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Geospatial Modeling of Blue Carbon Ecosystem Coastal Degradation in Jakarta Bay

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Abstract

Jakarta Bay is shallow water which is used for various activities, currently experiencing environment, soil, and sediment degradation. Jakarta Bay experienced rapid development, population growth, increased economic activity and utilization of coastal resources. The development of Jakarta Bay is carried out to balance land necessity and overcome the problem of land subsidence through reclamation and construction of sea dikes. Ecosystem services are the contribution of various interrelated ecological structures and functions, mangrove ecosystems provide services as an important part of the carbon cycle. Mangroves use CO_2 for photosynthesis and store it in Biomass and sediment stock. Mangrove ecosystems in Jakarta Bay have been degraded and deforested due to land conversion for settlement, facilities, and other activities, in line with the increasing population. The calculation of the service value of mangrove ecosystems is limited to economic valuation and descriptive account, geospatial modelling has not been widely carried out, this has caused widespread and temporal unknown data on ecosystem services. The Coastal Blue Carbon geospatial modelling used in this study requires land use classification data input based on the interpretation of Landsat satellite's images and global carbon deposits in mangrove ecosystems while carbon prices are based on Social Cost Carbon (SCC), Greenhouse Gas Initiative (RGGI) and International Voluntary Market Price (IVMP). This study produced a map of the dynamics of carbon stock, sequestration, emissions, accumulation and net present value of carbon. The output of these maps is expected to be a reference for sustainable mangrove management, coastal area planning optimization with mangrove ecosystem protection so it can be part of climate change mitigation efforts in Jakarta Bay.

Keywords: Geospatial, ecosystem, blue carbon, Jakarta

INTRODUCTION

The coastal region is a transitional area (Asyiawati and Akliyah, 2014), which is a transition between freshwater and brine so they have high natural resources (Parawansa, 2007). Sedimentation occurs in 13 river mouths along the bay, including Cisadane river to the west and Citarum river to the east. (P2O-LIPI, 2017). Sedimentation from rivers was identified since the 70s (Lubis, *et al.,* 2007). Jakarta Bay is average shallow water of 15 meters (Pranowo *et al.,* 2014), used for shipping, ports, tourism, fisheries, settlement, industry, and trade (Arifin and Mustikasari, 2014). Environmental degradation is indicated by the occurrence of phytoplankton blooms, while also experiencing heavy metal pollution (Kusuma *et al.,* 2013). Land subsidence occurred from 1982 until 2010 and varied with an average of 1–15 cm/year and 20–28 cm/year (Abidin *et al.,* 2015).

Ecosystem services are the contribution of various interrelated ecological structures and functions, mangrove ecosystems provide ecosystem services as organisms that are able to maintain the carbon cycle (Sudirman *et al.,* 2018). According to (MEA, 2005), ecosystem services are defined into four basic categories, namely provision, regulation, culture and support. Mangrove ecosystems have ecological, economic and social values which are the main ecosystems on the coastal area (Saprudin and Halidah, 2012). Indonesia has a mangrove ecosystem of 3,112,989 ha which constitutes 22.6% of the total mangrove in the world (Giri et al. 2015), but is currently experiencing degradation of 30-50% due to land conversion (Donato *et al.,* 2012). Mangrove ecosystems grow in tidalzone, lagoons, and river estuaries (Kusmana *et al.,* 2005). Mangrove ecosystems have the function of producing oxygen and absorbing carbon. Saparinto, (2007) in (Majid *et al.,* 2016). Decomposition creates complex detritus, which enriches the productivity. (Suzana *et al.,* 2011).

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Mangroves use CO_2 for photosynthesis and store it in Biomass and sediment stock as climate change mitigation efforts (Ati *et al.,* 2014). Mangroves absorb carbon dioxide and transform it into organic carbon (Bouillon *et al.,* 2008; Alongi, 2014 (Murdiyarso *et al.,* 2015).

Muara Gembong Subdistrict has a mangrove ecosystem (Asyiawati and Akliyah 2011), also some in Teluk Naga District, Tanggerang Regency, and Penjaringan District, in North Jakarta, covering an area of 9,749 ha (Parawansa, 2007). Mangrove cover in Muara Angke and Muara Gembong is below 20% according to Santosa (2012) in Ambinari *et al.,* (2016). Mangrove ecosystems in Jakarta Bay have been degraded and deforested due to land conversion for settlement, facilities, and other activities, in line with the increase in population and for aquaculture businesses (Ambinari *et al.,* 2016). The consequences of global mangrove deforestation and changes in land use can cause carbon dioxide (CO_2) emissions to be around 10% or equivalent to 0.02 - 0.12 Mg C per year (Donato *et al.,* 2011). The calculation of the mangrove ecosystem services value in Indonesia is done through a direct and indirect benefit approach. (Suzana *et al.,* 2011; Saprudin and Halidah, 2012). Measurement and map of the ecosystem services as an input of resource management policies are experiencing inconsistent method constraints (Crossman *et al.,* 2013) if there is damage, the compensation cannot be demanded based on its value in market value or even non-market value.

Jakarta Bay is experiencing rapid development and being affected by various human activities. Population growth demands the availability of land, increased economic activity, and utilization of resources and coastal environment, increasing these activities causes a decrease in carrying capacity and ecosystem services inside. The development of Jakarta Bay coastal area is carried out to compensate for land needs due to population growth and human activities as well as overcoming problems of land subsidence accompanied by sea level rise that causing tidal floods. The need for land is responded by the government through reclamation (Prasetyo *et al.,* 2018), while to protect Jakarta's safety against flooding and slowing down land degradation through the construction of sea dikes (PTPIN, 2014).

The studies of ecosystem services that have already been carried out at this time are limited to economic valuation and descriptive account, spatial modelling with software has not been widely implemented, this has caused data on ecosystem services to be widely and temporally unknown. Spatial modelling used in this study resulted in the output of spatial and temporal maps regarding the dynamics of coastal blue carbon ecosystem services since 2004, 2018 to 2068. The output of these maps is expected to be a reference for sustainable mangrove management, coastal area planning optimization with mangrove ecosystem protection in order that it can be part of climate change mitigation efforts in Jakarta Bay.

MATERIAL AND METHODS

This modelling focuses on ecosystem services, spatially, providing biophysical, market and non-market output, based on planning, demonstrates the relationships between diverse ecosystem services, having modular and tiered approaches to accommodate various data availability and levels of knowledge systems (Guerry *et al.,* 2012). Coastal Blue Carbon modelling is used to support geographic information systems. This modelling was developed by Natural Capital Project at Stanford University, where the guidelines used to carry out this program refer to the Invest Documentation (Nelson *et al.,* 2018).

The satellite imagery used in this study uses Landsat in 2004 and 2018. In order to be used in spatial modeling of coastal blue carbon, these Landsat images need to be carried out radiometric and geometric corrections to eliminate atmospheric scattering, sequestration, and minimize light interference by the atmosphere (Phin et al. (2011), Kabiri, (2013) in (Helmi *et al.,* 2018)). Calculation of the carbon deposits value in the mangrove ecosystem stored in the three main storage (Carbon Pool), namely biomass, carbon sediment, and litter. (Pendleton *et al.,* 2012). Carbon values in biomass and sediment refer to the global carbon value of mangrove biomass at 84,912 TCO_2e/Ha and sediments at 2610,312 TCO_2e/Ha (Donato *et al.,* 2011). The pricing of the value of carbon deposits refers to carbon prices based on the prices of Social Cost Carbon (SCC), Regional Greenhouse Gas Initiative (RGGI), and International Voluntary Market Price (IVMP) (Jerath, *et al.,* 2016). The calculation of carbon values used in this study refers to the Invest Documentation (Nelson *et al.,* 2018), including:

1. Carbon Storage

   $Stotal = Sbiomass + Ssoil + Slitter$
2. Carbon Emission

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$$Ep = Dp \cdot \left(0.5^{\frac{t-(r+1)}{Hp}} - 0.5^{\frac{t-r}{Hp}}\right)$$

3. Clean Sequestration at this moment

$$Vx = \sum_{t=0}^{T} \frac{Pt(Ct,x - Ct-1,x)}{(1+d)t}$$

Description:

Sbiomass	:	The amount of carbon in the mangrove biomass
Ssoil	:	The amount of carbon in mangrove sediments
Slitter	:	The amount of carbon in the mangrove litter
Dp	:	Number of disturbed carbon stocks
Hp	:	The half-life of a disturbance
r	:	Year of transition
T	:	The number of years between the current date and the end of settlement land change
p_t	:	Price per ton of carbon in time
$C_{t,x}$	:	Carbon stock in pixels in time
d	:	Discount rate
t	:	Time stage

Figure1. Study Area

RESULTS AND DISCUSSION

Teluk Jakarta experienced changes in land use in both the coastal and central parts. Changes in land use in Jakarta Bay cause changes in the value of carbon in the mangrove ecosystem. This study examines changes in land use in 2004 and 2018 while changes in coastal blue carbon values were carried out from 2004 to 2018 and modelled carbon changes up to 2068. Changes in land use are shown in the following table:

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Table 1. Table of changes in land use in the Jakarta Bay in 2004 and 2018

Type of land use	Area of land use (Ha)	
	Year 2004	Year 2018
Water	89,324	87,648
Open field	44,462	9,018
Mangrove	12,903	4,002
Plantation	4,913	29,328
Settlement	139,764	172,204
Grasses	12,451	20,018
Rice field	55,696	20,580
Fishpond	13,771	24,181
Vegetation	65,552	72,404

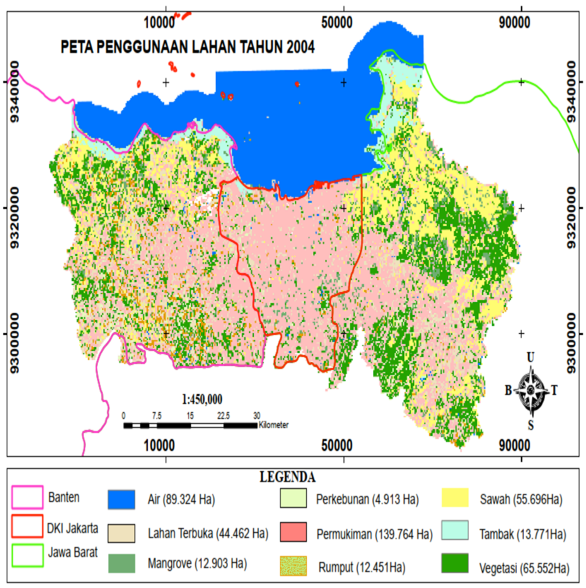

Figure 2. Map of land use in Jakarta Bay in 2004

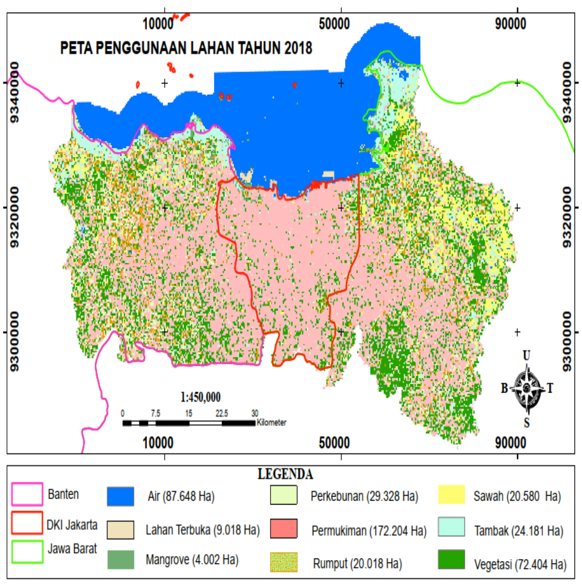

Figure 3. Map of land use in Jakarta Bay in 2018

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Land use is a major factor affecting carbon stocks in ecosystems that can be used to model carbon cycles (Houghton *et al.,* 2003). Changes in land use in the Jakarta Bay area are shown in **Table 1. Figure 2** shows a map of land use in 2004, while **Figure 3** is a land use in 2018. The use of land as an area of water, open land, settlement, fishpond is land use that has no value carbon. Plantation, grass, rice fields and vegetation are land uses that have carbon values, but in modelling blue carbon coastal areas, only mangrove ecosystems are referred to as carbon values. (Nelson *et al.,* 2018). Coastal marshes, mangroves, and seagrasses, in particular, store large amounts of carbon in sediments, leaves, and other forms of biomass. Land use besides mangroves in this model is considered to have no carbon value, such that despite changes in land use from other than mangrove to mangrove do not add carbon value from the use of plantation land, grass, rice fields and vegetation. Conversely, if there is a change in land use from mangrove to other than mangrove, it is a disturbance that has the potential to cause a reduction in coastal blue carbon value. Interference with coastal blue carbon has different properties depending on the changes. If mangroves turn into plantations, rice fields, fishponds, then the disturbance is a high impact disturbance because the change to land use causes the release of carbon from mangrove biomass and mangrove sediment due to the opening and excavation of the mangrove ecosystem. If it turns into water, open land, settlements then the disturbance is a medium impact disturbance because the change only causes the loss of mangrove biomass while the mangrove sediment still stores carbon (Nelson *et al.,* 2018).

Stock carbon in 2004 amounted to 2,698,224121 tC/ha (Figure 4). In 2018 there was an increase in carbon in certain regions but also showed a reduction in carbon stock in other regions. The stock carbon value in 2018 varied where the highest carbon stock value was 40,428.36328 tC/ha and the lowest reached -3,407,566.25 tC/ha (Figure 5). Stock carbon in 2004 and 2018 became a reference for software to model the amount of carbon stock in 2068. Figure 6 shows the estimated carbon stock in 2068 if the area of mangrove ecosystem in 2068 does not change land use or conversion, hence carbon stock values will be obtained at 137,456.4375tC/ha to -3,407,774 tC/ha.

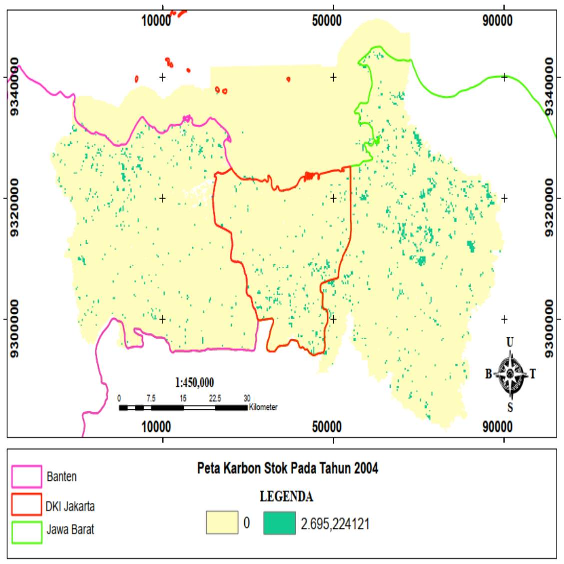

Figure 4. Stock carbon in 2004

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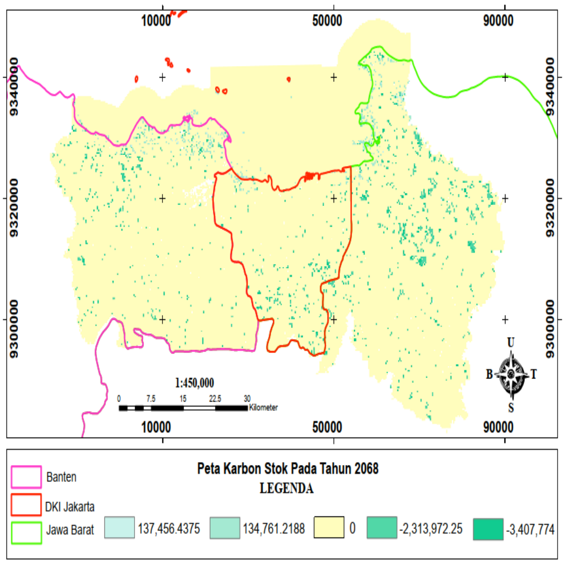

Figure 6. Stock carbon in 2068

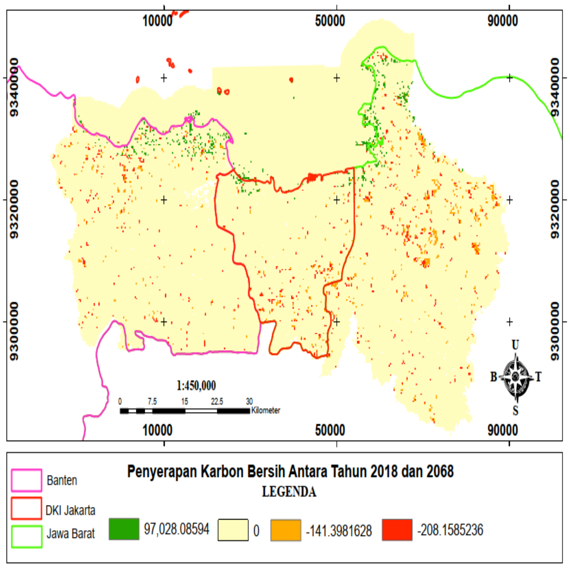

Figure 7. Net carbon sequestration between 2018 and 2068

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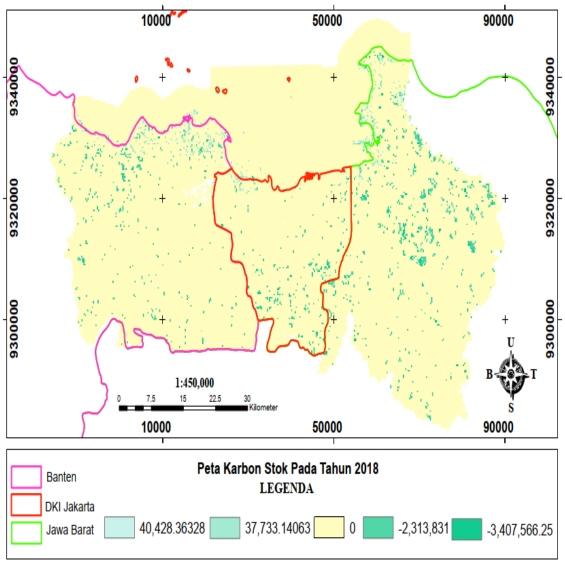

Figure 8. Stock carbon in 2018

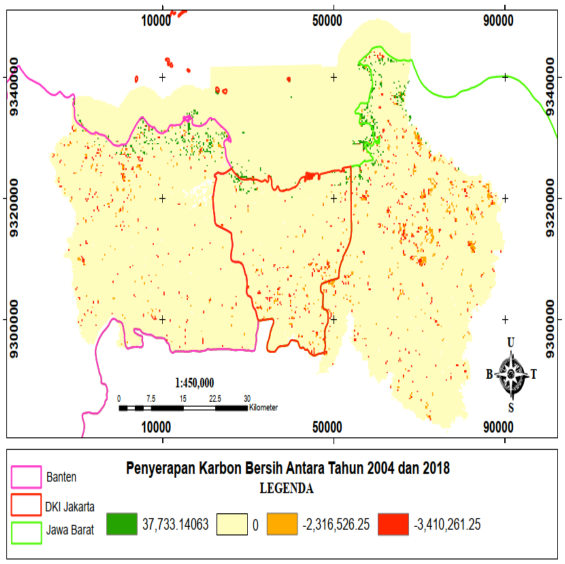

Figure 9. Net carbon sequestration between 2004 and 2018

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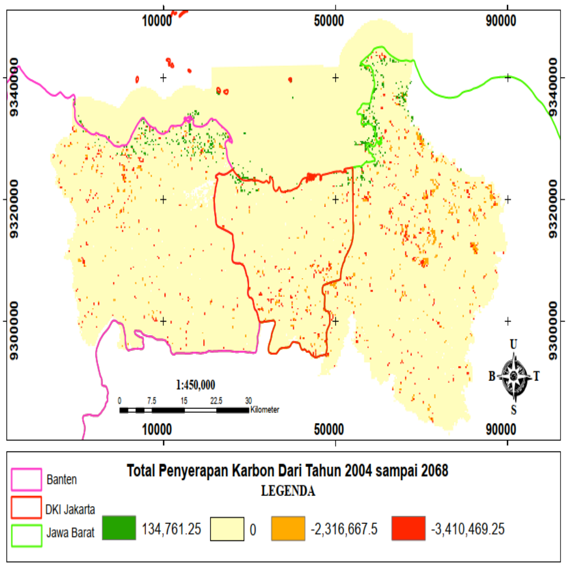

Figure 10. Total carbon sequestration from 2004 to 2068

The carbon uptake shown in Figure 7 is carbon uptake from 2004 to 2018 of 37,733,14063 tC/ha up to -3,410,261.25 tC/ha, where 2004 was the base calculation year. Figure 8 shows that carbon uptake in 2018 to 2068 is estimated to reach 97,028,08594 tC / ha up to -208,1585236 tC/ha where the base year used is 2018. Total carbon absorption for 50 years is 134,761.25 tC/ha up to -3,410,469.25 tC/ha Figure 9. Total carbon uptake will be achieved if land use is fixed up to 2068 where carbon values are obtained based on 2004-2018 land use inputs and carbon uptake in those years (Figure 10).

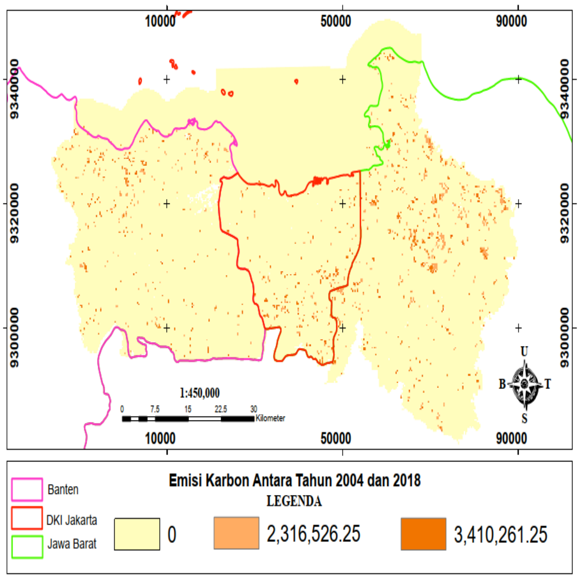

Figure 10. Carbon emissions between 2004 and 2018

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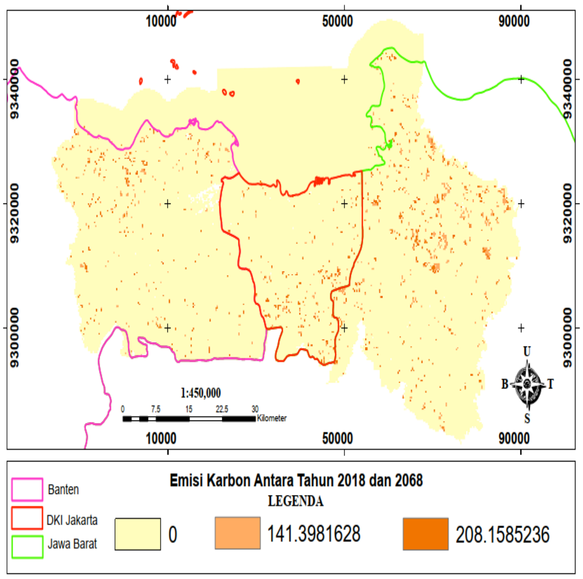

Figure 11. Carbon emissions between 2018 - 2068

Carbon emissions between 2004-2018 amounted to 2,316,526.25 tC/ha to 3,410,261.25 tC/ha. Emissions show the release of carbon from the mangrove ecosystem due to land conversion (Figure 10). Carbon emissions in 2068 are estimated to reach 141.3881628 tC / ha to 208.1585236 tC / ha (Figure 11).

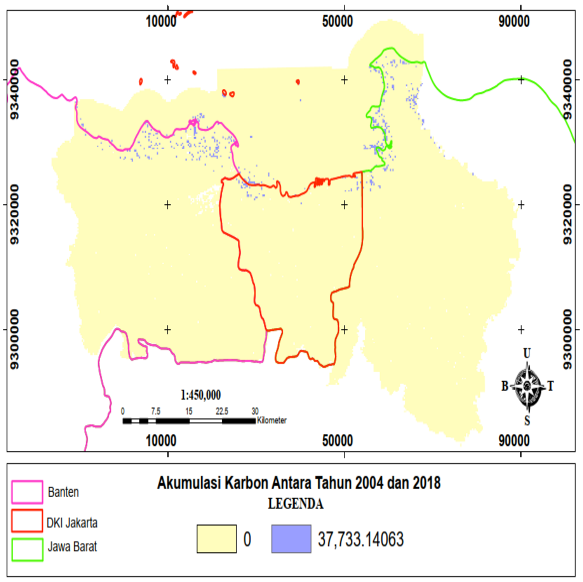

Figure 12. Carbon accumulation between 2004 and 2018

Carbon accumulation is the amount of carbon accumulated by biomass and sediment. Accumulation occurs all the time as long as there is no change in land use. Accumulation is affected by emissions and absorption by biomass and sediments either due to land changes or due to natural factors. Carbon accumulation values between 2004-2018 were 37,733.14063 tC/ha (Figure 12). Accumulation in 2018-2068 was 97,028,08594 tC/ha (Figure 13).

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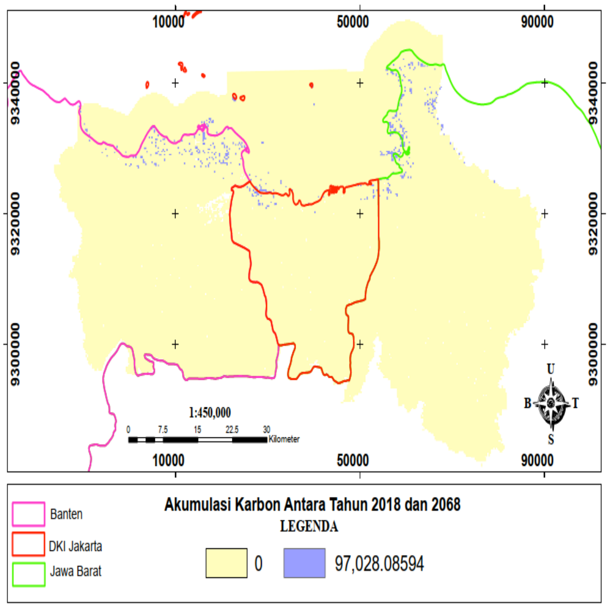

Figure 13. Carbon accumulation between 2018 and 2068

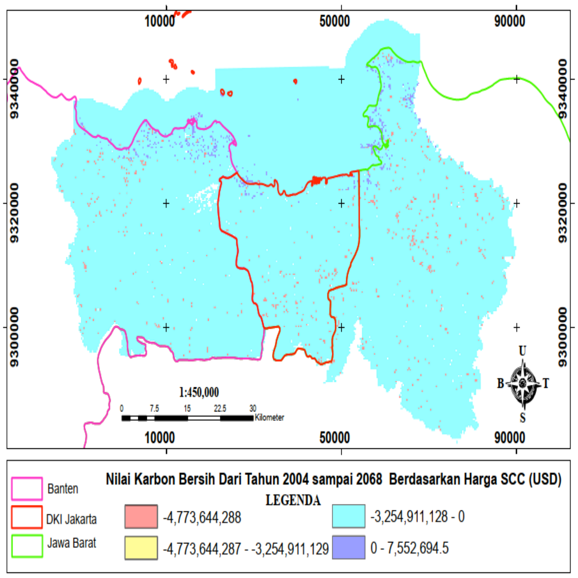

Figure 14. Net carbon values from 2004 to 2028 based on SCC prices (USD)

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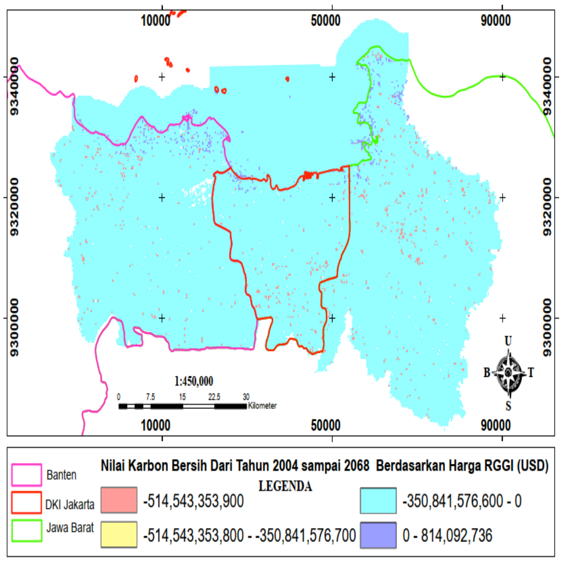

Figure 15. Net carbon values from 2004 to 2028 based on RGGI prices (USD)

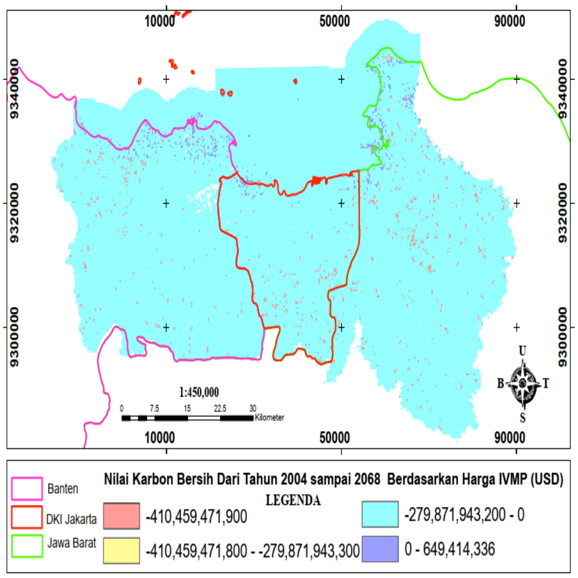

Figure 16. Net carbon values from 2004 to 2028 based on IVMP prices (USD)

In this study, the carbon price used refers to the 3 globally applicable market prices, namely Social Cost Carbon (SCC), Regional Greenhouse Gas Initiative (RGGI) and International Voluntary Market Price (IVMP). Carbon value is expressed in units of US dollars (USD), which in this study refers to the 2016 dollar price (Jerath, *et al.,* 2016). Carbon prices based on the SCC of $. 814,092,736 (Figure 14). Carbon prices based on RGGI for $. 162,818,496 (Figure 15). Carbon prices based on IVMP are $. 129,882,864 (Figure 16). The net present value obtained refers to carbon prices in 2016 based on Jerath, et al. (2016).

CONCLUSION

Changes in land use from mangrove ecosystems to water, open land, plantations, settlement, grasses, rice fields, fishpond, and vegetation have caused changes in coastal blue carbon values in Jakarta Bay from 2004-2018. Changes in carbon stock, absorption, accumulation, and carbon value based on market prices will continue to decrease, while the value of emissions will continue to increase as long as there is no effort to rehabilitate the mangrove ecosystem. This study is modelled for the next 50 years with conditions without rehabilitation efforts and assuming permanent land use and carbon prices in 2016 without a discount rate.

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