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The role of spatial planning in reducing exposure towards impacts of global sea level rise case study: Northern coast of Java, Indonesia

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ABSTRACT

Spatial planning is expected to facilitate climate change adaptation by directing future spatial and infrastructure developments away from zones that are exposed to climate-related hazards. This study attempts to confirm this understanding by mapping the effects of the various spatial plans on the northern coast of Java, Indonesia. First, the study maps the extent of coastal hazards for the baseline year of 2010 using a GIS-based inundation model. An overlay in GIS demonstrates the influence of spatial plans for the projection year of 2030. This allows for calculating the economic losses of the planned developments. The case study shows that the current provincial spatial plans direct land use conversions along the northern coast of Java to continue to occur in the future. This could significantly decrease the regional capacity in dealing with the exposure to coastal inundation. The analysis also demonstrates that a total area of 55,220 ha of land prone to inundation, consisting of protected area (1488 ha), fishponds (32,916 ha) and agricultural land (20,814 ha), is planned to be converted into industry (13,399 ha) and settlements (41,821 ha). Thus, these areas will be also prone to inundation in 2030. This change would potentially lead to an economic loss of 246.6 billion USD. The spatial plans issued by the national and provincial governments for regulating the future land use on the northern coast of Java have not integrated measures against hazards related to global sea level rise. Meanwhile, many existing developments have already been affected by coastal inundation. Rather than reducing the exposure towards coastal flood hazards, the case study shows that spatial plans could even increase the risk of climate-related hazards and cause higher economic losses. These findings provide a different perspective on the role of spatial planning for climate change adaptation than what is stated in the literature.

1. Introduction

Issues related to global climate change have dominated our day-to-day life ranging from purely scientific discussions and political debates to price instability of agricultural commodities in the markets. Following up on the Conference of the Parties (COP) 13 of UNFCCC in Bali in 2007, the mitigation of, and adaptation to, global climate change have become an important agenda in Indonesia. Since then, the government of Indonesia has begun to mainstream climate change mitigation and adaptation into its development planning system. Law No. 17 Year 2007 on 2005–2025 Long-Term Development Plan (GOI, 2007) clearly states that Indonesia's long-term sustainable development will face threats from climate change. To elaborate this law, in November 2007, the Indonesian government published *RAN-MAPI* (National Action Plan in Facing Climate Change), which contains guidelines to coordinate multi-sectoral efforts in climate change adaptation and mitigation. In July 2008, *Bappenas* (National Development Planning Agency) also published a document titled "National Development Planning: Indonesia's Response to Climate Change". This document, besides being specially designed to sharpen and strengthen the 2004–2009 Mid-Term Development Plan (RPJM), also served as input for the 2010–2014 RPJM in the context of climate change adaptation. Furthermore, following up on President Susilo Bambang Yudoyono commitment to reduce greenhouse gases (GHGs) emission at the G-20 Meeting in 2009, in Pittsburgh, USA, the government issued Presidential Regulation No 61 of 2011 on National Action Plan for Reducing GHGs emission. In the context of adaptation, the Indonesian government has also published the National Action Plan on Climate Change Adaptation in 2014. Recently, the Nationally Determined Contribution (NDC) has been enforced, as part of the 2015 Paris Agreement, which has been ratified through Law No. 16 of 2016. It consists of adaptation and mitigation measures towards climate change. The mitigation target of NDC for Indonesia is the reduction of emission up to 29% if using domestic resources and 41% if there is support from the international community compared to business as usual condition by 2030.

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1.1. Background

In the context of integrating climate change mitigation and adaptation into planning in Indonesia and to further elaborate the various climate change related policies mentioned above, *Bappenas* has published the "Indonesia Climate Change Sectoral Roadmap or ICSSR" in March 2010. This document contains a sectoral roadmap program of Climate Change Mitigation and Adaptation for a 20-year period to mainstream climate change issues into the 2010–2014 Mid-Term Development Plan (RPJM) onward, and into related Strategic Plans of ministry and non-ministerial agencies. One of the Bappenas (2010) main recommendations is to plan the future land use of the northern coast of Java to control land conversion into urban areas, from either agriculture or forestry. However, the National Spatial Plan and several further implementing plans such as the spatial plans of Java contain policies for further concentrating major investment along the northern coast of Java. Jakarta, Semarang, and Surabaya are appointed as "Center for National Activity (CNA)" based on Government Regulation (GR) 26/2008 on the National Spatial Plan and Presidential Regulation (PR) 28/2012 on the Java-Bali Island Spatial Plan.

Similarly, GR 26/2008 and PR 28/2012 designate their surrounding urban areas, called *Jabodetabek* (**Jakarta**-Bogor-Depok-Tangerang-Bekasi), *Kedungsepur* (Kendal-Demak-Ungaran-**Semarang**-Purwodadi), and *Gerbangkertosusila* (Gresik-Bangkalan-Mojokerto-**Surabaya**-Sidoarjo-Lamongan), as National Strategic Urban Regions. In effect, for an example, the Spatial Plan of Central Java 2009–2029 allocates the northern coastal corridor of Kendal-Semarang-Demak as an industrial zone. Similarly, the spatial plan of East Java 2011–2031 designates the coastal zone of Gresik, Surabaya, and Sidoarjo as an industrial area. These provincial plans, as a follow-up of the national policy, will accelerate regional economic development through urban expansion. However, such allocation could increase exposure to Global Sea Level Rise (GSLR) hazards as the existing land use of this coastal corridor is dominated by fishpond areas and mangroves.

Coastal systems constitute a dynamic interaction among sub-systems of natural processes and socio-economic, which have changed in form in reaction to geomorphological and oceanographical processes. Climate change is believed to influence the characteristics of climate parameters, which in turn change external marine and terrestrial influences (IPCC, 2007). Such global change has been seen to impose hazards that are mainly related to an increase in surface temperature, precipitation change, an increase in frequency and intensity of extreme weather events, and sea level rise, which is further exacerbated by environmental degradation.

Neumann et al. (2015) argue that coastal development, land use change, and urban expansion are important factors influencing an increase in exposure towards a combination of current hazards and sea level change. The urban expansion along the coastline has brought economic benefits. However, such development trend also further burdens coastal ecosystems causing serious environmental degradation as emphasized by Curran et al. (2002) that the function of coastal ecosystems as an ecological services provider, is not always compatible with other competing multiple uses of settlements, industries, and fishponds. On the other hand, for example, mangroves, which constitute 25 percent of tropical coastlines, could function as a buffer to reduce the threats from natural hazards such as storms and tsunamis as well as to provide nutrients for sustaining marine life (AAAS, n.d.). Therefore, coastal ecosystem degradation reduces its capacity to withstand hazards caused by both geological factors (e.g. tsunamis) and climate-related disasters such as global sea level rise.

This paper discusses the reinforcing trends that have been taking place in the urban centers and their surroundings along the northern coast of Java. Major investment, occurring for example in Jakarta, Semarang, and Surabaya have brought high economic growth, which in turn caused a high rate of migration, putting further pressure on the coastal ecosystems. In addition, anthropogenic climate change could further escalate the magnitude of coastal hazards. These hazards could offset the economic benefit of the developments in the region.

The northern coast of Java has been classified as the main economic corridor of Indonesia (Dardak, 2012). This is supported by Kuncoro (2013), who concluded that the share of employment and the output value of large and medium industries of Greater Jakarta and Greater Surabaya, which locate most industries along the northern coast of Java, are respectively 53.3% and 64.3% of the total for the whole of Java. According to Tan et al. (2016), the contribution of the secondary sector into the GRDP in Java in 2011 reached 36.48% and the tertiary sector was 52.06%. Regarding the secondary sector, the manufacturing industry is mostly located in Bekasi, Cikarang, and Tangerang (see Fig. 2), but also in East Java, e.g. the shipping industry in Surabaya. The main transportation occurs through road and rail networks along the northern coast of Java, which requires maintenance costs of around IDR 1.8 Trillion per year (Tan et al., 2016). The international seaports of Tanjung Priok, Tanjung Perak, and Tanjung Mas are also located along the northern coast of Java.

Given the above issues, the questions to be addressed in this paper are:

(1) To what extent do the coastal hazards at the baseline period (2010) threaten existing development?
(2) To what extent would the projected coastal hazards threaten planned land use in the future (2030)?
(3) To what extent do the current spatial plans reduce the exposure towards coastal inundation and how much is the potential economic loss of the damage exposure?

1.2. Global sea level rise and its impacts on coastal development

Global warming is considered to cause sea level rise (SLR) which could stem from the thermal expansion and the melting of glaciers and ice in the North and South Poles. IPCC (2007) reports that thermal expansion contributed about 0.42 mm per year (1961–2003) and ice melting contributed 0.68 mm per year (1961–2003), a total increase of 1.1 mm per year in the period of 1961–2003. Furthermore, from 1993 to 2003, thermal expansion added around 1.6 mm per year and ice melting 1.2 mm per year. Therefore, the total climate change contribution to SLR was 2.8 mm per year in the period of 1993–2003 (IPCC, 2007). In addition, IPCC (2014) reports that the average rate of global sea level rise was 1.7 mm/year from 1901 to 2010 and 3.2 mm/year from 1993 to 2010.

Several recent researches show an accelerating process of ice melting along with intensifying global warming. SLR due to global warming is projected to reach 35–40 cm in 2050 relative to the year 2000 (Bappenas, 2010), and by using IPCC-AR 5 modeling reaches up to 48 cm in 2050 (Sofian, 2015). Based on a scenario of RCP 8.5 in the period of 2081–2100, the rate of SLR would be 8 to 16 mm/yr (IPCC, 2014). Along with the increasing global warming, the frequency of ENSO (El Niño and La Niña) also increases (Timmermann et al., 1999). Bappenas (2010) projected that the frequency of ENSO in Indonesia from 2000 to 2020 will increase to every 2 years, based on sea surface data of the Java Sea and IPCC modeling.

According to Aldrian et al. (2012) based on NOAA's record from 1970 to 2009, there have been 4 (10%) strong El Niño (1972-73, 1982-83, 1991-92, 1997–1998) and 3 (8%) strong La Niña (1973-74, 1975-76, 1988-89) occurrences. Cai et al. (2014), using climate modeling data, project the frequency of extreme El Niño events due to greenhouse warming to double. Major forest fires mainly occurring in Sumatra in 2015 is correlated with extreme El Niño. Similarly with the smoke haze disaster in 1997/1998, which partly was reinforced by a prolonged drought related to extreme El Niño (Tangang et al., 2010). Similarly, during a La Niña event sea level rises as high as 20 cm, causing floods along coastal regions (Sofian, 2015). Moreover, referring to Wilson and Piper (2010), climate change impact along coastal areas is a combination of flood risk from rivers and sea level rise, which could increase exposure to transport networks, residential and industrial areas; and coastal aquacultures.

1.3. The role of spatial planning for climate change adaptation

To date, there has been a growing recognition that spatial planning has an important role in addressing both sources and impacts of climate change. The need to integrate climate change adaptation into spatial planning has been recognized for more than 10 years (Bajec, 2011). Adaptation to climate change is defined as "adjustment in natural or *human systems* in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities" (IPCC, p.6, 2007). Carter and Sherriff (2011, p.9) argue that "in relation to adaptation responses, spatial planning's main role is to zone urban areas, permitting or discouraging certain land uses". Therefore, spatial planning could increase the adaptive capacity of a city through conserving land, which has a role for adaptation and decreases the exposure of development to hazards caused by climate change (Carter and Sherriff, 2011).

The spatial plans can provide guidance on future urban form in response to impacts of climate change. Roggema (2009, p.61) states that "spatial planning can be a very powerful tool to spatially shape climate proof regions". In addition, the essence of planning practice is knowledge of present conditions and an ongoing orientation to seeking future improvements while avoiding emergent problems. This highlight the potential of planning to deal with adapting to climate change impacts (Hurlimann and March, 2012).

The spatial configuration of cities and towns and the way in which land is used and developed have significant impacts on the vulnerability of cities to the effect of climate change and will be central to enacting adaptive responses to this change (Davidse et al., 2015). Furthermore, Hurlimann and March (2012) find that land use planning has been identified as the most effective tool to reduce exposure and sensitivity to extreme weather events in many instances.

2. Materials and methods

The methodology of this study is divided into two main stages, i.e. (1) Mapping Coastal Inundation along the Northern Coast of Java, and (2) Assessing the Role of Spatial Planning in Reducing Exposure toward Coastal Inundation and Damage Exposure Estimation. The methodological framework of this research is illustrated in Fig. 1. Meanwhile, both stages are explained in detail in subsection 2.2 and subsection 2.3.

2.1. Study area

As stated before, this study focuses on the northern coast of Java. This is not an administrative area but rather a corridor comprising cities and regencies located along Java's northern coast directly adjacent to the Java Sea. The study area stretches from Cilegon City in the west to Situbondo Regency in the east. The area is incorporated into five provincial administrative regions consisting of Banten, Capital Special Region (CSR) Jakarta, West Java, Central Java, and East Java. For the record, CSR Jakarta is excluded from the analysis because the government of Jakarta plans to reclaim Jakarta's northern coast (this is already under construction) and to build a huge offshore seawall in the Jakarta Bay. Both projects will significantly modify the regional oceanographic characteristics of the Jakarta Bay, which could cause more complex impacts than merely coastal inundation. The scope of the study area can be seen in Fig. 2 below.

According to Suroso et al. (2009), planning can be divided into three scales, i.e. the macro, meso, and micro scales with their respective national, provincial, and regency/city scopes. This scale of planning is in line with Law No. 26 Year 2007, which hierarchically divides the spatial plan into national, provincial and regency/city plan levels. Furthermore, there are also island spatial plans and national strategic area spatial plans that function as detailed plans of the national spatial plan.

In relation to the scale and hierarchy of planning, the northern coast of Java is included in macro-scale planning (national) and regulated in the detailed spatial plan of the Java-Bali Island Spatial Plan as stipulated in Presidential Regulation No. 28 Year 2012. The spatial structure plan is enacted to establish the Center for National Activity (CNA), which is primarily located on the northern coast of Java. This CNA is envisioned to strengthen the function of the primary arterial road network connecting the entire northern coast of Java, as well as optimizing existing railway lines in the region. Meanwhile, this Presidential Regulation aims to optimize and develop industrial estates into areas designated as Center for National Activity.

Although the study area is on the macro scale, the depth of analysis of this study covers the provincial and even district/city administrations because each region has its own characteristics. Since the geographical, social, economic, and urban-rural characteristics of each region are unique, the exposure of coastal inundation hazards will be different in each region. Therefore, the results of this study could be used for recommendations to revise the Java-Bali Island Spatial Plan as macro analysis unit and for each provincial spatial plan as meso analysis unit.

2.2. Mapping Coastal Inundation along the Northern Coast of Java

2.2.1. General consideration of climate change impacts on coastal hazards

Climate change is understood to affect global sea level rise. Global sea level rise needs to be added with other local factors to calculate the cumulative effect. This is because "one climate change factor alone may not produce significant impacts, but multiple impacts can result in a failed system" (USACE, p. 2–8, 2014). According to New Zealand-CCO (2004), changes in sea level are caused by a combination of three main components, i.e. global average eustatic or absolute sea-level rise, departures from the global average in different sub-regions of the world's oceans, and local vertical land movements. In addition, climate change will also affect other physical drivers influencing coastal hazards, as stated by New Zealand-CCO (2004, p.1) that "climate change will not introduce any new types of coastal hazards, but it will affect existing coastal hazards by changing some hazard drivers". In general, the impacts of climate change on the physical drivers influencing coastal hazards are illustrated in Fig. 3.

2.2.2. Determination of the inundation scenarios

Coastal inundation hazards are the accumulation of various parameters of hazards. Coastal inundation hazards are obtained through the analysis of a coastal dynamics model that represents the cumulative various inundation hazards that may occur in coastal areas according to certain scenarios. Sea level elevation is not only affected by sea level rise but also by various elements such as tides, wind-waves, ENSO variability, and tsunami (see Fig. 3). Therefore, coastal inundation hazards largely depend on the proposed inundation scenario, which consists of the accumulation of various coastal hazards. Simple coastal inundation scenarios can be developed using the following mathematical model.

$$H = \sum_{i=1}^{N} h(i)$$

where:

H = the height of coastal inundation hazard above the mean sea level
H(i) = the height of each element of coastal hazard involved in an inundation scenario
N = the number of hazards involved in an inundation scenario

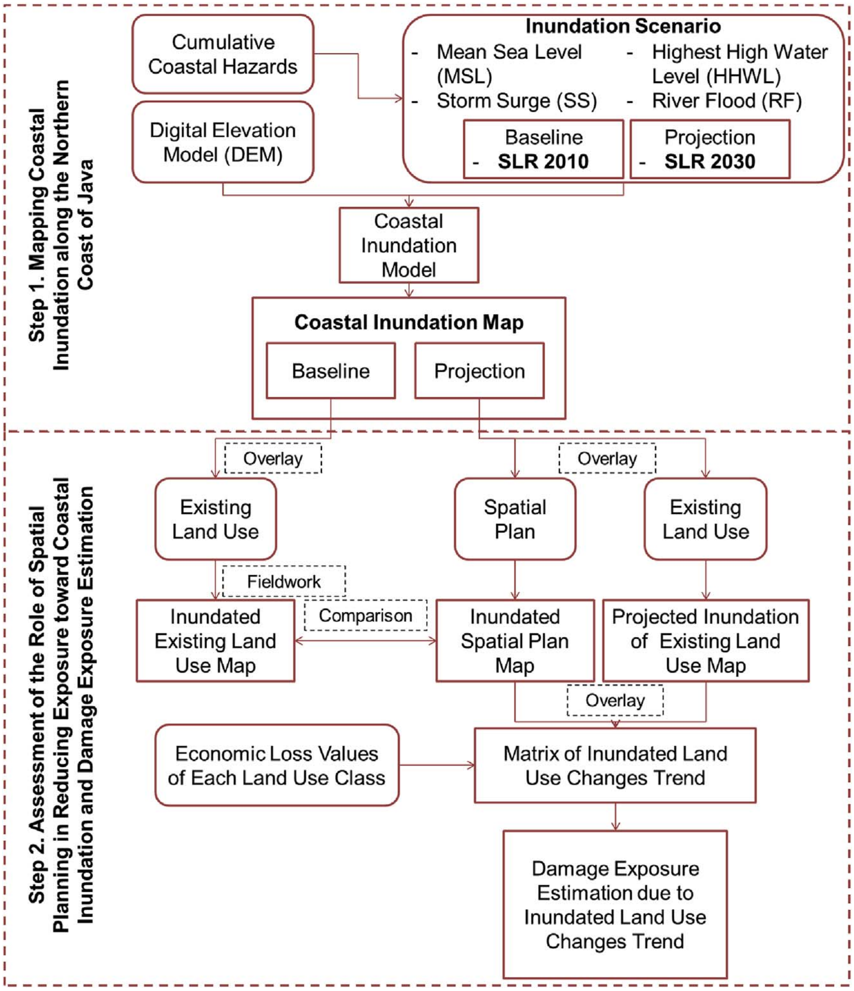

Fig. 1. The Framework of Research Methodology.

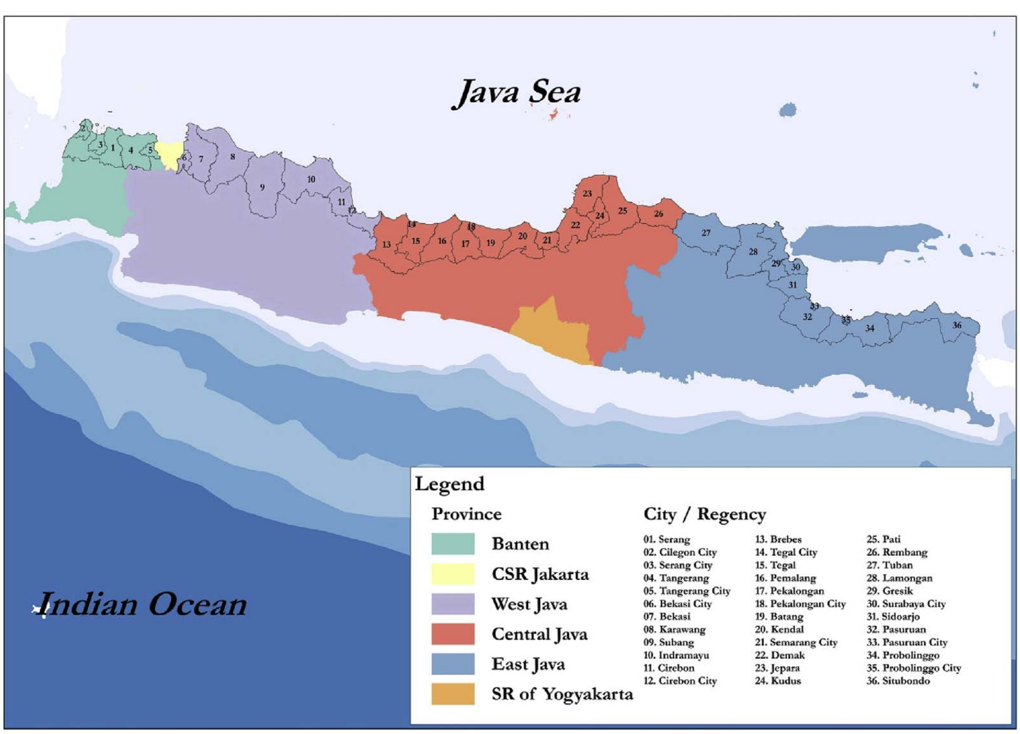

Fig. 2. Location Map of Study Area.

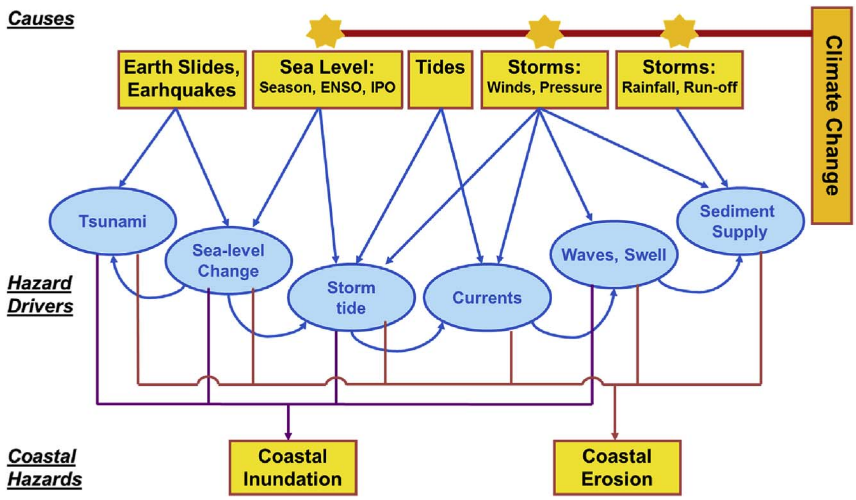

Fig. 3. Summary of Climate-Related Coastal Hazards (New Zealand-CCO, 2004).

Table 1
Data Used for Each Hazards Component.

Components of Hazard	Baseline (2010) of Cumulative Sea Level (cm)	Projection (2030) of Cumulative Sea Level (cm)	Sources of data
MSL monthly variance	3.4	3.4	Latief, 2015
HHWL Tides	40.27	40.27	Latief, 2015
SLR	7	21	Sofian, 2015
SS	41	41	Sofian, 2015
RF	100	100	Latief, 2015
Total	**191.67**	**205.67**	

This study includes the following hazard components in a coastal inundation scenario i.e. MSL (Mean Sea Level), HHWL (Highest High Water Level) Tides, SLR (Sea Level Rise), SS (Storm Surge), and river flood (RF). It is assumed that these hazard components accumulate and cause coastal inundation along the northern coast of Java. Table 1 summarizes the data used for each component of coastal hazards with their data sources.

The trend analysis of historical data shows that the average sea level rise in Indonesia increases from 0.7 cm to 1.1 cm per year (Sofian, 2015). Long-term estimations of the average sea level rise in Indonesia are as follows: 2030: 21–33 cm; 2050: 35–55 cm; and 2100: 70–110 cm (Sofian, 2015). Table 1 shows that the scenarios developed in this study consist of a baseline scenario and a projection scenario. The difference between the two scenarios lies in the SLR hazard component, which has a 7 cm sea level baseline and 21 cm for the projection scenario.

2.2.3. The use of digital elevation model

The Digital Elevation Model (DEM) is one of the input data for the model of coastal inundation. The DEM used in this study was processed from raw data of Digital Surface Model (DSM) Terra Synthetic Aperture Radar (TerraSAR) with a resolution of 5 meters for Java in 2014, provided by BIG (Agency for Geospatial Information). These DSM data were then corrected into Digital Terrain Model (DTM), which shows the surface without canopies of plants and buildings, to be used as input data for the coastal inundation model. For this scale of study (macro level), the elevation throughout the study area was assumed to be unaffected by the local land subsidence because the subsidence rate on the northern coast of Java will vary, thus, the DEM used for projected inundation was the same as the DEM in the baseline scenario.

2.2.4. Developing coastal inundation model

The Coastal Inundation Model was developed using the bathtub model. This model was used because “most sea level rise (SLR) vulnerability assessments are undertaken using the easily implemented bathtub approach, where areas adjacent to the sea and below a given elevation are mapped using a deterministic line dividing potentially inundated from dry areas” (Leon et al., p.1, 2014). The bathtub model functions by “treating the ocean like a bathtub that fills up the same way that a tub does when you add water” (Mulin and French, para.3, 2015). Similarly, in this study, coastal inundation maps were generated using DEM data and the cumulative sea level data as specified in Table 1.

As outlined above, in relation to the impact of climate change on coastal regions, there are two kinds of hazards, i.e. coastal inundation and coastal erosion. However, due to the small scale of the flooding model, the resulted map only shows coastline retreat. It is impossible to differentiate whether the coastal retreat was caused by erosion or flooding. Therefore, observation is needed through field surveys along the northern coast of Java, supported by in-depth interviews with key informants and secondary data to identify whether the coastline retreat was caused by inundation or erosion.

2.3. Assessment of the role of spatial planning in reducing exposure toward coastal inundation and Damage Exposure Estimation

Three main analysis approaches assess the role of spatial plans in reducing the exposure and estimation of damage of exposed land as follows.

2.3.1. Analysis of coastal inundation exposure to the existing land use and planned of land use

The first step in assessing the role of spatial planning in reducing coastal inundation exposure is by identifying the exposure level for two conditions, namely the baseline and the projection conditions.

In general, this assessment uses overlay analysis using a GIS tool, with the level of analysis up to the regency/city level. For the baseline condition, the coastal inundation map, which has been produced in the previous analysis, is overlaid on the existing land use map provided by the Geospatial Information Agency (BIG). In addition to land use, the inundation exposure map is also overlaid on the map of national road provided by the Ministry of Public Works, in order to determine the extent of coastal inundation that has already affected existing developments. The result of this overlay analysis is verified by field observations in several sites of the case study area. Meanwhile, for the projection condition, the future coastal inundation map is overlaid on the map of land use plan respectively of the Spatial Plan of Banten

2010–2030, Spatial Plan of West Java 2009–2029, Spatial Plan of Central Java 2009–2029, and Spatial Plan of East Java 2011–2031. This shows the extent to which the projected coastal hazards potentially threat planned land use.

The next stage of the study is to compare the results of both conditions in order to see the change in the extent of inundation for each type of land use that is analyzed, either on the provincial and district/city level. Up to this stage, the changes in the level of coastal inundation exposure are only seen based on the increase of the area of the inundation, while the next stage of analysis will demonstrate the role of spatial planning for these changes.

2.3.2. *Trend analysis of changes in inundated land use*

To assess the role of the spatial planning in reducing the exposure toward coastal inundation, an in-depth analysis of inundated land-use change was conducted. This analysis consists of three steps as follows. Firstly, the projected inundation is overlaid with planned land use. Secondly, the projected inundation is overlaid with the existing land use. Finally, both are overlaid using the intersect tool to determine the change from one type of inundated existing land use into other types of inundated planned land use, the result of this process is then presented in the matrix of change. This makes it possible to identify to what extent spatial plans influence the increase of exposure toward coastal inundation. The matrix of change resulted from this step then will be used for estimating the damage exposure.

2.3.3. *Estimation of damage exposure due to change of land uses which are prone to future inundation*

The purpose of a Damage Exposure Estimation is to provide an indicative future economic loss due to land use change from non-built-up into built-up areas. The economic value of built-up areas is higher than non-built-up areas; however, from the perspective of potential damage due to disasters, which is used for this paper, damage exposure is interpreted as the potential economic loss (Ward et al., 2010; Purnama et al., 2015). As an example, when coastal land is initially used for fishponds, due to changes of spatial plans is used for industry, then the economic value of the land would increase. Ward et al. (2010) simulated that the changes from non-built up area to built-up area would increase the damage exposure caused by coastal inundation since the built-up areas, such as industry and settlement, have higher land value compared to non-built up areas. However, if in the future the industry experiences coastal flooding, there would be an economic loss of the same as monetary value of industrial land.

Step 1. Determining the Approach and Standard of Land Value for Damage Exposure Estimation

This paper uses an approach developed by ELDI (Economic Land Degradation Initiative, 2015) which describes a method of comprehensive TEV. However, the calculation of the future economic value in this paper focuses only on the use value (excluding non-use value) based on the market value of each type of land use. This is done because the objective is to provide the indicative monetary value of damage that could be avoided if the land use is not converted. There are four types of land use i.e. fishponds, agriculture, settlements, and industry. The standard value for settlements is based on the market value in 2010 taken from DBS Research Group (2016) which was 23.6 billion IDR per Ha. The market value for industrial land use is based on Bachdar (2017) data and this paper uses an industrial land price of 21.1 billion IDR per Ha. The standard value of agricultural land (0.9 billion IDR) and fishponds (1.1 billion IDR) is based on Ward et al. (2010).

The future value of land for the projection year of 2030 uses the below formula based on LaDue (p. 3, 1993) who defines that “future value techniques are designed to determine the value of an amount, or series of amounts of money as of some fixed point in time in the future”.

Table 2
Standard Value of each Land Use Type.
Step 2. Estimating Damage Exposure due to Trend of Inundated Land Use Change

Land Use Class	Value per Ha (million USD)
Settlements	5.2
Agriculture Areas	0.2
Industrial Areas	3.2
Fishponds	0.2

$$FV = PV\,(1 + i)^n$$

Notes: FV = Value in period n (n periods in the future)
PV = Value in period 0 (now)
i = Interest rate per conversion period
n = Number of conversion periods

The interest rates for the period of 2010–2016 are based on the published rate of the Central Bank of Indonesia (BI), which is available on their official website (BI, 2016). For the period of 2017 onward, the interest rate is assumed flat and is based on the Decision of the Governor Board, which is 4.75% per year (Setiawan, 2017). These standard values are then converted to USD with exchange rate of 13.000 IDR. The standard value for calculating the future economic value of each land use class in 2030 is presented in Table 2.

The damage exposure is estimated by multiplying the standard value with the total area of each type of land use that according to the inundation model would experience flooding. The total area of each land use type is calculated based on the difference of area of each inundated land use type between baseline (2010) and projection (2030) conditions.

To assess whether the change in the area size of each type of land use in accordance with provincial spatial plans would reduce the level of exposure towards coastal flooding in 2030, Delta Damage Exposure Estimation (DDEE) is applied using two scenarios:

1. Scenario 1: Damage Exposure Estimation (DEE) based on Spatial Plan. It is assumed that future land use would dominantly reflect the land use designated by provincial spatial plans. Thus, the future standard value of each planned land use is multiplied by the area of each planned land use to calculate the potential damage exposure.
2. Scenario 2: Damage Exposure Estimation (DEE) based on Existing Land Use. It is assumed that future land use would remain similar to existing land use. Thus, the future standard value of each future land use is multiplied by the area of each existing land use to calculate the potential damage exposure.

Delta Damage Exposure Estimation then is calculated using the following formula:

$$DDEE = DEE\ based\ on\ Spatial\ Plan - DEE\ based\ on\ Existing\ Land\ Use$$

The interpretation of the results is as follows, if DDEE > 0, then the implementation of provincial spatial plans would cause economic loss due to exposure towards coastal inundation, and if DDEE < 0, then the implementation of provincial spatial plans would provide economic gain due to reduced exposure towards coastal inundation.

3. Results

3.1. *Potential impacts of coastal inundation on the existing land uses and land uses based on the provincial spatial plans along the Northern Coast of Java*

Comparison of coastal inundation along the northern coast of Java for the period of 2010 (282,962 ha) and 2030 (300,774 ha) shows an

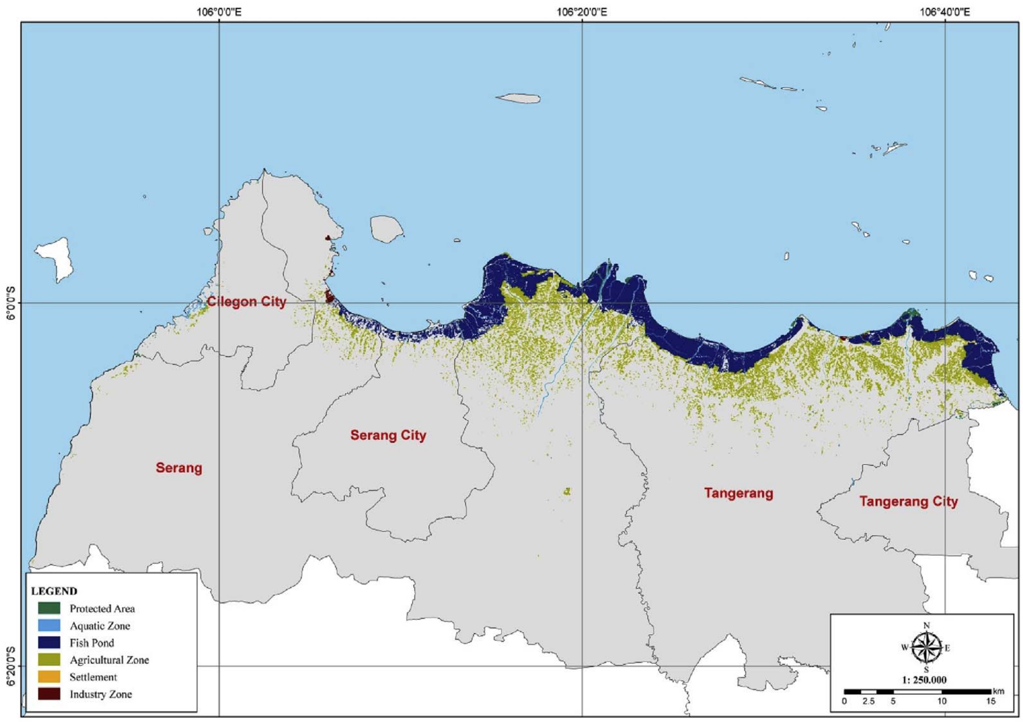

Fig. 4. Inundation of Existing Land Use in Banten.

increase of 17,812 ha. West Java may experience the largest coastal inundation, as well as the highest increase from baseline to projection conditions. At the regency/municipality level, the largest increase will be experienced by Karawang Regency, Indramayu Regency, and Bekasi Regency.

Fishpond area was the widest inundated land use along the northern coast of Java, located in Banten (11,435 ha), West Java (41,555 ha), Central Java (34,244 ha), and East Java (49,273 ha). The second largest inundated land use was agricultural land, spread over Banten (10,129 ha), West Java (69,926 ha), Central Java (28,113 ha) and East Java (6743 ha). The two largest coastal flooded industrial area were found in West Java (2,466ha) and East Java (2226 ha), at the regency/municipality level, the two largest inundation were in Surabaya City (1138 ha) and Indramayu Regency (849ha). In terms of settlement area, the widest was also experienced by West Java (3,106ha).

The overlay maps of projected coastal inundation and spatial plans shows that the land allocated for industrial areas which will be flooded in Banten is about 8746 ha, in Central Java 3069 ha, and in East Java 2820 ha. Inundated areas which are planned for settlement would be located in Banten (938 ha), West Java (33,500 ha), Central Java (7864 Ha) and East Java (5893 Ha).

3.1.1. Northern coast of Banten

Fig. 4 shows that the largest inundated land use in Banten is fishponds (11,435 ha), followed by agriculture (10,129 ha), protected areas (393 ha), settlements (152 ha), and industry (138 ha). The two largest inundations of fishpond areas occurred in Serang Regency and Tangerang Regency. Field observations and time series analysis of satellite images conducted by BLHD Banten (2016) shows that from 1995-2015, Tangerang Regency had lost around 580 ha of fishpond and mangrove areas due to coastline retreat, so that the rate of coastline retreat was 29 ha/year. The highest lost occurred in Ketapang Village, Mauk District which was 5.4 ha/year. The mangrove areas in Tangerang Regency has also decreased significantly from 487.5 ha in 1996 to 79.1 ha in 20016 (BLHD Banten, 2016).

For settlement land use, the two largest inundated areas were found in Tangerang Regency and Serang Regency. Inundation map for Tangerang Regency resulted from the model is in accordance with the data from the Ministry of Public Work that, on January 17, 2014 coastal flooding occurred in Dadap Village, Kosambi District (KPUPR, 2014).

Table 3 shows that the amount of potentially inundated industrial area in Serang Regency will significantly increase from 109 ha to 8420 ha. The largest inundated agricultural land (10,049 ha) will be in Tangerang Regency, and for the future settlement area which will experience the widest inundation (553 ha), located in Serang City.

3.1.2. Northern coast of West Java

Based on the inundation model, Fig. 5 shows that in West Java, 2466 ha of the total existing industrial zone was flooded, spreading along Bekasi, Karawang, Subang, Indramayu, and Cirebon Regencies. The three largest inundated industrial areas were located in the regencies of Indramayu (849 ha), Karawang (781 ha), and Cirebon (642 ha). In Bekasi, Power Plant of Muara Tawar together with other industrial activities at Marunda Center (around 200–500 m from coastline) form zones which were flooded by coastal inundation for the period of baseline, The largest amount of inundated settlement areas occurred in West Java with total of 3106 ha, including Subang Regency (2051 ha) and Karawang Regency (476 ha). In Subang, in Districts of Blanakan, Sukasari, and Legon Kulon, the average rate of erosion from 1996 to 2010 was 40.4 m/year, caused by conversion of mangroves, and happened along17.15 km of coastline (Taofiqurohman and Ismail, 2012). Abrasion can also be observed at the tourism site of Pondok Bali, Mayangan Village, Subang. Comparing coastlines of 2002 and 2011 shows a retreat of about 200–300 meter which is confirmed to be partially contributed to climate change (Archiari et al., 2015). In Karawang Regency, the largest coastline retreat was experienced by District of Cibuaya with the rate of 44 ha/year which caused loss of houses (Heriati et al., 2012). In Bekasi Regency, a coastal segment of the Village of Harapan Jaya, Muara Gembong District has experienced the most serious coastal flooding with the characteristics of the height (10–30 cm), length of inundation (3–12 h/day) and happened less than 14 days per month (Rosemarry, 2014). Similarly, on August 1, 2016, coastal flood impacted a rural settlement of 400 houses in Eretan Wetan Village, Kandanghaur District, Indramayu Regency.

In West Java, the largest inundated fishpond is found in Karawang Regency, sized 14,736 ha and around 10,000 ha in Indramayu. The

Table 3
Coastal Inundation for the Period of Baseline and Projection in Banten.

Area/Region	Inundated Area per Land Use Class (Ha)									
	Industry		Protected Area		Fishpond		Settlement		Agriculture	
	B	P	B	P	B	P	B	P	B	P
Cilegon City	–	26	30	29	–	–	1	197	144	–
Serang City	–	90	2	62	470	–	12	553	654	19
Tangerang City	–	29	1	–	–	–	–	–	12	–
Serang Regency	109	8420	149	556	5805	–	51	188	10,377	2096
Tangerang Regency	29	181	211	1995	5159	–	88	1	11,059	10,049
Total	**138**	**8746**	**393**	**2642**	**11,434**	**-**	**152**	**939**	**22,246**	**12,164**

Notes: B = Baseline (2010).
P = Projection (2030).

model has been verified by the occurrence of coastal flooding from 8 to 11 January 2017 of around 700 ha of fishpond at the Waledan Block, Lamarantung Village, Cantigi District, Indramayu Regency. In Cirebon Regency, Rositasari et al. (2011) based on sedimentary budget analysis and geophysical survey concluded that most coastline of Mundu District was eroded causing loss of fishpond and saltpond as well as seawater intrusion.

In terms of land transport infrastructure, the longest inundated primary arterial road was 8.14 km and was located in Indramayu Regency. Based on field observations, some sections of the primary arterial road have experienced significant coastal erosion, for an example, at Kertawinangun Road, Eretan Kulon District, Indramayu Regency.

Table 4 shows that in West Java, the largest future land use that will experience inundation is agriculture land with 67,623 ha, mostly located in Karawang and Indramayu regencies. Around 33,500 ha of settlement areas will be inundated, expanding along the regencies of Bekasi, Cirebon, Indramayu, Karawang, and Subang, with the largest potential inundation in Indramayu Regency (10,310 ha).

3.1.3. Northern coast of Central Java

In Central Java, the largest flooded fishpond was located in Brebes Regency (8826 ha). Based on coastline change analysis using satellite images and observation on April 13–14, 2017, there was retreat of 513ha from 2003 to 2016 in the villages of Kaliwlingi, Randusanga Kulon and Randusanga Wetan, Brebes District. In Pekalongan Regency, on May 27, 2016, around 5937 houses were flooded in the Districts of Tirto, Wiradesa, Wonokerto, and Siwalan as well as 891 persons were evacuated to 11 shelters (BNPB, 2016). Field observations on July 14, 2016 confirmed that for example, in Api-Api Village, Wonokerto District, many houses and village roads had been flooding at about 30–50 cm for around three months. A local inhabitant, Rasmin (56 years old), said that this is the worst coastal flooding since he was born there. Similarly, in Semarang City, based on observations on June 8, 2016, Kaligawe, Genuk, and Kemijen Villages experienced the worst inundation in 5 years (see Fig. 6).

Furthermore, in Semarang City, flooded primary arterial road accounted for 0.49 km. This was verified in early June 2016 along Kaligawe road, when this primary arterial road to Demak Regency was seriously flooded, causing traffic congestion. Rail networks have already been submerged by coastal inundation with a length of 6.2 km from Semarang Tawang Station to Muktiharjo Station and Alastuo Station, on February, 22 of 2013, causing flooding up to 16 cm and traffic disruptions (KAI, 2013). Several facilities in Tanjung Mas seaport

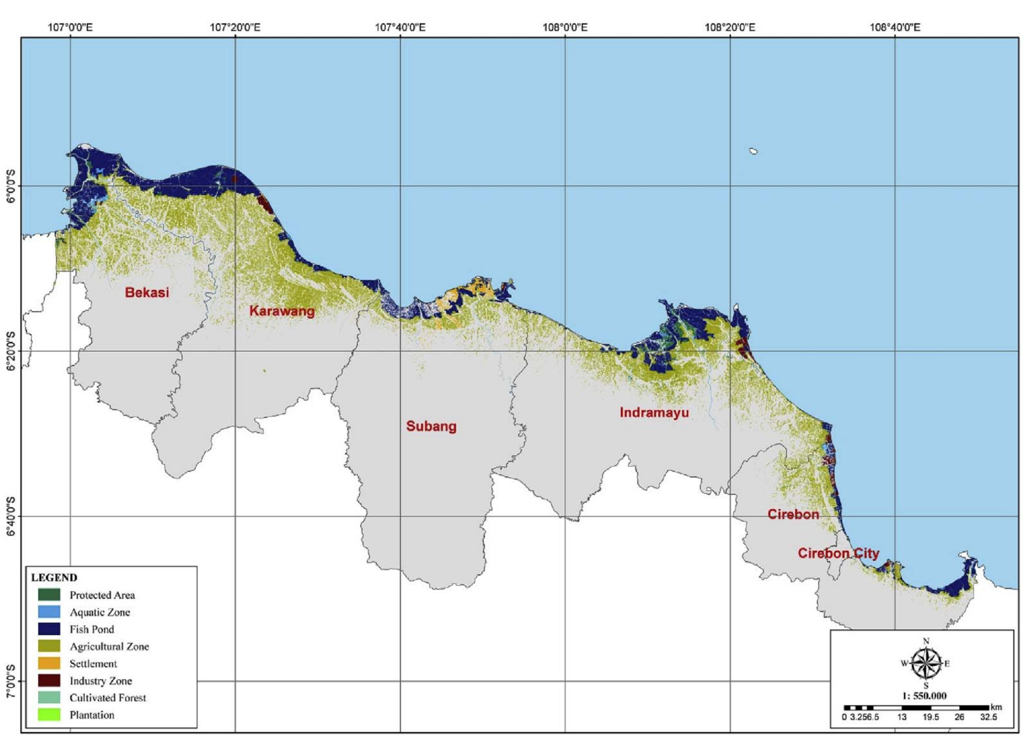

Fig. 5. Inundation of Existing Land Use in West Java.

Table 4
Coastal Inundation for the Period of Baseline and Projection in West Java.

Area/Region	Inundated Area per Land Use Class (Ha)											
	Industry		Protected Area		Fishpond		Settlement		Agriculture		Water Body	
	B	P[a]	B	P	B	P	B	P	B	P	B	P
Bekasi City	–	n/a	10	–	–	–	2	37	18	–	–	–
Cirebon City	–	n/a	20	–	53	–	10	111	15	–	–	1
Bekasi Regency	67	n/a	532	5480	8876	–	208	4759	9800	6258	–	501
Cirebon Regency	642	n/a	123	–	3873	–	69	6310	5644	5252	–	168
Indramayu Regency	849	n/a	2244	6236	9758	–	288	10,310	21,033	20,869	–	782
Karawang Regency	781	n/a	282	8465	14,736	–	476	8852	27,820	29,056	–	296
Subang Regency	126	n/a	1	3638	4259	–	2051	3121	5596	6188	–	253
Total	**2465**	n/a	**3212**	**23,819**	**41,555**	**-**	**3104**	**33,500**	**69,926**	**67,623**	**-**	**2001**

Notes: B = Baseline (2010).
P = Projection (2030).
[a] Spatial Plan of West Java 2009–2029 does not specify the areas for industry. The plan only indicates the industrial areas in the form of point. Therefore, it is impossible to calculate the projected amount of inundated industrial land use.

have also been permanently submerged, hampering the facility's functioning. In Rembang Regency, the primary arterial road has experienced coastal abrasion in several sections, such as along Kragan Road with a length of about 400 m eastward from the coordinate of 6.63 southern latitude, 111.53 west longitude.

As can be seen in Table 5, industrial areas in Central Java will experience an increase of coastal inundation from 1173 ha to 3069 ha and the largest inundation will occur in Demak (1949 ha). Demak Regency will also experience the largest flooding for settlement areas within Central Java (1659 ha).

3.1.4. Northern coast of East Java

As seen in Fig. 7, the two largest inundated fishponds in East Java were located in Gresik (16,381 ha) and Sidoarjo (15,434 ha). In Gresik, using landsat images, it was found that the areas experiencing the fastest abrasion are Tanjungwidoro, Bedanten, and Bungah Villages, District of Bungah with the rate of 22 m/year (Sulma et al., 2012).

In Surabaya City, based on a survey by Muklis (2011), the tidal flood happened on 11–13 of July 2010 in Pabean Cantikan District, with an elevation of 1.7 m above sea level (asl) or about 0.3–0.35 m above the streets of Kebalen Wetan. In the Krembangan district, on 22 December 2010, the depth of coastal flood was around 1.4 m asl or 0.6 m above land surface (Muklis, 2011). According to Prawira (2015), on May 25, 2013, coastal flood reached Morokrembangan Village, north of Surabaya and impacted 400 houses. He also reported that on July 15, 2010, tidal flood spread over a residential area in Perak Barat Block with a depth of 30 cm.

In East Java, the longest section of inundated primary arterial road was found in Tuban Regency (1.80 km), which has been verified by field observation. A section of this strategic road has been eroded as observed in Sukolilo Village, Bancar District (6.77 SL, 111.7 WL). A similar occurrence was observed at coordinate 6.9 SL, 112.1 WL in Gesik Harjo Village, Palang District, Tuban Regency. In Lamongan Regency, erosion was observed from 6.87 SL, 112.30 WL in Blimbing Village until 6.87 SL, 112.38 WL in Kranji Vilage, Paciran District. In Surabaya City, based on the model, this city has the second longest inundated primary arterial road in East Java (1.78 km). It was flooded 30 cm depth along Tambak Osowilangun street, 7.23 SL, 112.68 WL on

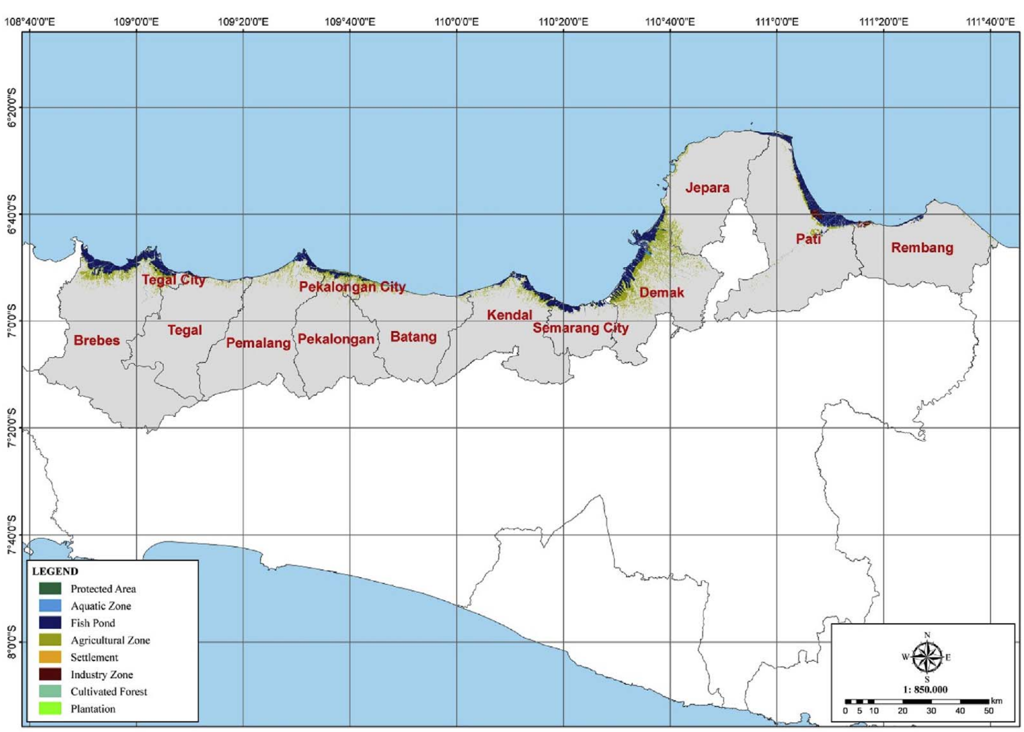

Fig. 6. Inundation of Existing Land Use in Central Java.

Table 5
Coastal Inundation for the Period of Baseline and Projection in Central Java.

Area/Region	Inundated Area per Land Use Class (Ha)											
	Industry		Protected Area		Fishpond		Settlement		Agriculture		Water Body	
	B	P	B	P	B	P	B	P	B	P	B	P
Pekalongan City	–	31	30	72	193	167	164	581	792	382	–	65
Semarang City	–	805	168	28	1954	537	52	402	256	860	–	–
Tegal City	–	–	20	36	351	–	18	607	355	212	–	–
Batang Regency	–	176	21	109	244	8	36	404	1173	897	–	3
Brebes Regency	–	–	121	609	8826	5471	39	794	4426	6720	–	1075
Demak Regency	1	1949	327	734	6254	2929	127	1659	11,035	12,078	–	614
Jepara Regency	–	4	57	273	1238	1122	12	499	2242	2130	–	30
Kendal Regency	–	2	35	331	2964	988	8	271	2111	3825	–	78
Kudus Regency	–	–	–	24	–	–	–	2	11	12	–	2
Pati Regency	736	–	3	794	8243	5731	147	1020	1778	3481	–	314
Pekalongan Regency	–	19	2	369	796	381	73	360	1239	1119	–	17
Pemalang Regency	3	2	12	309	2036	1041	27	360	1782	1934	–	388
Rembang Regency	427	–	40	195	681	604	8	320	280	385	–	1
Tegal Regency	6	80	2	130	465	–	14	558	634	489	–	15
Total	**1173**	**3068**	**838**	**4013**	**34,245**	**18,979**	**725**	**7837**	**28,114**	**34,524**	**-**	**2602**

Notes: B = Baseline (2010).
P = Projection (2030).

Dec 30, 2016, for a length of around 500 meters.

Based on the Spatial Plan of East Java (see Table 6), the three industrial areas which will experience the largest coastal flooding are located in Surabaya (823 ha), Sidoarjo (1021 ha), and Tuban (656 ha). In terms of settlement area, the three largest coastal floods will happen in Sidoarjo (935 ha), Gresik (913 ha), and Surabaya (822 ha).

It can be concluded that the coastal inundation map which resulted from the model is extensively well verified by observational and historical data in several locations from Banten to East Java. It is shown that combination of existing coastal hazards and sea level rise have already inundated industrial zones, settlements, agricultural areas and fishponds as well as primary arterial roads and railway networks.

3.2. Increase of exposure towards coastal inundation due to current spatial plans

Further analysis was done to assess the change from inundated existing land use to planned land use as determined by the spatial plans which will also be prone to inundation. As seen in Table 7, in Banten, inundation of land allocated for industrial areas is currently used as fishponds (5741 ha) and agriculture (2556 ha). Allocated land for settlement areas prone to coastal flooding will be converted from fishpond (357 ha) and agriculture (456 ha) uses.

In 2030 there would be potential total economic loss of around 28.6 billion USD due to land use change in Banten. The potential loss due to land use change from fishpond and agriculture to industry in Banten would be 24.5 billion USD. Interestingly, there is a positive trend of change from fishpond to protected area which potentially could provide

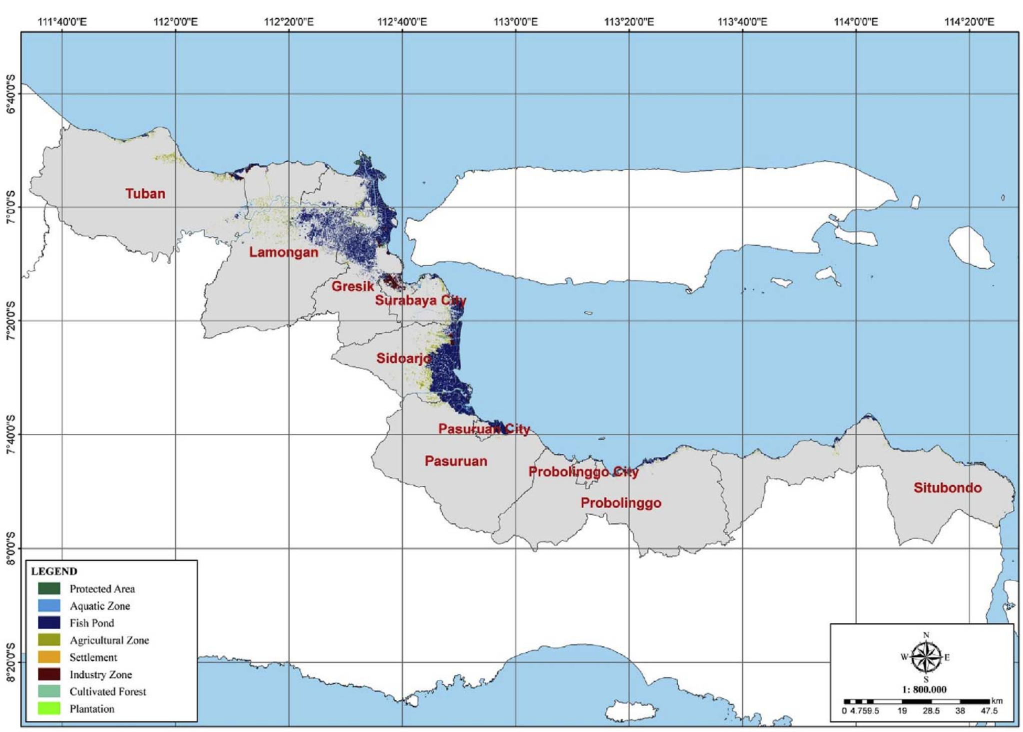

Fig. 7. Inundation of Existing Land Use in East Java.

Table 6
Coastal Inundation for the Period of Baseline and Projection in East Java.

Area/Region	Inundated Area per Land Use Class (Ha)											
	Industry		Protected Area		Fishpond		Settlement		Agriculture		Water Body	
	B	P	B	P	B	P	B	P	B	P	B	P
Pasuruan City	–	–	31	–	600	–	3	70	17	598	–	–
Probolinggo City	–	–	6	–	85	–	–	–	17	113	–	–
Surabaya City	1138	823	408	–	2485	720	69	822	418	2706	–	–
Gresik Regency	349	188	752	–	16,381	–	16	913	649	5851	–	–
Lamongan Regency	220	105	124	400	8065	–	47	1300	1781	9989	–	26
Pasuruan Regency	1	28	60	–	3550	892	13	654	203	2484	–	–
Probolinggo Regency	20	–	36	–	1204	–	30	364	228	1263	–	–
Sidoarjo Regency	261	1021	479	2	15,434	16,810	100	935	1846	308	–	–
Situbondo Regency	37	–	143	231	811	–	14	250	360	1040	–	–
Tuban Regency	157	656	122	290	659	–	14	586	1222	1196	–	–
Total	**2183**	**2821**	**2161**	**923**	**49,274**	**18,422**	**306**	**5894**	**6741**	**25,548**	**-**	**26**

Notes: B = Baseline (2010).
P = Projection (2030).

Table 7
The Change of Existing Land Use into Future Land Use as Designated by the Spatial Plan of the Province of Banten (ha).

Existing Land Use\\\ \Future Land use	Protected Area	Agriculture	Industry	Settlement
Water Body	56	220	211	90
Protected Area	139	148	114	21
Agriculture	112	8290	2556	456
Fishpond	2271	3380	5741	357

Table 8
The Change of Inundated Existing Land Uses into Planned Land Uses Prone to Coastal Inundation in the Province of West Java (Ha).

Existing Land Use\\\\Future Land use	Water Body	Protected Area	Agriculture	Industry	Settlement
Water Body	1934	511	43	–	960
Protected Area	25	2346	85	–	729
Agriculture	22	1087	66,784	–	8660
Fishpond	17	17,796	204	–	19,606

economic benefit of 0.6 billion USD.

For West Java, Table 8 shows that existing fishpond area (19,606 ha) and agricultural area (8660 ha) which prone to flooding are allocated for future settlement.

In 2030, the potential of total economic loss due to changes of inundated land use would be around 136.5 billion USD. The value of possible economic loss of West Java is the largest compared to the three other provinces. The potential loss due to land use change from fishpond and agriculture to settlement would be around 139.5 billion USD. Instead, there would be land use changes from fishponds and settlements to protected areas that could provide economic benefits of 12.7 billion USD. Interestingly, in West Java Province there is no change from other land use to industry since industrial area in the Spatial Plan is not in the form of area delineation of area but in the form of points of industrial estate. However, if the industrial area is assumed to be maintained in 2030, it would provide an economic losses of around 5.4 billion USD.

In Central Java, a similar trend occurs, as presented in Table 9 where land will be converted from inundated fishponds (1326 ha) and agriculture (1554 ha) uses to flooded industrial zones. Also there is a plan to convert existing fishpond areas (1463 ha) and agricultural land (5380 ha) which are prone to coastal hazards to become inundated settlement area.

In term of damage exposure, in 2030 there would be total economic loss around 39.2 billion USD. The potential loss due to land use change from fishpond and agriculture to industry in Central Java would be 8.5 billion USD. There would be also land use change from fishpond and agriculture to settlement that would cause economic loss of 33.9 billion USD. In addition, there would be land use changes that provide economic benefits, i.e. from settlement and industry to protected areas and agriculture, which provide total economic benefit of 0.5 billion USD and 2.9 USD.

Based on the East Java Spatial Plan, as shown in Table 10, the source of land allocated for industrial areas is from inundated land currently being used for fishpond (1277 ha) and agriculture (618 ha). Similarly, inundation hazards prone of fishponds (3146 ha) and agricultural land (1592 ha) are allocated for future settlements.

In 2030 there would be potential total economic loss of around 29.5 billion USD due to land use change in East Java. The potential loss due to land use change from fishpond and agriculture to industry and settlement which are flood prone areas in East Java would be 5,6 billion USD and 23.4 billion USD respectively. Interestingly, there is a positive trend of change from industry to agriculture which potentially could provide economic benefit of USD 3.2 billion USD.

4. Discussion

The northern coast of Java, as the most important economic corridor of Indonesia, faces serious threats from coastal inundation hazards, which climate change further amplifies. Over time, this corridor

Table 9
The Change of Inundated Existing Land Uses into Planned Land Uses Prone to Coastal Inundation in the Province of Central Java (Ha).

Existing Land Use\\\\Future Land use	Water Body	Protected Area	Agriculture	Fishpond	Industry	Settlement
Water Body	251	337	1229	459	53	325
Protected Area	36	167	238	235	80	151
Agriculture	671	1047	21,096	1197	1554	5380
Fishpond	1620	2319	11,152	16,595	1326	1463

Table 10
The Change of Inundated Existing Land Uses into Planned Land Uses Prone to Coastal Inundation in the Province of East Java (Ha).

Existing Land Use\\\\Future Land use	Water Body	Protected Area	Agriculture	Fishpond	Industry	Settlement
Water Body	26	216	1368	494	133	673
Protected Area	–	58	1085	554	133	260
Agriculture	–	529	3460	1147	618	1592
Fishpond	–	115	25,478	15,912	1277	3146

has undergone intensive land use conversion. The common pattern of land use change on the northern coast of Java is from mangroves to fishponds and then to urban land use or mangroves are directly converted into built-up areas. In addition, agriculture is commonly converted into settlements and industry. These changes of land use could increase the exposure towards coastal flooding. Therefore, the question is whether spatial planning can control the future land use conversions along the northern coast of Java, where coastal inundation is projected to occur in a higher magnitude.

The GIS-based inundation model used in this paper consists of four cumulative hazard components, i.e., Highest High Water Level of Tide (HHWL), Sea Level Rise (SLR), Storms Surge (SS), and River Flood (RF) as seen in Table 1. The model shows an increase of about 17,812 ha of flooded areas from 2010 (282,962 ha) to 2030 (300,774 ha). The difference between the baseline and the projected inundation stems from the difference in sea level rise. This indicates an increase in the magnitude of coastal hazards affecting the northern coast of Java due to global sea level rise. The projected inundation of 2030 is overlaid with the provincial existing land uses and spatial plans to assess the role of each provincial spatial plan in the study area in reducing the exposure towards coastal flooding.

The analysis of land use change shows that the land use allocation in provincial spatial plans has further continued the previous trend of land conversion from mangroves, fishponds, and paddy fields into industry and settlements. Based on each provincial spatial plan, the amount of land designated for industry (13,399 ha) and settlements (41,821 ha) that could inundate is currently used as a protected area (1488 ha), agriculture (20,816 ha), or fishponds (32,916 ha).

Comparing the inundation for each type of existing land use with each provincial spatial plan shows that flooded industrial land allocated by each provincial plan will increase. The largest increase will occur in Banten (from 138 ha to 8748 ha). Similarly, allocated land for settlements in all provincial spatial plans would result in an increase of inundated settlements. The largest increase will be experienced by West Java from 3104 ha to 33,500 ha. This indicates that the Jakarta Metropolitan Area will continue to develop in the coastal areas of the adjacent provinces, i.e., Banten and West Java. The industrial development in Banten may be related to the newly constructed seaport in Cilegon, which is developed to reduce the pressure on Tanjung Priok, Indonesia's main port located in North Jakarta. Meanwhile, the increase in settlements in West Java is probably due to an extension of the Trans Java Toll Road, which is planned to connect Jakarta with the eastern tip of the province, intersecting West, Central and East Java. Likewise, in East Java, the further increase of inundation in the future land use plan is also distributed along the coast near Surabaya, which is the second largest city in Indonesia. Despite the current situation where built-up areas and strategic roads already experience major disturbances due to coastal floods, the spatial plans do not seriously take into account the threat from coastal hazards.

Furthermore, the estimated potential economic loss of inundated industry and settlement areas in 2030 is around 246.6 billion USD (4.5 million USD/ha). Therefore, a combination of an increased magnitude of coastal inundation and an increase in built-up areas as allocated in provincial spatial plans has increased the exposure towards coastal hazards.

Ward et al. (2010) and Purnama et al. (2015) used a similar GIS-based model of coastal inundation and estimation of damage exposure to assess a case in northern Jakarta. However, the differences between this research and the two previous papers are as follows. Firstly, the time horizon of the projection in this paper is 20 years in accordance with the timeframe of the spatial plans, whereas Ward et al. (2010) projected the inundation for the year 2100. Meanwhile, Purnama et al. (2015) did not specify a projection year but applied three scenarios of inundation height (30 cm, 115 cm, 200 cm). Secondly, this paper concerns the role of spatial plans in reducing exposure to climate change, thus, it overlays the coastal inundation for the baseline period of 2010 (a hazards height of 191.67 cm) with the existing land use and potential coastal flooding for the period of 2030 (hazards height of 205.67 cm) with the land use designated by spatial plans. Ward et al. (2010) overlaid the baseline (2009) and projection (2100) inundation maps with existing land use map. Similarly, Purnama et al. (2015) overlaid the maps of the three scenarios of inundation only with the existing types of land use. Thirdly, in terms of the spatial scope of the study, this paper assessed coastal inundation on the island level, as the purpose of this paper is to study the role of provincial spatial plans along the northern coast of Java, excluding the northern coast of Jakarta. The other two papers focus only on the northern coast of Jakarta. Fourthly, this paper also verified the inundation model for the baseline period by using observational data through fieldwork and secondary data. Finally, this research provides a different estimated value of damage exposure in 2030, as can be seen in Table 11.

The comparison of estimated damage exposure as shown in Table 11 indicates that the height of inundation which represents a certain scenario determines the approximate value of potential damage due to coastal flooding. It means that due to the similar characteristics of coastal topography (especially slope and elevation), a higher inundation height will produce a larger flooded area which penetrates further inland and would impact higher value types of land use.

New developments of land use conversion from non-built-up areas into industry and settlements, at the local level, confirm the results of this paper. For example, on November 14, 2016, the President of Indonesia officially opened Kendal Industrial Estate (2700 ha) located on the northern coast of Central Java, about 21 km west of Semarang City (Kemenperin, n.d.). The development of Kendal Industrial Estate has required the conversion of fishponds and mangroves. Angkatno (2017) as the head of the Development Planning Agency of Brebes provided another example from Brebes Regency in Central Java that revised its spatial plan, converting prime agricultural land into industry (increasing the amount of land for industrial uses with around 5500 ha). The development such as in Kendal and Brebes are enabled through the revision of regency/municipality spatial plans following the direction of the provincial and national spatial plans.

Table 11
Comparison of Various Inundation Height and Estimation of Damage Exposure.

No.	Scenario of Height of Inundation Hazard (cm) above sea level	Value per Ha in 2030 (million USD)
Purnama et al. (2015)	200.00	3.2
This Paper	205.67	4.5
Ward et al. (2010)	209.60	4.6

This research rejects the current understanding that spatial planning plays an important role in climate change adaptation due to its expected capacity of controlling future land use by steering developments away from climate-related disaster-prone areas (Davoudi, 2009; Carter and Sherriff, 2011); Friesecke et al., 2012). Carter and Sherriff (2011, p.9) further state that spatial planning can increase the adaptive capacity of a region by "protecting land with significant adaptation functions and reducing the exposure of developments (and their inhabitants) to climate change hazards". Despite the fact that many authors emphasize the important role of spatial planning in climate change adaptation, the case study in this paper demonstrates that the national, provincial, and local spatial plans could further increase the exposure towards the impacts of climate change.

One of the possible causes of this contradictory situation was identified by Galderisi and Menoni (2015) who observed that "planner's risk awareness is still too low", despite the fact that insufficient land use planning increases exposure towards disasters, which leads to larger economic losses and a significant amount of casualties. In addition, McClure and Baker (2013) and Roggema (2009) warn that putting a higher priority on economic growth in the current spatial planning practices could weaken efforts of climate change adaptation. An example of what these authors warned against happened in the early 1990s when the revision of a spatial plan enabled the conversion of mangroves into a luxury-housing complex on the northern coast of Jakarta. Similarly, Suroso (2001) found that a consortium of property developers was able to significantly influence the revision of a spatial plan on the eastern coast of Surabaya. This revision converted conservation areas dominated by mangrove forests into urban residential and business areas.

From the perspective of ecological economy, however, prioritizing on economic growth, which could contribute to higher income, more jobs, and economic multiplier effects is inherently problematic. They argue that the externality costs of ecological degradation and environmental pollution is not yet properly valued within the conventional calculations of economic growth (Daly and Farley, 2004). The economic valuation in this paper provides an indicative value of a potential economic loss of about 246.6 billion USD, resulting from land use changes of mangroves, fishponds, and agriculture into industry and settlements. The assumption behind this estimation is that the projected inundation of 2030 would cause maximum damage to the built-up areas. Furthermore, if it is assumed that the storms surge and river flood hazards would happen at least once every year as stated by Latief (2015), the scenario used by this paper of a cumulative height of 205.67 cm would occur at least once every year until 2030.

5. Limitation and future work

This paper indicates that the future development of industry and settlements not only facilitates economic growth but could also generate economic costs. Based on this indication, the study offers a reminder to planners and policy makers that spatial plans need to take into consideration the future risks of climate change to avoid making spatial plans that induce economic losses. However, it does not provide detailed policy recommendations. Further research on more comprehensive TEV (total economic valuation) could provide decision makers with more options in achieving the goal of economic growth in line with an increased capacity of regions to face coastal hazards. The future economic valuation used in this paper only applied one scenario of no hazard-proof infrastructure. This limitation could be significantly improved in future research. For example, further studies could develop at least three scenarios based on a combination of projected land use change and levels of hazards. These three scenarios could consist of (1) a small increase in land use change mixed with the worst case scenario of hazards (a combination of all components of coastal hazards including an increase of sea level due to La Niña); (2) a high increase in land use change combined with the worst hazard levels; (3) a high increase in land use change combined with a medium level of hazards (applying disaster mitigation). This further research should provide clear recommendations on spatial planning designs and policies for plans that can provide a synergy of economic growth and climate change adaptation. Based on this more comprehensive valuation of the economic costs of new policy options, decision makers can choose the best spatial planning policy that balances the goals of economic growth, while reducing the exposure towards coastal hazards.

6. Conclusion and recommendation

The methods of this paper consist of two steps: (1) a GIS-based model of coastal inundation mapping; and (2) an analysis of land use changes with an estimation of damage exposure. The model is intended for rapid assessment whether spatial plans at the provincial level of regions that are prone to coastal inundation could reduce the exposure to hazards.

It can be summarized that along the northern coast of Java a total amount 55,220 ha of areas prone to inundation, consisting of protected area (1488 ha), fishponds (32,916 ha) and agricultural land (20,814 ha), is planned to be converted into industry (13,399 ha) and settlements (41,821 ha) that, thus, will be prone to inundation. This change would potentially lead to an economic loss of 246.6 billion USD. The largest change is expected to be experienced by West Java (28,995 ha), which could potentially cause economic losses of 143.3 billion USD. In terms of land use type, West Java will also experience the largest conversion of protected area (729 ha), fishponds (19,606 ha) and agriculture (8660 ha) into built-up areas prone to inundation.

These methods demonstrate that previous and current land use conversion along the northern coast of Java will continue in the future, as directed by current spatial plans. This could significantly decrease the regional capacity in dealing with the exposure of coastal inundation. Although existing developments have already been affected by coastal inundation, the spatial plans issued by the national and provincial governments to regulate the future land use on the northern coast of Java have not integrated measures against hazards related to global sea level rise. Therefore, rather than reducing the exposure towards coastal flood hazards, the case study shows that spatial plans could even increase the risk of climate-related hazards. These findings contribute to a different perspective on the role of spatial planning for climate change adaptation than what is stated in the literature. This study shows that, in reality, land use planning is insufficient to reduce the exposure towards disasters, which could lead to higher economic losses.

According to Law No. 26 Year 2007 on Spatial Planning, there are three spatial levels i.e., national, provincial and local, which all develop spatial plans. As described above, the methods used in this paper enable the evaluation of the role of provincial spatial plans along the northern coast of Java for climate change adaptation. In fact, recent observations at the local level confirm the results of this paper. These observations show a revision of regency/municipality spatial plans to accommodate the demand for land for industrial and settlement purposes. Additionally, they show the launching of new industrial estates as occurred in Kendal.

National and provincial policies on spatial plans for the northern coast of Java are recommended to incorporate coastal hazards in the planning process. Sufficient information regarding coastal hazards is available to be used for climate change adaptation-based spatial planning. As the pressures of economic growth on the coastal ecology of the northern coast of Java have been very high, a comprehensive total economic valuation, which integrates the economic value of ecological services, is also urgently needed. This could provide decision makers and private businesses with a comprehensive understanding that economic growth cannot be sustained if the ecological system is significantly degraded.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.ocecoaman.2017.12.007.

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