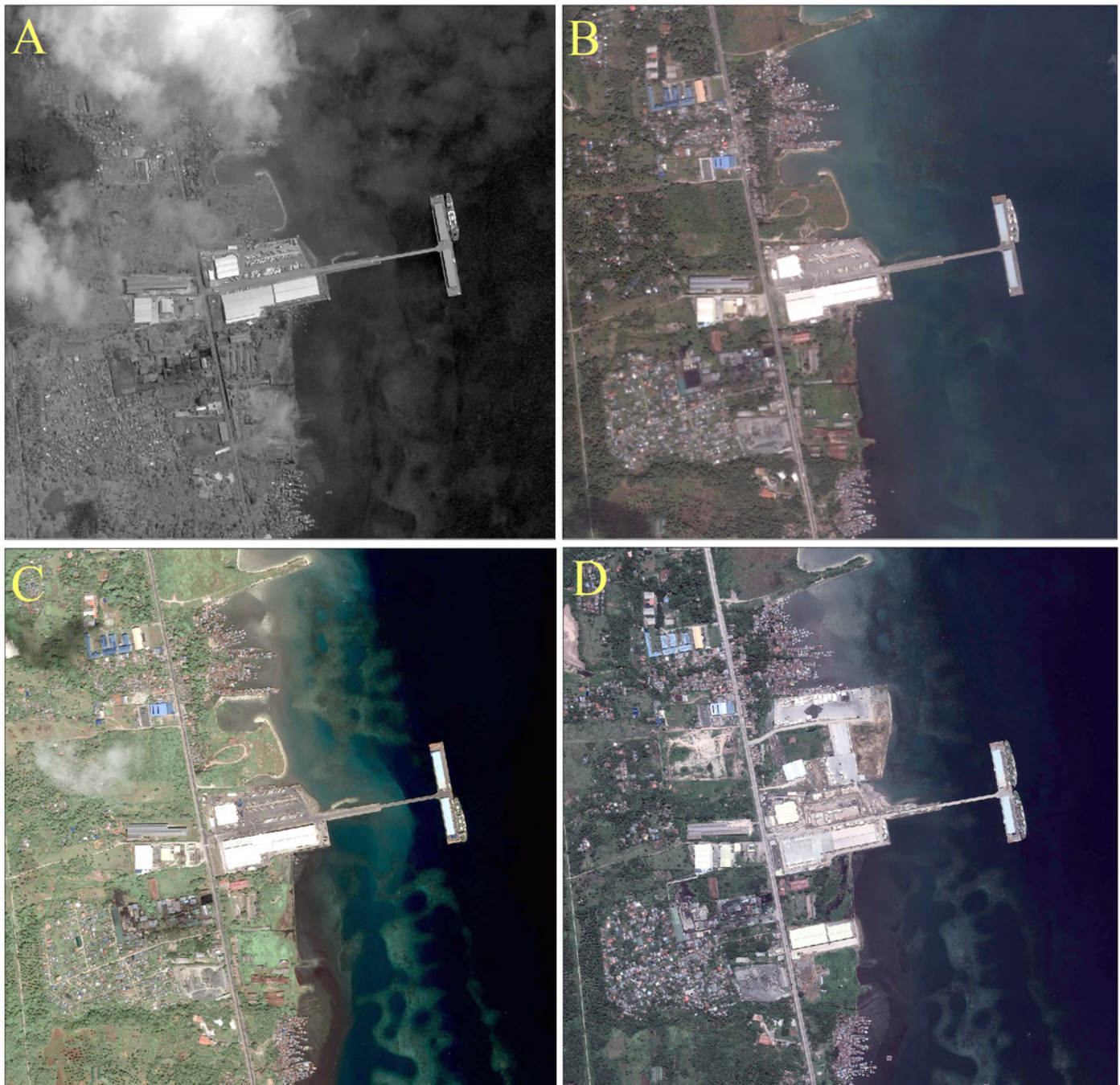



Figure 2

High-definition images of the 2008(A), 2009(B), 2010(C) and 2012(D) in study areas

"Google Earth High Definition imagery"

Local object identification and judgment methods

Feature type	Color, shape and obvious features
Road	Dirt road: the color is grayish white, the road is thinner and the shape is irregular (Fig.3A); the cement road: the color is grayish black, the road is straight and very wide (Fig.3B); roads within the port: the color is gray, long Strips, wide roads, located in the inner area of the port (Fig.3C)
Building	The colors are white, dark green, blue, etc., the shape is a regular polygon, the area is large, and there are generally roads around (Fig.3D)
Waters	The color is dark green, which is a large area, and there are a small amount of sandstone and silt accumulation in the coastal area (Fig.3E).
Pier	The color is gray, and the shape is a regular rectangle. In the coastal area, there are ships nearby, and there are generally goods and vehicles on the dock (Fig.3F).
Container yard	The colors of the containers are different, the shape of the yard is relatively regular, and there are many roads and containers inside (Fig.3G).
Bare land	The general color is brown, the shape is irregular, and there is no vegetation, construction and construction facilities inside (Fig.3H)
Other facilities	The color is dark blue or dark gray, and the area is relatively regular, generally for various mechanical equipment or workshops (Fig.3I)
Green space	The color is green, it is a flaky area, and there are various trees, grasses and other vegetation inside (Fig.3J)
Residential area	The color is mostly red and blue, and the flaky area is irregular. There are roads and a small number of trees inside (Fig.3K)
Construction area	The color is grayish white, irregular, with obvious construction traces or construction equipment (Fig.3L)

Figure 3

Visual interpretation of various features

(A) dirt road, (B) cement road, (C) roads within the port, (D) building, (E) waters, (F) pier, (G) container yard, (H) bare land, (I) other facilities, (G) green space, (K) residential area, (L) construction area

"Google Earth High Definition imagery"

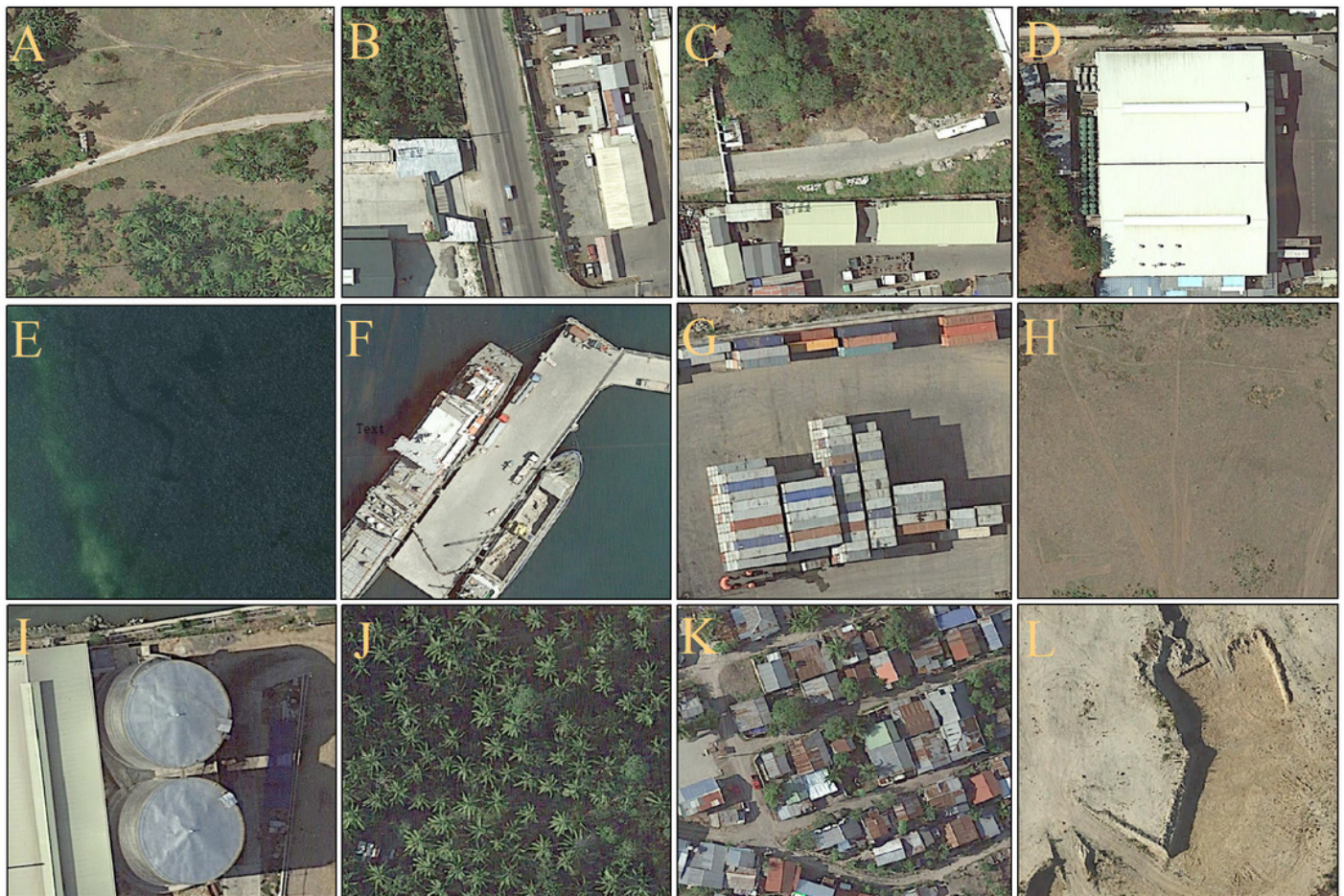



Figure 4

Port expansion chart of the 2009(A), 2012(B), 2015(C) and 2018(D)

"Google Earth High Definition imagery"

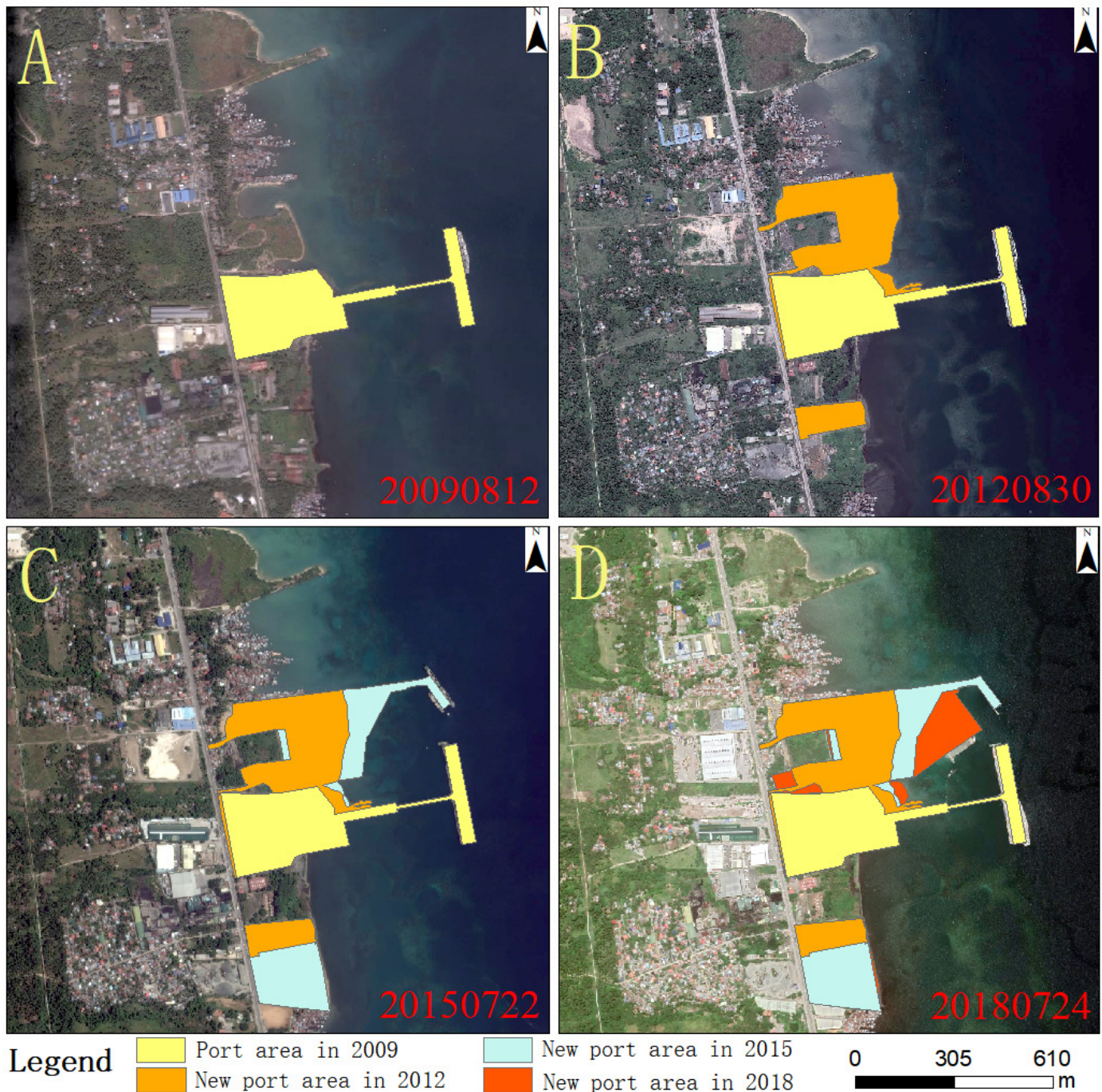
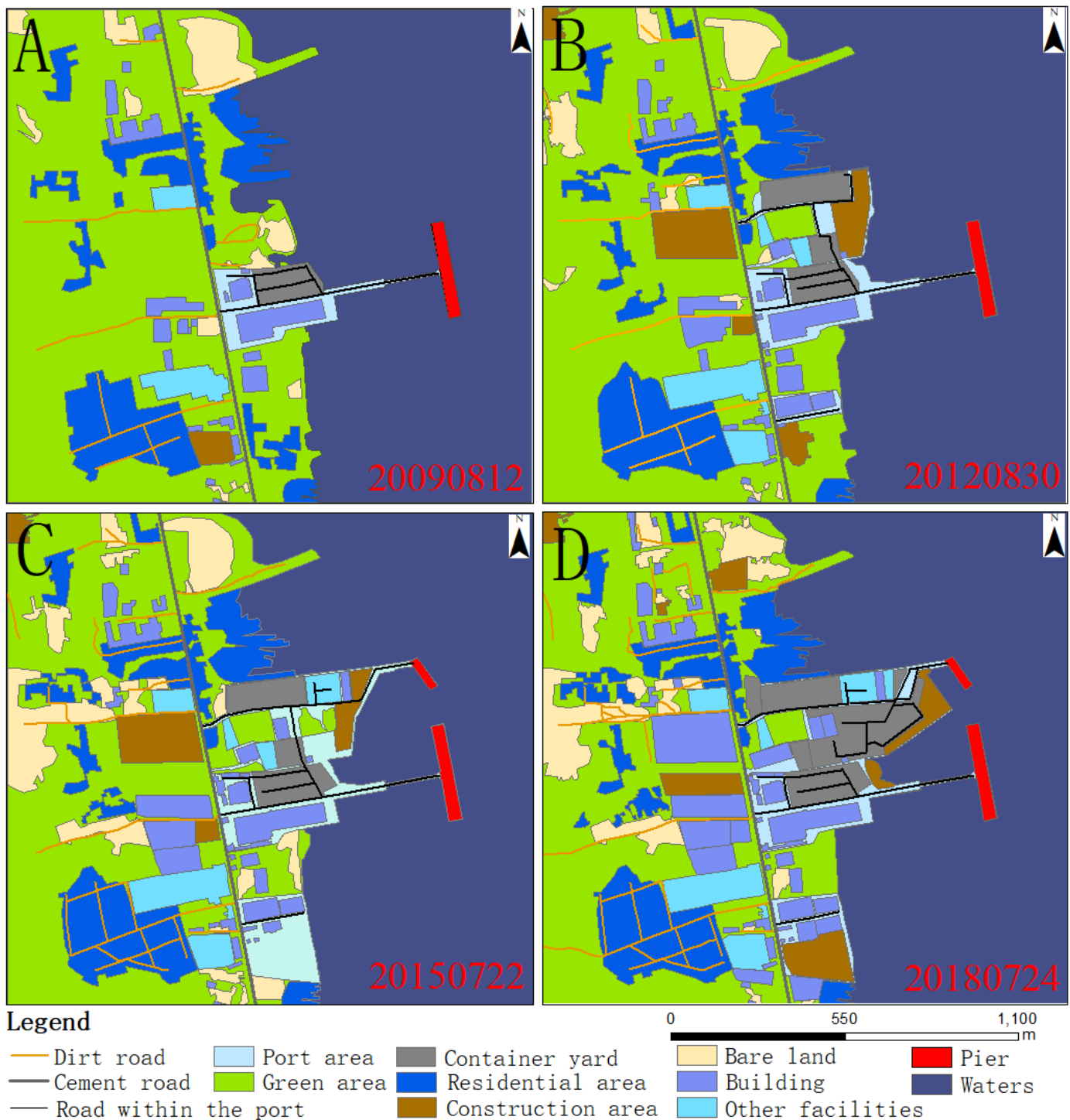



Figure 5

Land use change map of the study area in 2009(A), 2012(B), 2015(C) and 2018(D)

"Google Earth High Definition imagery"

Legend

─── Dirt road	Port area	Container yard	Bare land	Pier
─── Cement road	Green area	Residential area	Building	Waters
─── Road within the port	Construction area	Other facilities		

Area of various types of features in the study area (hectare)

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	14.61	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
Other facilities	3.22	6.29	6.32	7.65
Container yard	2.23	5.33	5.49	10.91

Figure 6

Vegetation coverage accuracy verification map

Five sets of samples of vegetation coverage accuracy verification map in 2009(A&B,C&D,E&F,G&H,I&J)。Five sets of samples of vegetation coverage accuracy verification map in 2018(K&L,M&N,O&P,Q&R,S&T)

" Google Earth High Definition imagery "& " USGS/NASA Landsat "

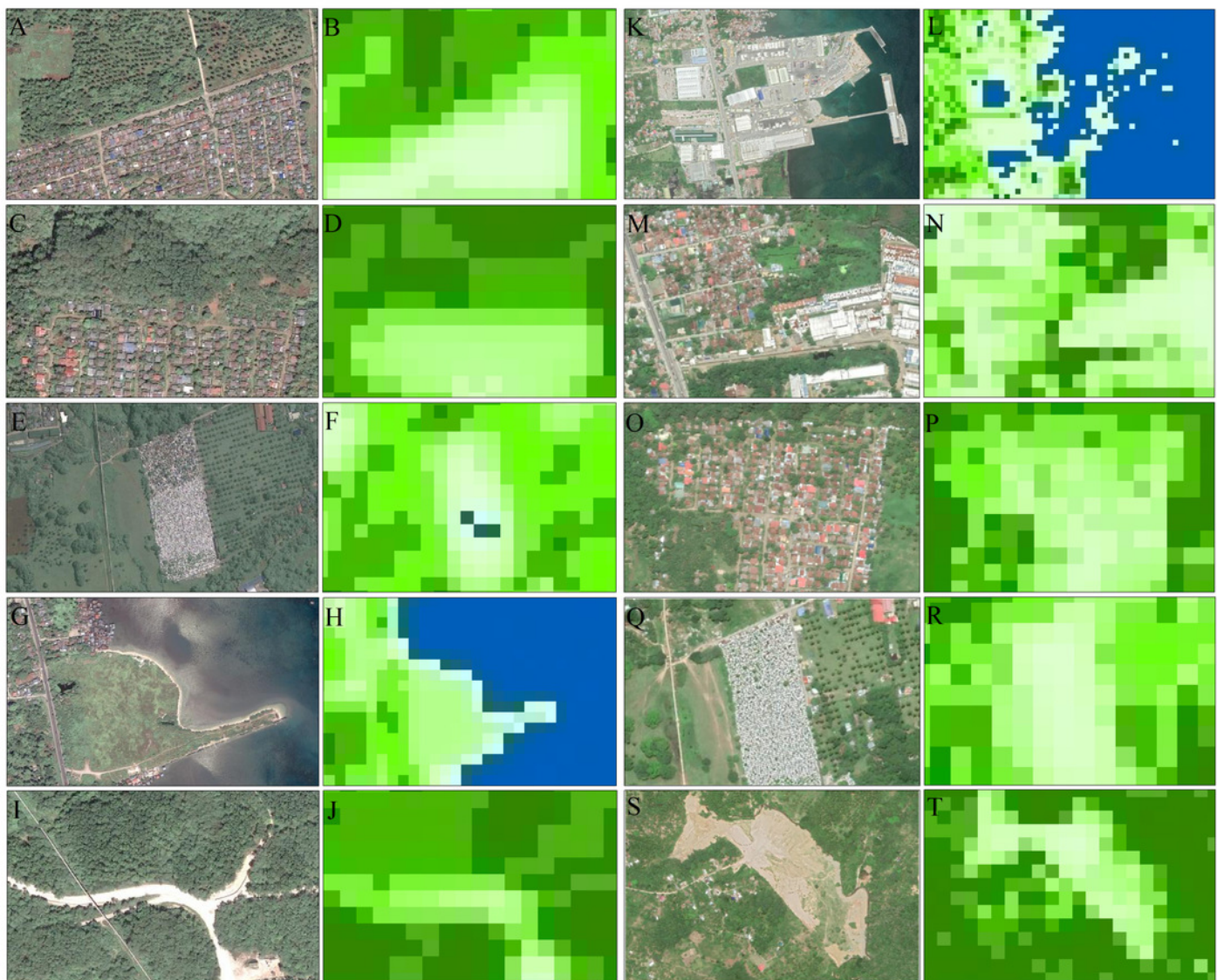
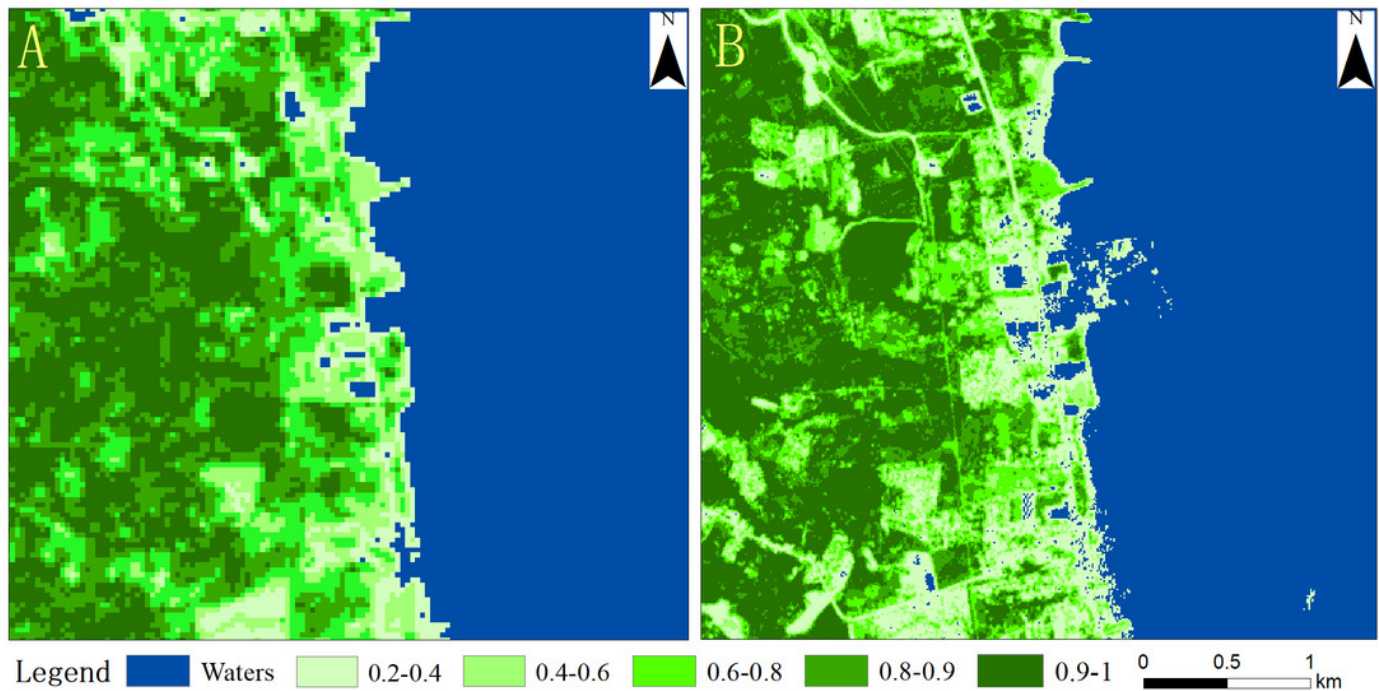



Figure 7

Vegetation coverage map for 2009 (A) and 2018 (B)

"Landsat imagery courtesy of NASA Goddard Space Flight Center and U.S. Geological Survey"

Statistics of 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)	11.25	1.25	1.59	2.71	3.52	4.71	25.03
	Proportion (%)	44.95	4.99	6.35	10.83	14.06	18.82	100.00
2018	area (km^2)	10.8	2.05	1.61	2.09	2.38	6.11	25.04
	Proportion (%)	43.13	8.19	6.43	8.35	9.50	24.40	100.00

Figure 8

Port road and building change map for 2009(A) and 2018(B)

"Google Earth High Definition imagery"

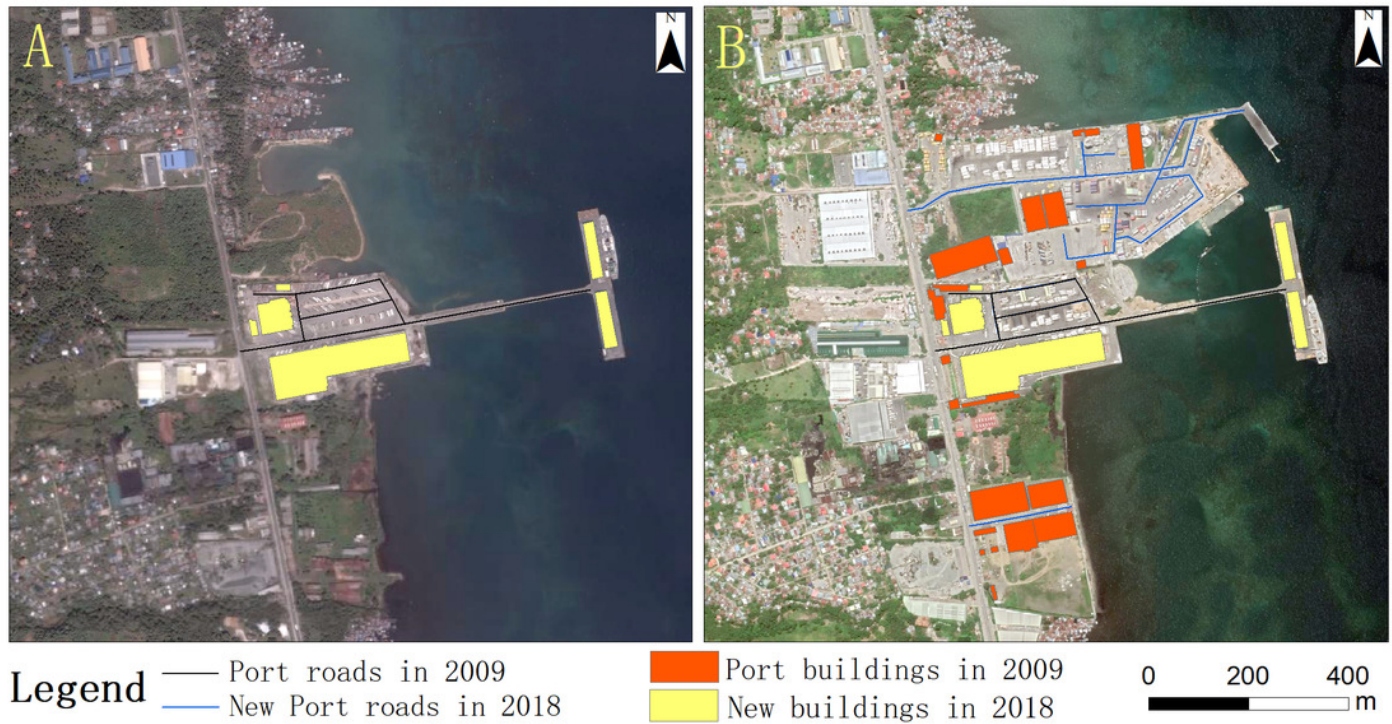



Figure 9

Davao City, Panabo City and Ajmr Port light change curve in 2009-2018

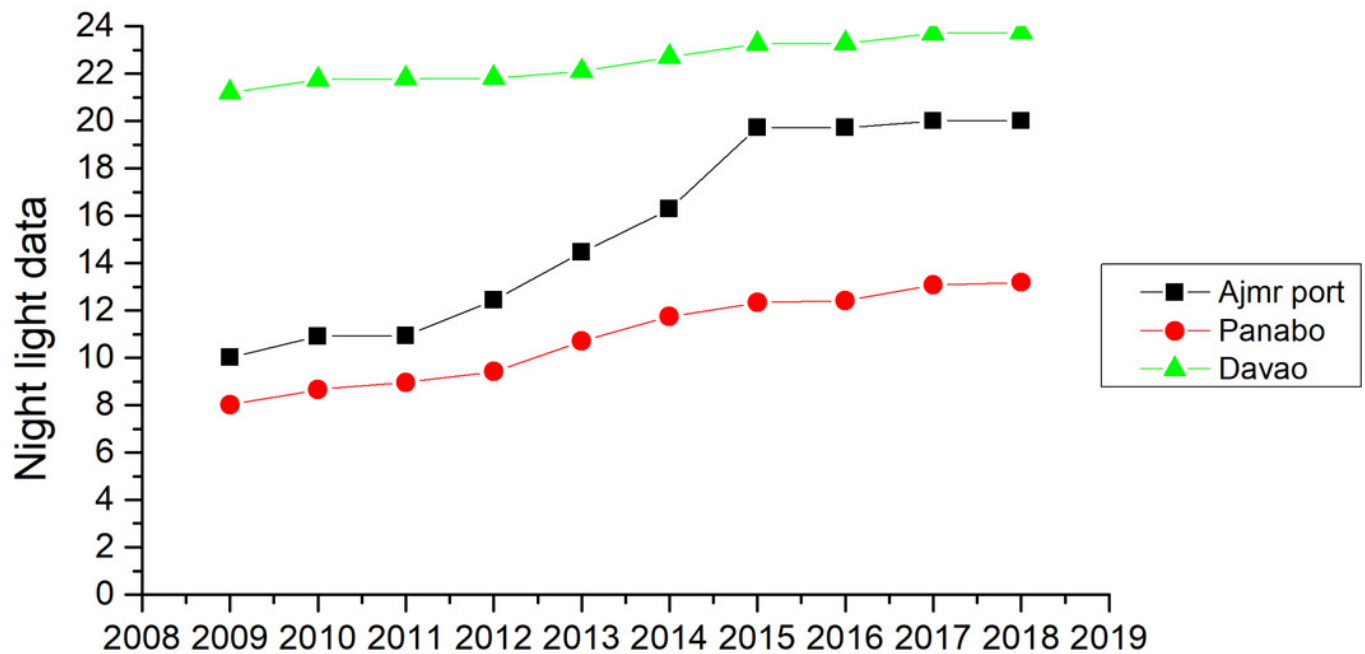



Figure 10

Growth chart of the surrounding lights of the port in 2009-2018