Land Subsidence Affects Coastal Zone Vulnerability

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Abstrak

Penurunan Tanah Mempengaruhi Kerentanan Wilayah Pesisir

Pesatnya perkembangan kota di daerah pesisir menyebabkan degradasi lingkungan secara cepat. Kerentanan wilayah pesisir sangat dipengaruhi oleh kenaikan permukaan laut, penurunan tanah, gelombang badai, transport sedimen, kebijakan sosial ekonomi dan manajemen pesisir. Penelitian ini meneliti faktor utama yang mempengaruhi kerentanan pesisir pada pengembangan kota pesisir di pantai utara Jawa. Dua faktor yang diamati dalam penelitian ini; pertama penurunan tanah diamati dengan metode geodetik dan leveling. Kedua, genangan rob diukur dengan survei lapangan dan pemetaan partisipatif. Model genangan rob dilakukan dengan menggunakan model spasial. Model kerentanan fisik dilakukan dengan scoring dan pembobotan. Hasil penelitian menunjukkan rata-rata tingkat penurunan tanah antara tahun 2003-2014 adalah -0.021 (0.0-0091) m.th^{-1}. Genangan rob pada 2014 seluas 1.286,29 ha, dimana dampak tertinggi terjadi di area tambak (969,63 ha). Prediksi genangan rob pada 2031 akan menggenangi 1.786,76 ha, dimana genangan rob terbesar berada di area perumahan (646,85 ha). Kerentanan wilayah pesisir di wilayah penelitian dominan dipengaruhi oleh penurunan tanah, dan diklasifikasikan dalam kerentanan sedang. Penurunan tanah terjadi karena sebagian besar daerah penelitian terdiri dari unit morfologi dataran aluvial yang masih dalam proses konsolidasi. Kondisi penurunan tanah sangat mempengaruhi luasan genangan rob di masa depan.

Kata kunci: *penurunan tanah, genangan rob, kerentanan, kawasan pesisir*

Abstract

Vast development of urban cities in coastal area has caused rapid degradation of the environment. Coastal zone vulnerability is mainly influenced by sea level rise, land subsidence, storm surge, sediment transport, socio-economic and coastal management policies. Present study investigates the main factor influences coastal vulnerability of developing coastal urban city at north coast of Java. Two factors were observed in the study; firstly land subsidence was observed by geodetic and leveling methods. Secondly, tidal inundation was measured by field work and participatory mapping. Tidal inundation model was performed using spatial model. Physical vulnerability model was conducted by scoring and weighting. The results show that Average rate of land subsidence between 2003-2014 is -0.021 (0.0-0,091) m.yr^{-1}. Tidal inundation in 2014 covering 1286.29 hectares, where the highest impact happened at brackish water pond (969.63 ha). Tidal inundation prediction on 2031 will inundate 1786.76 ha, which the largest tidal inundation is in the residential area (646.85 ha). Coastal zone vulnerability in the research areas predominantly was influenced by land subsidence, and classified in moderate vulnerable. Land subsidence happened due to most of research areas are consists of alluvial plains morphology units that are still in consolidation process. Land subsidence conditions strongly influence the extent of tidal inundation in the future.

Keywords: *land subsidence, tidal inundation, vulnerability, coastal zones*

Introduction

Tidal inundation a serious threat to coastal areas, where the presence of environmental and socio-economic change will increase the threat and affect to coastal communities and economic sectors more vulnerable in the future (Ward *et al.*, 2011). First, the global mean sea level rise (GMSLR) will

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increase the risk of tidal inundation in coastal areas. Second, land subsidence decreasing in coastal areas and estuaries or deltas (IPCC, 2013). The third, increasing the frequency and intensity of storms as a result of climate change (IPCC, 2013). Finally, the vulnerability is exacerbated by the changes in socio-economic factors such as population growth and sustainable economic growth (IPCC, 2007). Climate change, socio-economic and coastal management policies have a significant influence on the risk of tidal inundation. Furthermore, the mechanism of sediment transport along the shore and shallow waters, and coastal dynamics also affect the risk of tidal inundation (Dawson *et al*., 2009).

Several studies on sea level rise using tide gauge data is Wirasatriya *et al.* (2006), Jevrejeva *et al.* (2008), and Church and White (2011). In addition the study using TOPEX / Poseidon, Jason-1 and OSTM / Jason-2 satellite altimeter data from 1993-2010 is Church and White (2011), Ray and Douglas (2011), and Nerem *et al.* (2010). Global mean sea level rise (GMSLR) is 1.26 to 3.30 mm.yr^{-1} from the tide gauge data (from 1900 to 2010) and 2.2 to 3.8 mm.yr^{-1} from satellite altimeter data (from 1993 to 2010) (IPCC, 2013). Other than that prediction of GMSLR using RCP8.5 models is 0.45 to 0.82 mm.yr^{-1} (in 2081-2100) (IPCC, 2013). The spatial distribution of relative sea level rise is affected by the geocentric conditions resulting from vertical motion of the land surface and sea water, while the melting of glaciers or ice from the Greenland and Antarctic ice sheets cause a global sea level rise (IPCC, 2013).

Tidal inundation caused coastal areas become vulnerable, especially to the physical aspects or regional infrastructure (Hartoko *et al*., 2008). Coastal vulnerability to the effects of tidal inundation had occurred in almost all coastal areas around the world as happened in Indonesia (Marfai *et al*., 2007; Marfai, 2009; Nugraha *et al*., 2012; Sihombing *et al*., 2012 and Ward *et al*., 2011); USA (Weiss *et al*., 2011; Zhang K., 2011; Heberger *et al*., 2011; Condon and Sheng, 2011; Parkinson and McCue, 2011); UK (Dawson *et al*., 2009); Turkey (Demirkesen *et al*., 2007 and Demirkesen *et al*., 2008); Cina (Huang *et al*., 2004); Egypt (Wöppelmann *et al*., 2013); also India (Kumar, 2006; Kumar dan Kunte, 2012). Successful management of coastal areas is needed and it is a challenge to resolve the tidal inundation problems in the future (Dawson *et al*., 2009), and the estimates of coastal vulnerability is indispensable to make adaptation strategies against the tidal inundation threat (Ward *et al*., 2011). Predictions in the future that some parts of the coastal zone be inundated by sea water, it will make the coastal zones becomes more vulnerable, especially to the physical environment aspects. Based on these problems, it is necessary to assess of the tidal inundation distribution, land subsidence, and spatial models of coastal vulnerability to the impacts of tidal inundation.

Materials and Methods

This research was conducted at Tegal City, where the research material is the bench mark elevation of Geospatial Information Agency (BIG) and Tegal Public Works Service (DPU). Land subsidence observed by measuring elevation change in Bench Mark (BM) using geodetic and leveling methods (Abidin *et al*., 2009 and Hartoko *et al.,* 2008). Vertical control points that used were BM 16 which is located in Selerok village, South Tegal district, Tegal. This vertical control points is choosen based on stable location or does not in degrade land elevation (Ismanto *et al*., 2009). Land subsidence distribution areas obtained using analysis of digital elevation models (DEM) using ArcGIS software (Hartoko *et al*., 2008). Future DEM scenarios that result from land subsidence scenario are generated using Marfai and King (2007) algorithms:

$$DEM_{t(x)} = DEM_{t(0)} - (s * (t_x - t_0))$$

Where: $DEMt_{(x)}$ is the current DEM (t) (ie years x); $DEMt_{(0)}$ is DEM in the beginning (t0); and s is annually rate of land subsidence.

Tidal inundation models were performed using two-dimensional spatial models with Digital Elevation Map (DEM) (Dawson *et al*., 2009). The predictions timing of tidal inundation based on spatial planning time (Nugraha *et al*., 2012), which is to predict tidal inundation to Tegal Spatial Planning in 2031. Input in tidal inundation model is the prediction of tidal value (Nugraha *et al*., 2012); DEM that results from elevation measurement (Hartoko *et al*., 2008); and prediction of GMSLR (IPCC, 2013). Spatial analysis algorithms used in this tidal inundation model (Nugraha *et al*., 2012 and modified by adding GMSLR variable):

$$[Land\ Elevation] - n * [Land\ Subsidence] < HWL + GMSLr$$

Where: Land Elevation is DEM from land elevation at the beginning year; land subsidence is annually rate of land subsidence; HWL is the highest water level prediction; GMSLR are predictions of global mean sea level rise; and n is the difference between prediction and data sources year.

Observations of tidal inundation done by direct observation of physical areas, actual furthest tidal inundation and land subsidence affects to coastal zone vulnerability. Actual tidal inundation obtained from participatory mapping (Nugraha *et al.*, 2012). Furthermore, spatial analysis using ArcGIS software (Hartoko *et al.,* 2008). Tidal inundation vulnerability emphasis on physical vulnerability related in Tegal Spatial Planning to tidal inundation and land subsidence threat. Physical vulnerability obtained by performing the overlaying process (Ward *et al.*, 2011), which is overlaid on tidal inundation prediction with Tegal Spatial Planning (2011-2031). Further modeling vulnerability created by scoring and weighting method. All process done using a vulnerability spatial analysis model, where the assumption of polygon unit is village polygon (Nugraha *et al.*, 2012). Criteria in physical vulnerability can be seen in Table 1.

Results and Discussion

Land subsidence

Land subsidence is obtained if the comparison between early Bench Mark (BM) elevation and actual BM elevation has a minus value (Abidin *et al.*, 2009). The average rate of land subsidence in Tegal (2003-2014) from the results of geo-statistical analysis using DEM is -0.021 $m.yr^{-1}$ (0.0-0.091 $m.yr^{-1}$). This condition is relatively lower than the rate of land subsidence in other cities in the northern coast of Java. Spatial distribution of land subsidence in Tegal spread almost throughout of Tegal, where the highest rate of land subsidence occurred in the coastal areas. This spatial distribution of land subsidence similar to conditions that occurred in Semarang and Jakarta coastal areas (Wirasatriya *et al.*, 2006; Hartoko *et al*., 2008; Ismanto *et al.*, 2009; Abidin *et al.*, 2009). Land subsidence in Tegal is caused by Tegal plains is covered by alluvium sediment (Djuri, 1975). This sediment type has young and soft soil layers, which is still continue to compression or consolidation (Wirasatriya *et al.*, 2006). In addition, development of Tegal area cause increasing changes in land use especially for settlements, trade and services also industrial area, so it will increasing the groundwater need and reduced water catchment areas. The condition according to Abidin *et al.* (2009), where land subsidence caused by a combination of natural consolidation of young alluvium soil, groundwater extraction and pressure from building and construction load. Land subsidence condition in research area can be seen in Figure 1.

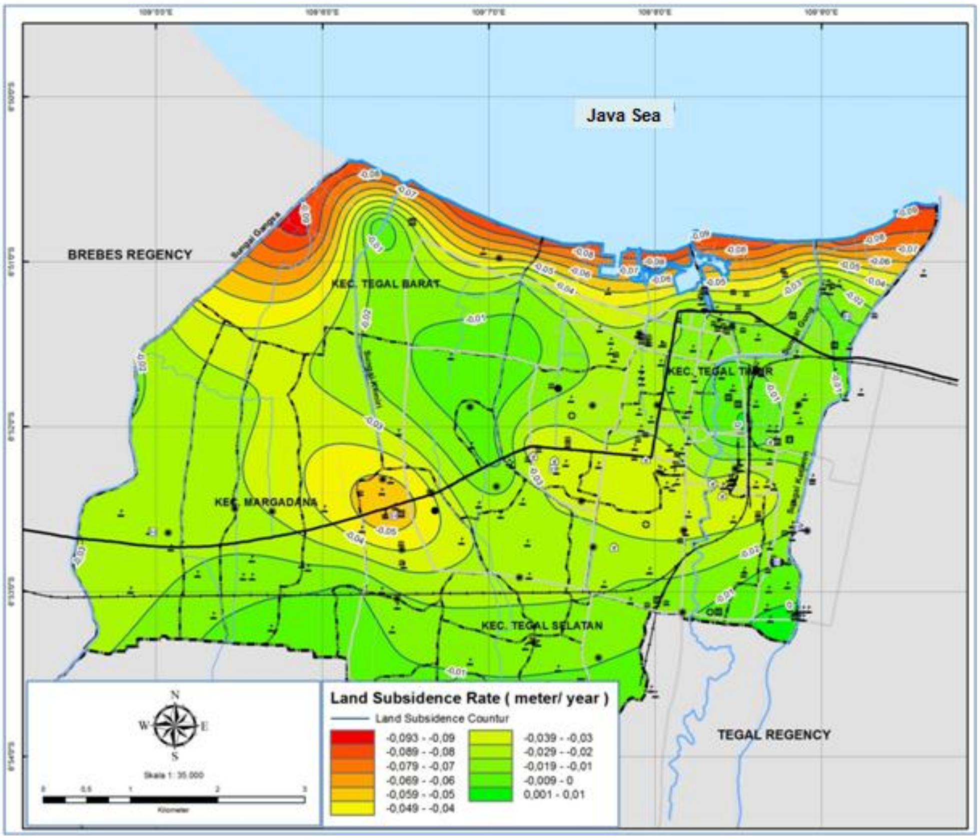

Figure 1. Land subsidence Map in Tegal, 2014

Actual tidal inundation

Actual tidal inundation in Tegal found in 10 villages and 3 districts, *i.e*. Krandon, Kaligangsa, Cabawan, Margadana, Pesurungan Lor (Margadana District); Kraton, Tegalsari, Muarareja (West Tegal District); and Panggung, Mintaragen (East Tegal District). Tidal inundation area covered 1286.29 ha which the widest tidal inundation is located on Muarareja, Tegalsari, and Mintaragen. Tidal inundation farthest from the coastline is 4.12 km which located at the Margadana. The highest impact of tidal inundation in 2014 was in brackish water pond (969.63 ha). The impact of tidal inundation cause substantial losses for the socio-economic, damage to buildings and settlements, also loss of productivity of fishery. These tidal inundations impact same as proposed by Marfai (2009). In addition, tidal inundations also provide indirect impacts such as increasing emergency response program cost, public services problem, and health problems (Marfai and King, 2008). Tidal inundation conditions in research area 2014 can be seen in Table 2 and Figure 2.

Prediction of tidal inundation in 2031

Prediction of tidal inundation in Tegal (2031) obtained when land elevation in 2031 (results from reduction of land elevation in 2014 with the rate of land subsidence) lower than sea level (sum of HWL and GMSLR). These model inputs are avarage rate of land subsidence (0,021 m.yr^{-1}), HWL (0.3929 m), and GMSLR (0.0059 m.yr^{-1}).). Land subsidence conditions strongly influence the extent of tidal inundation, where in 2013 tidal inundation will inundate 1786.76 ha in 10 village in 3 District of Tegal. The widest inundate area is predicted in Muarareja, Tegalsari, and Mintaragen. The overlay results between tidal inundation predictions map in 2031 and Tegal Spatial Planning maps obtained the most affected from tidal inundation is residential area (646.85 ha) and the road network (15561.0 m). Prediction of tidal inundation impact in 2031 is in accordance with Marfai (2009). More results for tidal inundation predictions in research area 2031 can be seen in Table 3, Table 4 and Figure 3.

Table 1. Criteria of physical vulnerability models. The classification of vulnerability value: 1 (low), 3 (moderate), and 5 (high). The classification of total vulnerability: < 2 (low), 2 – 4 (moderate) and > 4 (high). Source: Nugraha *et al.,* 2012; modified, 2014.

Physical Vulnerability Variable	weight (%)	Vulnerability classification		
		Low	Moderate	High
Percentage of Electricity Network	20	<30 %	30 % - 60 %	>60 %
Percentage Long Road	20	<30 %	30 % - 60 %	>60 %
Percentage of Telecommunication Network	10	<30 %	30 % - 60 %	>60 %
Percentage of Clean Water Network	20	<30 %	30 % - 60 %	>60 %
Percentage of Built Region	30	<30 %	30 % - 60 %	>60 %

Table 2. The extent of flooded areas by tidal inundation in Tegal, 2014

Sector	Area(Ha)	Sector	Area(Ha)
Office	5,13	Open Spaces	29,41
Agriculture	0,18	Trade and Services	27,91
River Border	1,09	Settlement	215,52
Port	37,42	Brackish Water Pond	969,63
Total			1.286,29

Table 3. Impact prediction of tidal inundation to spasial planning (land use) in Tegal, 2031

Land Use	Area (Ha)	Land Use	Area (Ha)
Campgrounds	13,70	Agriculture	182,04
Health facilities	0,58	Settlement	646,85
Port	70,34	Industrial Area	141,86
Education and Sport	41,72	Livestock	9,29
Waste Treatment	4,59	Polder	2,35
Landfills	20,31	Open Spaces	212,86
Trade And Services	96,21	Turkish Border	49,60
Worship Place	0,47	River Border	40,80
Brackish Water Pond	200,64	Bus Station	0,22
Office	20,03	Natural Tourism	32,30
Total			1.786,76

Physical vulnerability against tidal inundation prediction in 2031

Physical vulnerability analysis is performed by calculating the infrastructure vulnerability of a planned area in the Tegal Spatial Planning (2011-2031) against tidal inundation prediction. Builds region is the most vulnerable area in 2031; this was cause of land use changing from open space into builds region such as residential, industrial, office, also trade and services. This physical vulnerability in accordance with that proposed by Marfai and King 2008), Diposaptono *et al.* (2009) and Ambariyanto and Sugianto (2012). The spatial analysis results in determining the level of physical vulnerability in Tegal that the highest level of physical vulnerability are located in Pesurungan Lor Village, because it's located in the downtown, so it many building and infrastructure such as roads, telecommunication, clean water and electricity networks are predicted to be inundated in 2031. Coastal zone physical vulnerability model 2031 in research area is shown in Table 5 and Figure 4.

Table 4. Impact prediction of tidal inundation to infrastructure planning in Tegal, 2031

Infrastructure Planning	Length (m)
Road Network	15.561,0
Electricity Network	11.416,3
PDAM Network	12.409,7
Telecommunication Networks	10.958,3
Total	50.345,30

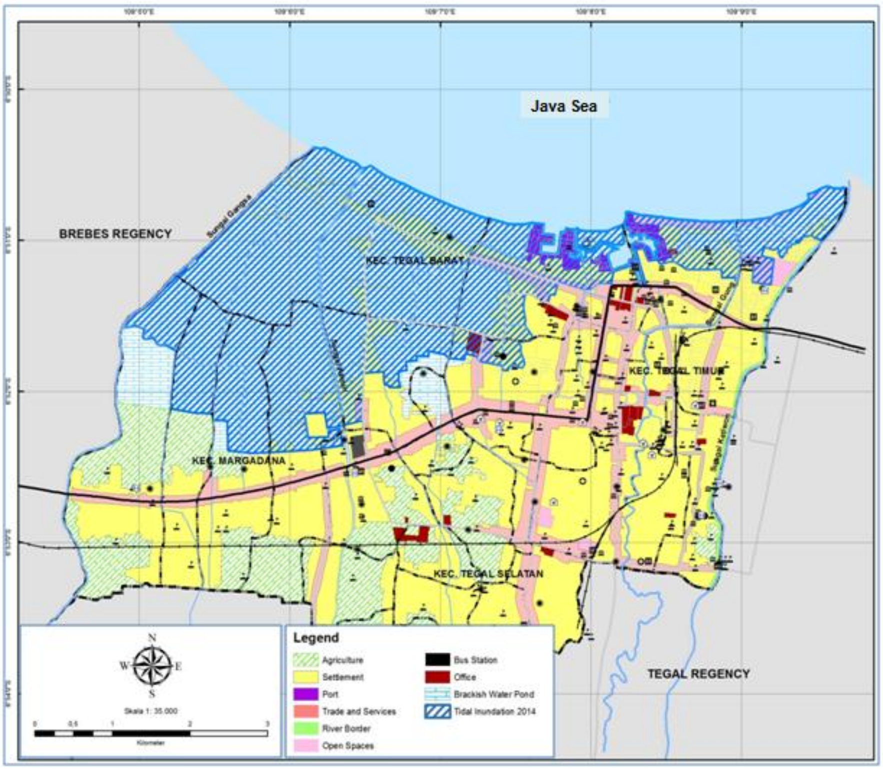

Figure 2. Tidal inundation in Tegal City in 2014

Table 5. Physical vulnerability against tidal inundation prediction in Tegal, 2031

Vilage	Built Regions		Roads		Telecomunication Networks		Clean Water Networks		Electricity Networks		Vulnerability Total Score	Vulnerability Class
	Value (%)	Score	Value (%)	Score	Value (%)	Score	Value (%)	Score	Value (%)	Score		
Krandon	16,97	1	0,00	1	0,00	1	2,47	1	0,00	1	1,0	Low
Kaligangsa	5,37	1	0,00	1	0,00	1	0,00	1	0,00	1	1,0	Low
Cabawan	19,57	1	22,15	1	36,86	3	27,82	1	46,89	3	1,6	Low
Margadana	47,14	3	10,46	1	50,43	3	39,91	3	62,02	5	3,0	Moderate
Pesurungan Lor	68,25	5	77,19	5	89,74	5	100,00	5	89,29	5	5,0	High
Kraton	65,13	5	40,58	3	5,08	1	0,00	1	6,02	1	2,6	Moderate
Tegalsari	92,76	5	92,99	5	100,00	5	0,00	1	100,00	5	4,2	High
Muarareja	38,76	3	100,00	5	100,00	5	100,00	5	100,00	5	4,4	High
Panggung	21,67	1	15,72	1	0,00	1	33,75	3	100,00	5	2,2	Moderate
Mintaragen	60,15	5	57,76	3	94,06	5	90,58	5	100,00	5	4,6	High

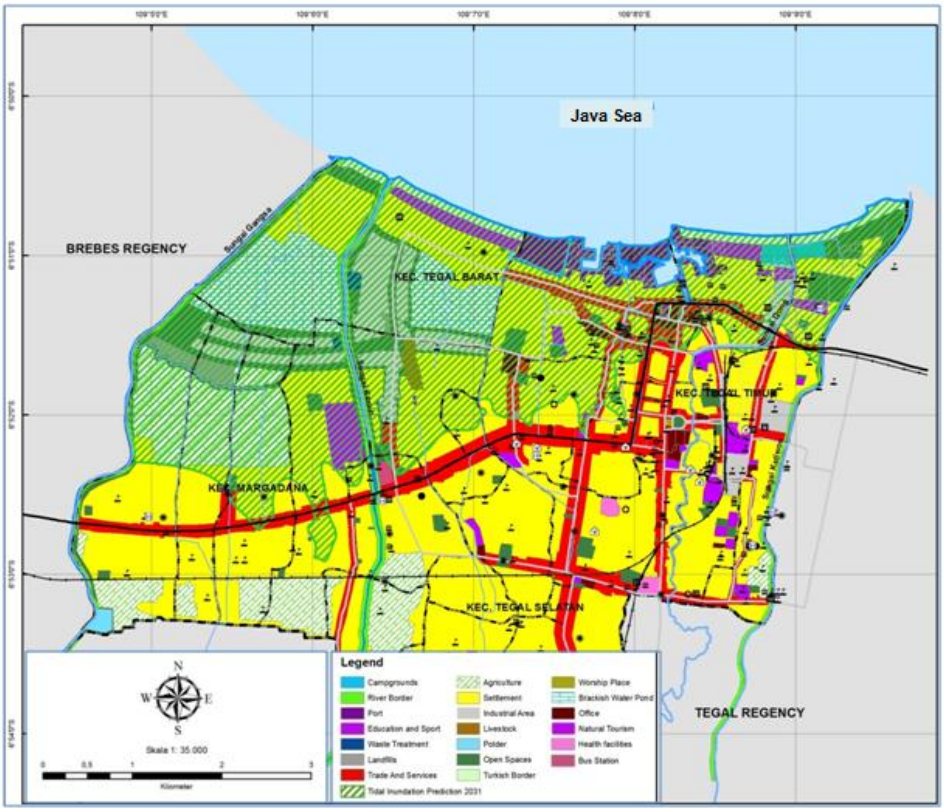

Figure 3. Tidal inundation prediction in Tegal City the year 2031

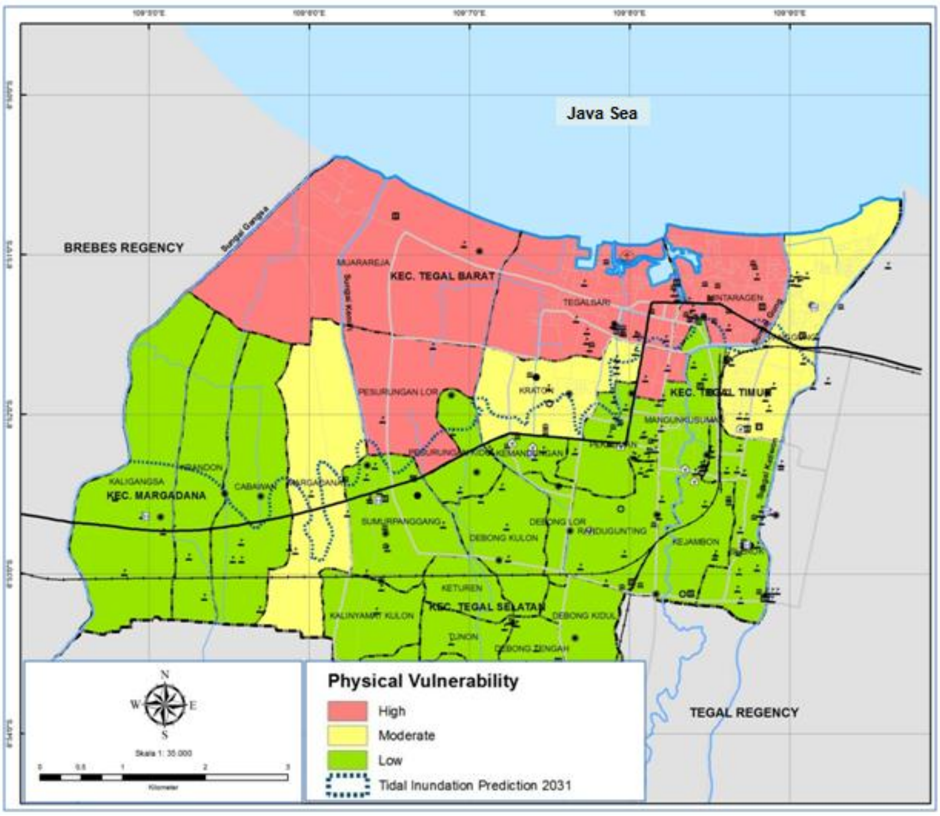

Figure 4. Physical vulnerability against tidal inundation prediction map in Tegal, 2031

Conclusion

Coastal zone vulnerability in the research areas predominantly influenced by land subsidence. Coastal zone vulnerability in the research is classified in moderate vulnerable. Land subsidence happened due to most of research areas are consists of alluvial plains morphology units that are still in consolidation process. Land subsidence conditions strongly influence the extent of tidal inundation in the future.

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