CORRELATION ANALYSIS BETWEEN SEAWATER INTRUSION AND MANGROVE GREENBELT

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CORRELATION ANALYSIS BETWEEN SEAWATER INTRUSION AND MANGROVE GREENBELT. Seawater intrusion is an entry process of seawater to land. Many factors have caused seawater intrusion from freshwater exploitation until mangrove degradation. Mangrove ecosystem is a type of forest ecosystem which has an ability to reduce seawater intrusion. This paper analyzes the estimation and prediction of seawater intrusion and correlation between widths of mangrove with seawater intrusion. The relation analysis between the width of mangrove greenbelt with seawater intrusion used an equation model to predict seawater intrusion. The research method used sampling technique, system analysis with powersim software, correlation analysis and mathematical method with trend line analysis. Results show that (1) the mangrove density in the coastal area is approximately $50 - 109$ trees/ha. (2) Simulation results showed seawater intrusion rate was about 0.20 km year^{-1} (with mangrove as a component system), but reached $0.3 - 0.4$ km/year (without mangrove as a component system). (3) The simulation result also showed that freshwater salinity was estimated to increase from 1.92 ppt to 4.86 ppt. (4) The relation model between seawater intrusion and mangrove greenbelt showed that correlation coefficient was 0.97 with the equation seawater intrusion (m) = 2264.9 * exp (-0.009 * the width of mangrove greenbelt (m)), the correlation of mangrove width with seawater intrusion was 0.97. (5) *Avicennia marina*, *Avicennia alba*, *Rhizophora styllosa*, *Sonneratia alba* and *Sonneratia caseolaris* were the mangrove species that had the best ability to reduce seawater intrusion.

Keywords: Seawater intrusion, mangrove, water salinity, system analysis

*ANALISIS KORELASI ANTARA INTRUSI AIR LAUT DENGAN JALUR HIJAU MANGROVE. Intrusi air laut merupakan proses masuknya air laut ke daratan. Faktor-faktor yang menyebabkan terjadinya intrusi air laut diantaranya adalah pemompaan air tawar hingga kerusakan ekosistem mangrove. Ekosistem mangrove adalah suatu ekosistem yang memiliki kemampuan untuk mengurangi proses intrusi air laut. Penelitian ini menganalisis pendugaan dan prediksi intrusi air laut, hubungan antara lebar jalur hijau mangrove dengan intrusi air laut. Analisis hubungan antara lebar jalur hijau dan intrusi air laut menggunakan suatu model persamaan. Penelitian ini dibangun dengan menggunakan pendekatan teknik sampling, analisis sistem dengan powersim, analisis korelasi, analisis matematika dengan menggunakan "trendline". Hasil dari penelitian ini adalah (1) potensi kerapatan mangrove adalah sekitar 50 – 109 pohon/hektar. (2) hasil simulasi menunjukan laju intrusi air laut jika ada mangrove mencapai 0,20 km/tahun, tapi jika tidak ada mangrove mencapai 0,3 – 0,4 km/tahun. (3) hasil simulasi menunjukan bahwasalinitas air tawar diduga meningkat dari 1,92 ppt hingga 4,86 ppt. (4) dari model hubungan antara intrusi air laut dan lebar jalur hijau menunjukan koefisien korelasi sekitar 0,97 dengan persamaan pendugaan intrusi air laut adalah 2264,9 * exp (-0,009 * lebar jalur hijau mangrove (m)), (5) jenis-jenis Avicennia marina, Avicennia alba, Rhizophora styllosa, Sonneratia alba dan Sonneratia caseolaris merupakan jenis mangrove yang memiliki kemampuan terbaik untuk mengurangi intrusi air laut.*

Kata kunci : Intrusi air laut, mangrove, salinitas air, analisis sistem

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I. INTRODUCTION

Seawater intrusion occurs as an impact of mangrove degradation, seawater expansion and freshwater exploitation toward unbalanced potential of freshwater in the coastal ecosystem (Andrari, Nandang, Masmui & Priyono, 1996). The high exploitation of freshwater, as a desirable source of water, to support different domestic activity (Hussain, Javadi, & Sherif, 2015), industrial and agricultural sectors and pumping of groundwater (Hussain et al., 2015) are critical factors of seawater intrusion in Jakarta. The other factors are population growth, land use changes and urbanization that have also increased the pressure on the source of freshwater to the extent leading to the extraction of groundwater as the alternative to surface water to cope with the scarcity of freshwater resources (Narayan, Schleeberger & Bristow, 2007). Seawater intrusion usually occurs due to rapid disturbances which give negative impact for coastal sustainability as a risk to coastal aquifers in the coastal area (Morgan & Wernera, 2015). Seawater extent represents the condition of the respective aquifers under stress (Morgan & Wernera, 2015).

The worst effects of seawater intrusion for environment are reduction of freshwater, agriculture degradation, increasing water salinity, soil degradation (Badarudeen, Damodaran, Sajan & Padmala, 1996), destruction of water gradient, and unbalance in freshwater potential (Todd 1980). The seawater intrusion in Jakarta is a specific case of seawater intrusion in Indonesia. The high degradation and deforestation of mangrove ecosystem causes increased freshwater degradation and also the degradation of soil physic is another causing factor of seawater intrusion. This condition shows that mangrove vegetation has the function of retaining and reducing the potential and effect of seawater intrusion (Ellison & Farmsworth, 1997; Kairo, Dahdouh-Guebas, Bosire & Koedam, 2001).

Mangrove in Jakarta has many functions, for example, buffering of coastal area, habitat of flora and fauna and reduction of seawater intrusion. However, the important functions of mangrove ecosystem are the preservation of habitat for spawning, representing nursery and feeding grounds for several aquatic organisms (Nagelkerken et al., 2008; Kusmana, 2005; Hutchings & Saenger, 1987; Snedaker & Snedaker, 1984), reducing and retaining heavy metal pollution (Machado, Moscatelli & Rezende, 2002; Hilmi et al., 2014), reducing abrasion (Cai, Su, Liu, Li, & Lei, 2009; Hilmi 2014), reducing of tidal wave effect (Mazda, Kanazawa & Wolanski, 1995; Massel, Furukawa & Brinkman, 1999), and buffering of coastal stabilities (Mazda et al., 1995). To support this function, the mangrove ecosystem has the specific vegetations that are growing to interface between terrestrial and ocean ecosystem (Kusmana, 2005; Kathiresan & Bingham, 2001; Parvaresh et al., 2011; Hilmi, Syakti & Siregar, 2014). But, an important function of the mangrove in Jakarta is the function to reduce seawater intrusion.

The mangrove ecosystem has ability to reduce seawater intrusion because mangrove can eliminate the effect of salinity, pH, pyrites and anaerobe conditions. The mangrove ecosystem also has salt-excreting gland, salt-accumulating gland and salt-excluder gland (Bengen & Dutton, 2004), specific root (Alongi, Wattayakorn, & Boyle, 2004), root activity, salinity absorption, salinity accumulation, specific growth (Lunstrum & Chen, 2014) and another metabolism to reduce impact of seawater in mangrove metabolism. Therefore, the degradation and deforestation of mangrove ecosystem causing reduction of the mangrove function to reduce seawater intrusion. The objective of this research is to simulate correlation between seawater intrusion with the width of mangrove ecosystem. The research used Stella software, trend line analysis and datafit analysis.
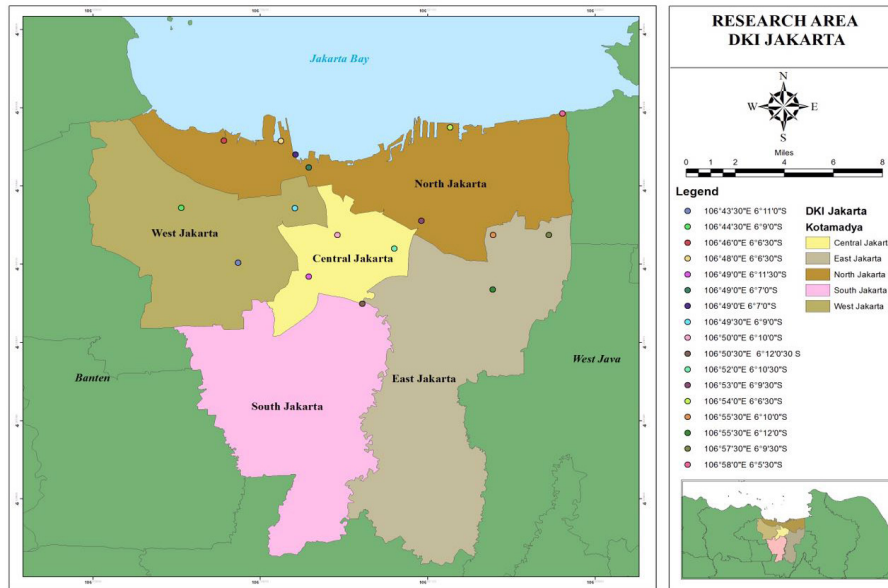
Remarks: O= sampling plots

Figure 1. Research sites

II. MATERIAL AND METHOD

A. Study Site

This research was conducted in North Jakarta (Figure 1). The research area is part of the coastal ecosystem (5°19'12" South Latitude (N) – 6°23'54" South Latitude (S) and 106°22'42' East Longitude (W) – 106 °58'18" East Longitude (E)) as the estuarine ecosystem to support water distribution from *Angke, Ciliwung*, and Cisadane rivers, as well as the North Java Ocean. Seawater intrusion is a big problem in North Jakarta. The high exploitation of freshwater with pumps and mangrove degradation (Hilmi, 1998) were the triggering factors of seawater intrusion. The locations of research for analysis of mangrove domination were Greenbelt North Jakarta, *Suaka Margasatwa Muara Angke*, and Ecotourism in North Jakarta and Silvofishery Area in North Jakarta. The sampling plots were U1 (106°43'30"E – 06°11'00"S), U2 (106°44'30"E – 06°09'00"S), U3 (106°46'00"E – 06°06'30"S), U4 (106°48'00"E – 06°06'30"S), U5 (106°49'00"E – 06°11'30"S), U6 (106°49'00"E – 06°07'00"S), U8 (106°49'10"E – 06°07'00"S), U9 (106°49'30"E – 06°09'00"S), U10 (106°50'00"E – 06°10'00"S), U11 (106°50'30"E – 06°12'30"S),U12 (106°52'00"E – 06°10'30"S), U12 (106°53'00"E – 06°09'30"S), U13 (106°54'00"E – 06°06'30"S), U14 (106°55'30"E – 06°10'00"S), U15 (106°55'30"E – 06°2'00"S), U16 (106°57'30"E – 06°09'30"S), U17 (106°58'00"E – 06°05'30"S).

B. Research Procedures

1. Research Variables

The variables of seawater intrusion were the distance of seawater intrusion, water quality, water salinity, soil porosity, the density of mangrove ecosystem, and the width of mangrove greenbelt.

2. Sampling Technique

The collection of research data used clusters with stratified sampling (Cochran, 1997) following the density of mangrove. The sampling design to observe the density of mangrove, the area of mangrove ecosystem, water salinity, distance of seawater, soil properties and the width of mangrove greenbelt used 17 sampling stations with three

Table 1. Standard criteria of mangrove degradation (Ministry of Environment Decree No 2004)

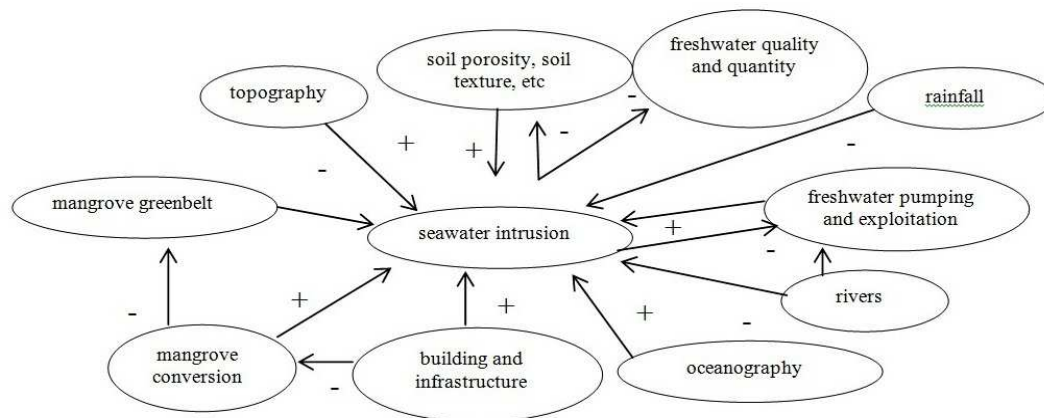| Degradation class	Density criteria	Mangrove coverage	Mangrove density level (trees/ha)
No degradation	Dense	≥ 75	≥ 1500
	moderate	≥ 50-≥ 75	≥ 1000 - < 1500
Degradation	rare	< 50	< 1000

Figure 2. Causal loop modeling of seawater intrusion

replications. The number of sampling plots were (1) North Jakarta (7 stations), (2) West Jakarta (3 stations), (3) Central Jakarta (3 stations) (4) East Jakarta (3 stations) and (5) South Jakarta (only one station).

3. Width and Area of Mangrove Greenbelt

The research procedure to analyze the width and the potential area of mangrove greenbelt used geographical information system (Prahasta, 2008; Purwadhi 2001) to overlay satellite imageries for 1980, 2000, 2010, and 2016. The satellite imagery interpretation used ERR mapper software. After interpreting with ERR mapper, the width and mangrove area was analyzed by Arc GIS 9.1.

4. Mangrove Density

The density of mangrove ecosystem (collection of all species) used the modification of quadrant transect method (Kusmana, 1997). The collection of data used plot sizes of 10

m x 10 m for mangrove trees, 5 m x 5 m for mangrove saplings and 2 m x 2 m for mangrove seedlings. These activities were carried out in Greenbelt North Jakarta, Suaka Margasatwa Muara Angke, Ecotourism in North Jakarta, Silvofishery Area in North Jakarta and other areas as research stations. To calculate the density of mangrove the equation below was used (Kusmana, 1997; Bengen, 2002).

$$\text{Di} = \frac{ni}{A} \qquad (1)$$

Where:

Di = density, ni = number of individuals (seedlings, saplings and trees) and A = mangrove area (ha)

For degradation of mangrove ecosystem the mangrove degradation criteria was used from Menteri Lingkungan Hidup No. 201 in 2004 (Table 1) which was divided into degraded and not degraded.

5. Water Salinity, Soil Salinity and Soil Porosity

The measurement of water salinity used APHA (2005) method with hand refractometer. The measurement of soil texture used gravimetric method. The soil analysis was done at the Soil Laboratory of Land Resources and Soil Departement, Bogor Agricultural University (Soil Research Department, 2005).

6. Potential of Seawater Intrusion

The measurement of seawater intrusion distances used water salinity method in the water pump with hand refractometer. The sampling points of water salinity were marked by global positioning system to measure the distance of seawater intrusion (km).

C. Data Analysis

1. Mapping of Mangrove Greenbelt

The mapping of mangrove greenbelt used Arc GIS 9.1 to overlay mangrove area from 1980, 2000, 2010 and 2016. These data were used to calculate mangrove area in Jakarta.

2. Modeling of Seawater Intrusion.

The seawater intrusion model used casual loop system among variables to develop the seawater intrusion model. The variables of causal loop system in this model were freshwater demand, oceanography effect, mangrove potency, river debits, runoff, rainfall, topography, and freshwater resource (Figure 2).

3. Modeling of Water Salinity

The modeling of water salinity used casual loop system among soil and water salinity. The variables of this model were Ca, Mg, Na, K, water salinity and pH in mangrove and other areas.

4. Relation between Mangrove Greenbelt and Seawater Intrusion

The relation between seawater intrusion and mangrove greenbelt used the trend line analysis l with the equation below (Steel & Torrie, 1980; Hilmi et al, 2014; Hilmi, 1998; Muhidin et al., 2011).

$$Y_{ij} = f(X_i) \qquad (2)$$

Where:

Y_{ij} = distance of seawater intrusion (Km)

X_i = width of mangrove (m)

f = mathematic function (exponential, linier, etc.)

The trendline equation was a statistic method to construct and select the best equation of seawater intrusion. This equation interpreted the estimation and relation between the width of mangrove greenbelt and the distance of seawater intrusion.

III. RESULT AND DISCUSSION

A. Density of Mangrove Ecosystem

The garbage, domestic waste, agriculture waste, pollution of oils and heavy metals, deforestation and conversion of mangrove ecosystem were the triggering factors of the mangrove density (Hilmi, 1998) The mangrove density in Table 2 show the classification of mangrove density in Jakarta. Mangrove must have tolerance toward extensive erosion, abrasion (Paris et al., 2009), heavy metal pollution (Wang et al., 2012), soil sedimentation (Ferreira, Vidal-Torrado, Otero & Macias, 2010), seawater inundation, sea tide, garbage, pollution (Krauss et al., 2008), oceanography, freshwater supply (Finkl, 2004) and climate change (Robins et al., 2016) to live and grow in the coastal area of Jakarta. Mangrove has good grows when water salinity is between 10 – 30 ppt and pH is about 6-9 (Hutchings & Saenger, 1987; Snedaker & Snedaker, 1984) with soil textures which are sandy clay, clayey sand, silty sand, sandy silt, clayey silt, silty clay, clay, sand and silt (Pirzan, Gunarto, Daud & Burhanuddin, 2004).

Table 2 shows that the mangrove area in the greenbelt, ecotourism, and preservation areas of Muara Angke and Silvofishery had differences in density and species domination of the mangrove vegetation. Table 2 also shows that *Rhizophora apiculata*, *Rhizophora mucronata*, *Avicennia alba* and *Sonneratia alba* were the mangrove species dominating in North Jakarta,

Table 2. Mangrove density in Jakarta.

Mangrove Area	Species	Mangrove density (trees ha^{-1})			Class of forest degradation (Kusmana, 2005; Hilmi et al, 2011, KemenLH 201, 2004)
		Seedlings	Saplings	Trees	
Greenbelt North Jakarta	*Avicennia alba*	30000	2691	92	rare
	Rhizophora mucronata	40000	883	17	
Suaka Margasatwa Muara Angke	*Rhizophora apiculata*	2500	1000	0	rare
	Sonneratia alba	2000	1183	50	
Ecotourism in North Jakarta	*Avicennia alba*	30000	2773	127	rare - moderate
	Rhizophora apiculata	0	483	17	
	Rhizophora mucronata	13333	1350	50	
Silvofishery Area in North Jakarta	*Avicennia alba*	0	360	40	rare
	Rhizophora apiculata	0	252	15	
	Rhizophora mucronata	0	218	15	

because these species have the highest tolerance for garbage, domestic waste, oil, heavy metal and sea inundation. The mangrove density in Jakarta showed that (1) mangrove density in the greenbelt area was 1650 trees ha^{-1} (diameter > 4 cm) and 109 tree ha-1 (diameter > 10 cm) (rare), (2) *Suaka Margasatwa Muara Angke* had density about 433 trees ha^{-1} (diameter > 4 cm) and 50 trees ha^{-1} (diameter > 10 cm) (rare), (3) ecotourism area had density about 2800 trees ha^{-1} (diameter > 4 cm) and 194 trees ha^{-1} (diameter > 10 cm) (rare – moderate) and (4) silvofishery area had density of 900 trees ha^{-1} (diameter > 4 cm) and 70 trees ha^{-1} (diameter > 10 cm) (rare).

The low density of mangrove trees (Macintosh, Ashton, & Havanon, 2002) showed the degradation of mangrove ecosystem in Jakarta and had been categorized as rare – moderate density (Kusmana, 2005, Hilmi et al., 2011 and KLHK, 2004). Macintosh et al., (2002) noted that the main reason for the loss and degradation and deforestation of mangrove were population pressure, wood exploitation, mangrove conversion, sand mining and coastal conversion. Another factors effecting the density and stabilization of mangrove ecosystem were silviculture-oriented, economic and ecological conditions (Lunstrum & Chen, 2014).

In Jakarta, the degradation and deforestation of mangrove ecosystem were the key factors for seawater intrusion. The integration between deforestation and degradation of mangrove ecosystem with freshwater pumping, mangrove conversion, settlement, industry and hotel caused increasing seawater intrusion in Jakarta. The conversion of the mangrove ecosystem in Jakarta was a triggering factor for losing the role of the mangrove ecosystem to reduce seawater intrusion. The rate of mangrove degradation, conversion and mortality increasingly gave impact for reducing the function of mangrove as the buffer area to preserve coastal stabilization and to reduce negative impact of seawater intrusion.

Redesigning of rehabilitation and replanting activity of mangrove ecosystem aimed to reduce sea water intrusion based on the natural regeneration of mangrove species in North Jakarta. Basically, the mangrove ecosystem in Jakarta is going to do a succession process, because mangrove in Jakarta has 2000 – 40.000 individual/ha (seedlings) and 400 – 1.663

Table 3. Area of mangrove ecosystem in North Jakarta Coast

No.	Year	Mangrove Area (ha)
1.	1980	1165.33
2.	2000	168.00
3.	2010	171.35
4.	2016	165.28
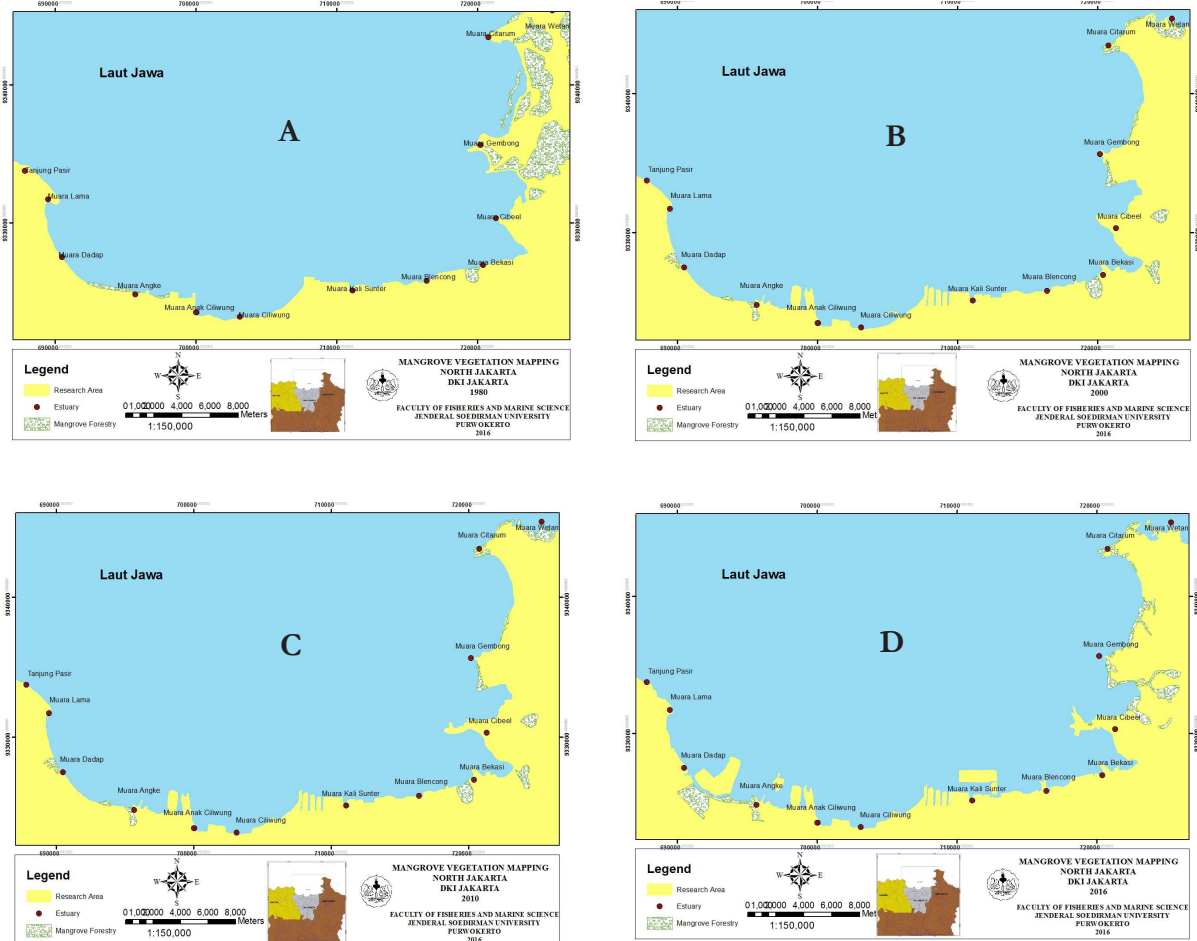
Remarks:
A: North Jakarta Coast in 1980, C: North Jakarta Coast in 2010,
B: North Jakarta Coast in 2000, D: North Jakarta Coast in 2016

Figure 3. The trend of mangrove ecosystem in Jakarta

individual/ha (saplings). The maintenance activities of seedlings and saplings will make mangrove grow well. The activity of mangrove succession is an effort to support mangrove growth in the coastal area (Chebo, 2009; Kathiresan & Rajendran, 2005; Kusmana, 2005; Macintosh et al., 2002). The existence of seedlings and saplings of mangrove vegetation in the succession of mangrove must be conserved as the dynamic process of mangrove ecosystem to reach vegetation climax (Kusmana, 2005; Lopes et al., 2009; Macintosh et al., 2002).

The other activity to conserve mangrove

ecosystem in Jakarta was mangrove plantation (Kusmana, 2005). The mangrove plantation must see the complex and dynamic system of mangrove environment (Lopes et al., 2009). The mangrove plantation in Jakarta must select mangrove species based on best domination in Jakarta area, because these species have the best possibility to survive and density to support the successful mangrove rehabilitation. The species to support the rehabilitation program in mangrove ecosystem were: *Rhizophora apiculata*, *Rhizophora mucronata*, *Rhizophora stylossa*, *Avicennia alba*, *Sonneratia alba* and *Bruguiera* spp.

B. Dynamic Analysis of Mangrove Ecosystem

The dynamic of mangrove ecosystem showed the rate of mangrove regeneration and conversion (Table 3 and Figure 3). Based on data from 1997, the mangrove area in Jakarta was 322.6 ha (Hilmi, 1998) of which 169.9 ha was mangrove forest area and 152.7 ha was for other usage. The degradation rate of mangrove ecosystem reached 9.3% year. The biggest factor of mangrove degradation in Jakarta was the conversion of mangrove for settlement and other activity

Jakarta was moderate-high. The mangrove areas in Jakarta were 1165.33 ha (1980), 168 ha (2000), 171.35 ha (2010) and 165.28 ha (2016). These data also showed that the area in Jakarta decreased by 1000.05 ha (over 36 years) from 1165.33 ha (1980) to 165.28 ha (2016).

Table 2 and Figure 3 show that the rate of mangrove degradation and deforestation in Jakarta had a positive correlation with mangrove density (Table 1). The high rate of mangrove conversion and mortality were the key factors for mangrove density and degradation. Basically, the mangrove ecosystem has high sensitivity toward environment change and conversion. Sedimentation, garbage, industry and domestic waste, mangrove cutting and mangrove exploitation, freshwater flood, seawater flood and long inundation were the biggest factors of mangrove degradation and deforestation (Chebo, 2009; Krauss et al.,

2008 and Xiao, Wang & Chen, 2010). The mangrove ecosystem was also sensitive and responsive toward climate change and human activity, the eco-geo-morphological processes and pressures (Al-Nasrawi, Jones & Hamilton, 2016). Therefore mangrove degradation and deforestation in Jakarta caused mangrove to stunt, dying, degradation of mangrove structure and mortality (Ellison & Farmsworth, 1997; Ellison, 2002).

The high mangrove degradation and deforestation also caused mangrove recovery and regeneration to be very difficult. Mangrove vegetation needs a long time to regenerate and recover to reach tree phase. The mangrove degradation was a triggering factor for coastal disasters including seawater intrusion. According to Salampessy et al., (2015), mangrove degradation, mangrove conversion, water unbalance and destruction of water gradient increased seawater intrusion in Jakarta. The conversion of mangrove ecosystem also was due to accelerated sea-level rise, seawater intrusion and land subsidence.

C. Prediction of Seawater Intrusion in Jakarta

Factors to predict seawater intrusion are: freshwater demand from industrial activity, settlement and hotel, sea tide, season, oceanographic, mangrove density, rivers' debit, source of freshwater and topography. Prediction of seawater intrusion in Jakarta with or without mangrove is shown in Table 4, Figure 4 and Figure 5. They show the existence of seawater in the coastal area, degradation of fresh water gradient, freshwater aquifer damage, and overexploitation of freshwater were the important factors of seawater intrusion in the coastal area of Jakarta (Andrari et al., 1996). The environmental degradation (seawater and freshwater aquifer) caused the change in hydraulic gradient of aquifer, accelerated the progressive landward invasion of seawater toward the abstraction wells, destructive for the chemical quality, water pollution and surrounding groundwater followed by other

Table 4. The prediction of the distance of seawater intrusion along Jakarta Coast

Year Prediction	Intrusion in Jakarta (km)	
	With mangrove	Without mangrove
1	1.85	8.90
2	2.05	9.25
3	2.24	9.59
4	2.44	9.94
5	2.64	10.29
6	2.84	10.64
7	3.03	10.98
8	3.23	11.33
9	3.43	11.68
10	3.63	12.03

problems such as decrease of freshwater availability, human health and ecosystem damage (Hussain et al., 2015; Howard, 1987; Patel & Shah, 2008).

Basically, the coastal aquifers are very vulnerable toward seawater intrusion because of the overexploitation of the coastal aquifers. Seawater intrusion models are more efficient tools for coastal aquifer management and protection. The disperse interface approach explicitly represents a transition zone or a mixing zone of the freshwater and saltwater within an aquifer due to the effects of hydrodynamic dispersion (Pramada & Mohan, 2015; Park, Kim, Yum, & Yeh, 2012). The instability of freshwater and seawater system in coastal aquifers due to overexploitation produces the landward movement of the seawater wedge. The hydraulic barriers method has the function to reduce seawater invasion with the injection of freshwater and raising aquifer's hydraulic head. The sensitivity of the rate and location to inject water used two laboratory-scale sandboxes under hydraulic confinement to measure the wedge length reduction. The coastal aquifers are principal sources of freshwater in various parts of the world due to their groundwater quantity and quality, suitable to cover water needs of cities, rural villages and agricultural and industrial activities (Acosta & Donado, 2015; Carruthers et al., 2013)

The seawater intrusion prediction with or without mangrove vegetation showed that mangrove ecosystem has an important role in reduction of seawater intrusion in Jakarta. The simulation model also explained the role and function of mangrove to prevent, release and reduce seawater intrusion (Soerianegara, 1987; Hilmi, 1998). The simulation of seawater intrusion model with or without mangrove vegetation used freshwater demand for industry, settlement, community, seawater tide, seawater inundation, rivers' debit, freshwater capacity, topography, rain intensity and mangrove density as elements of this model (Figure 4).

The design of seawater intrusion model used freshwater demand for industry $1,98$ m^3t^{-1}, domestic need 4.31 m^3t^{-1}, hotel and settlement 2.11 m^3t^{-1}, seawater tide 0.61 m, seawater level approximately 0.47 m, and domestic freshwater demand in Jakarta approximately 11.3 m^3t^{-1}, topography between -7 m to 10 meter, rain intensity 1750 mm $year^{-1}$, river debit 13.23 m^3dt^{-1}, and mangrove density and mangrove area in seawater Based on seawater mapping it showed that (1) if the width of mangrove greenbelt was 75 m, the distance of seawater intrusion reached 1 km, (2) if the width of mangrove greenbelt was 90 m, the distance of seawater intrusion was approximately 950 m, (3) if the width of mangrove greenbelt 115 m, the distance of seawater intrusion reached 800 m,
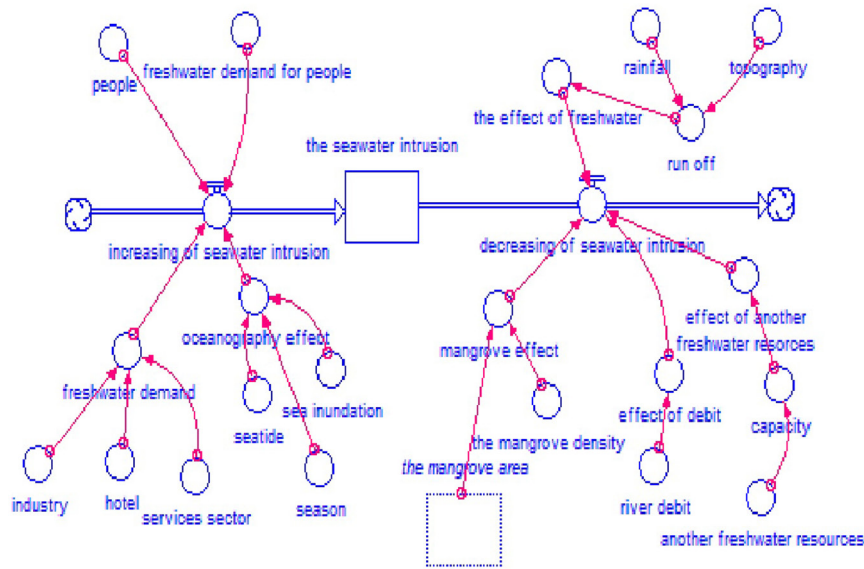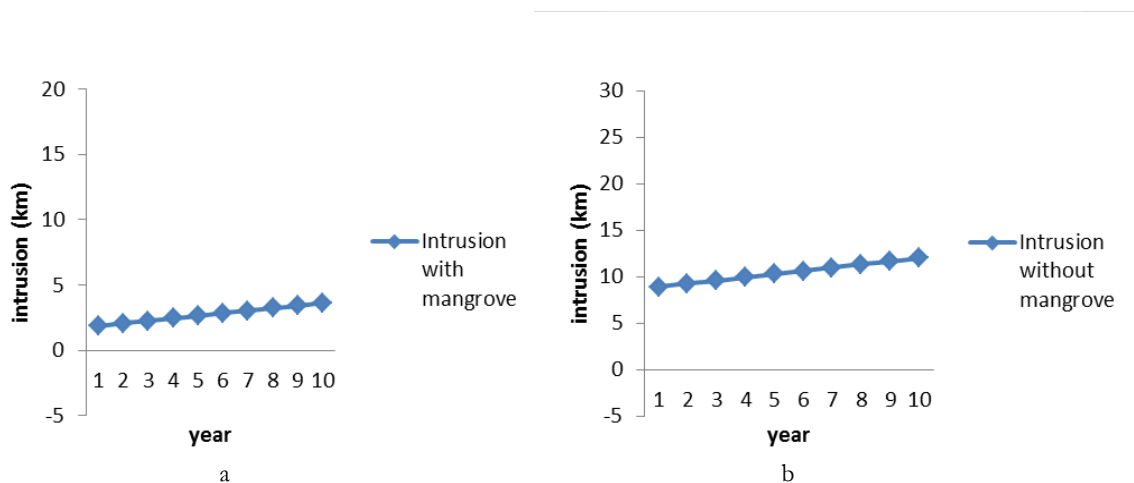
Figure 4. Diagram of modeling seawater intrusion

Remarks :   a. The trend in distance of seawater intrusion with mangrove
                             b. The trend in distance of seawater intrusion without mangrove

Figure 5. The trend of seawater intrusion prediction

(4) if the width of mangrove was more than 115 meter, the distance of seawater intrusion was 500 m - 600 m, and (5) if the width of mangrove < 85 meters, the distance of seawater intrusion reached until 1650 meters.

The simulation model of seawater intrusion shows the combination between freshwater consumption, soil texture, soil pore, soil porosity, topography, (Hilmi, 2003), organic matter (Kairo et al., 2008), density and mangrove zonation (Kairo et al., 2008; Bosire et al., 2005). The simulation model showed that the rate of seawater intrusion is about 0.20 km (with mangrove as a system component), and is about 0.30 – 0.40 km (without mangrove as a system component). The trend of seawater

intrusion in Jakarta is not different from seawater intrusion in Semarang which has increased by 0.575 km² years⁻¹ (Suhartono, Purwanto & Suripin, 2015).

Table 3 also shows that mangrove has an important role to play to reduce the rate of intrusion in Jakarta. Mangrove has ability to reduce seawater intrusion because (1) mangrove vegetations have salt excreation gland, salt accumulation gland, and salt excluder gland (Hamilton & Snedaker, 1984; Hilmi, 2014; Kusmana, 2005; Snedaker & Snedaker, 1984), (2) the decomposition of mangrove litter as the organic matter resource impacts the reduction of the salinity of freshwater. (Bosire et al., 2005), (3) root of mangrove vegetation has ability to prevent seawater penetration to land, (4) the root activity is a mangrove metabolism to recover soil characteristic and dilute salinity of soil water, (5) the extract matter metabolism is mangrove ability to decrease salinity of water (Sigalingging, 1985) and (6) the spesific architecture of mangrove root systems has function to release the negative impact of seawater intrusion (Purnobasuki & Suzuki, 2004).

In Jakarta, the existence of mangrove is a fragile ecosystem because conversion, illegal logging, waste, oil pollution, pesticide pollution, domestic waste, industry waste, etc occures in the mangrove ecosystem. But, mangrove is a resilient ecosystem to live in a wide range of environmental variables (Petrakis et al., 2016), including in freshwater. However, these factors still contribute to have a big impact on the sustainability of mangrove ecosystem in Jakarta. The degradation and mortality of mangrove ecosystem are critical factors (Xiao et al., 2009) that will increase seawater intrusion in Jakarta.

Basically, the ability of mangrove ecosystem to reduce seawater intrusion (Hilmi, 1998; Hilmi et al., 2014) is an important role to keep the sustainability of the ecological function and life supporting system to reduce and prevent seawater entry to land (Hilmi, 1998; Soerianegara, 1987). Seawater intrusion also has correlation with mangrove density which influences the litter degradation process, nutrient demineralization and efficiency of the ecological processes (Bosire et al., 2005). Mangrove also has ability to breakdown organic material in the mangrove ecosystem thus rapidly supporting the recycling of organic matter (Marchand, Allenbach & Lallier-Vergès, 2011; Bosire et al., 2005), increase ability to adsorbent, adsorption and absorption mechanism for organic matter, salinity and other material (Oo et al., 2009), increase supporting the nitrogen process in coastal ecosystem (Kadlec, 2008), reduce water pollution (Narayana et al., 2007) and has high primary productivity. The high productivity is often attributed to high litter degradation rates and efficient recycling of nutrients (Bosire et al., 2005) and finally give effect to release seawater intrusion (Cochard et al., 2008). Based on this reason, mangrove is an important ecosystem as the buffer ecosystem to reduce seawater intrusion (Sigalingging, 1985). Therefore mangrove rehabilitation and area redesign in Jakarta aimed to increase mangrove function to reduce seawater intrusion (Macintosh et al., 2002; Huang et al., 2003) is needed.

D. Effect of Seawater Intrusion on Freshwater Quality

The salinity degree of freshwater was a variable to predict seawater intrusion in the coastal area, and Ca, Mg, Na, Cl and K were used as potential variables to predict the freshwater quality in Jakarta coast. The rate of salinity degree also showed the influence of mangrove ecosystem for prediction of freshwater quality in the seawater intrusion area (Table 5, Figure 6 and 7). This simulation model used mangrove as a main factor to determine the trend of water salinity, because mangrove has secreting, filtering and accumulating processes to reduce water salinity in the coastal area (Hamilton & Snedaker, 1984; Hilmi, 2014; Kusmana, 2005; Snedaker & Snedaker, 1984). The result of this simulation model showed the correlation between mangrove ecosystem with salinity degree of freshwater in the coastal area.

Table 5. Rate of water salinity in Jakarta

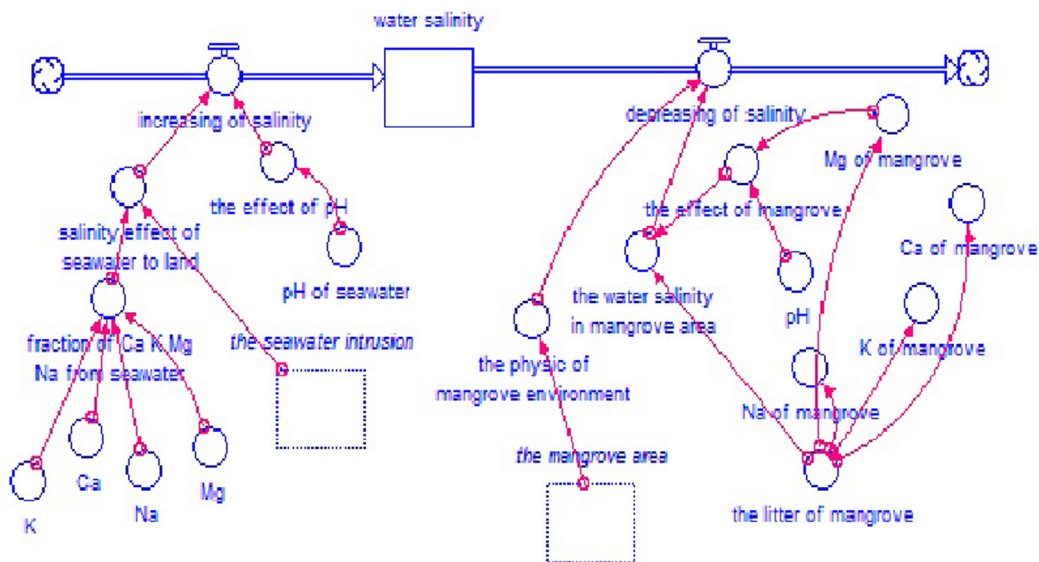| Year prediction	Rate of Water Salinity (ppt)
1	1.92
2	2.25
3	2.57
4	2.90
5	3.23
6	3.55
7	3.88
8	4.20
9	4.53
10	4.86

Figure 6. The modeling diagram of water salinity

The result of this simulation model in Figure 7 and Table 5 showed a raising trend of water salinity in Jakarta. The degree of water salinity in Jakarta was predicted between 1.92 ppt (the first year) to 4.86 ppt (year ten). The degree of water salinity was an indicator to analyze sea water intrusion. Todd (1980) noted that seawater intrusion occurred because the quantity of freshwater supply was less than seawater supply causing seawater completely entering into the groundwater as the seawater process in the coastal area.

The rate of seawater intrusion showed an increasing exploitation of freshwater by domestic, hotel, and industry pump. The increasing seawater intrusion caused the high rate of existence and distribution of water salinity in the freshwater ecosystem. The progressive rate of seawater entry to land became a water pollutant for freshwater in Jakarta. The positive trend of seawater intrusion in Jakarta showed significant correlation between mangrove
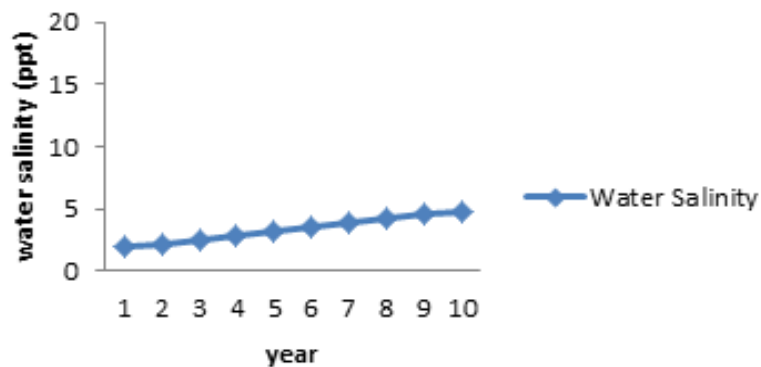
Figure 7. Trend of water salinity in Jakarta

degradation and freshwater demand with seawater intrusion as the significant effect for a destructive barrier line between freshwater and seawater. This condition was a triggering factor for the incidence of seawater intrusion.

E. Equation between Seawater Intrusion and Mangrove Greenbelt

Seawater intrusion and mangrove greenbelt were the variables in the model for estimation of seawater intrusion and the width of mangrove greenbelt. The trend line analysis was used to construct this model (Figure 8). The first equation showed that the distance of seawater intrusion (m) = 2264.9 * exp(-0.009 * the width of mangrove greenbelt (m)) with determination coefficient (R^2) = 94.65 % (Figure 7). The second equation showed that the width of mangrove greenbelt (m) = 781.76 * exp(-0.002 * seawater intrusion (m)) with determination coefficient (R^2) = 62.62 %.

Figure 8 shows that the correlation between seawater intrusion and mangrove width was of a negative exponential model. This model showed that mangrove greenbelt had negative correlation with seawater intrusion. Mangrove greenbelt has the role to reduce seawater intrusion (Hilmi, 2003; Ellison & Farmsworth, 1997; Kairo, Dahdouh-Guebas, Bosire, & Koedam, 2001). This equation also showed that mangrove greenbelt was a main indicator of seawater intrusion in the coastal area. The

ability of mangrove ecosystem to reduce seawater intrusion was the linkages with salt excretion, accumulation and exclusion activity. Based on the result of this equation it shows that to release seawater intrusion (the distance = 0 m) there is a need of a mangrove greenbelt approximately of 1.000 m width. and based on the optimal line, Jakarta needs to optimize a mangrove greenbelt of more than 115 m in width.

F. Strategy to Reduce Seawater Intrusion

This strategy aimed to reduce seawater intrusion. The design of mangrove rehabilitation used the following systems:(1) conservation and maintenance of mangrove seedlings, saplings and trees and (2) mangrove species plantation. This design has the purpose to increase mangrove density, biodiversity, ecological function and ecosystem resilience (Macintosh et al., 2002) as a conservation effort of mangrove ecosystem to increase allocation of area to rehabilitate integrated with environmental measures, ecosystem planning and management and complementing the approach of formally protected reserves (Simonsson, Ostlund, & Gustafsson, 2016)

The first stage, to take the best result of mangrove planting, was the selection of mangrove species based on the best ability of mangrove species to reduce seawater intrusion. Mangrove species have different
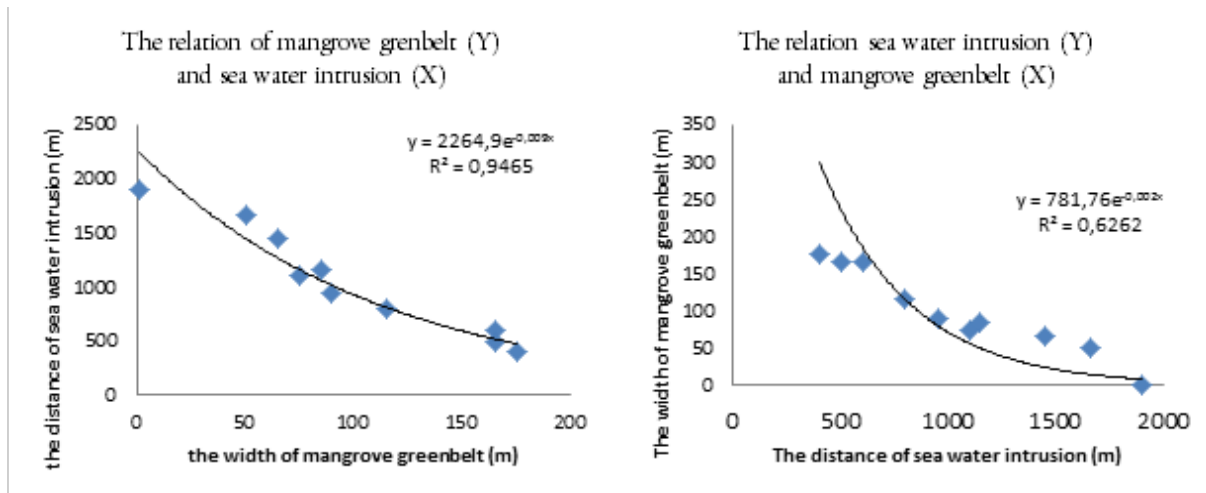
Figure 8. The estimation model for the width of mangrove greenbelt
and the distance of seawater intrusion

ability to secrete, accumulate and refuse water salinity. Based on the capacity of water salinity reduction *Avicennia marina*, *Avicennia alba* and *Sonneratia* spp., *Rhizophora apiculata*, *Rhizophora mucronata*, *Bruguiera* spp. are the best suited species for this purpose (Nurmayasri, 1999; Hutchings & Saenger, 1987; Hilmi, 1998). Basically mangrove plantation will construct a mangrove zone aiming to reduce seawater intrusion and to improve habitat changes, water salinity, soil texture and soil fertility (Sandoval-Castro et al., 2012)

Therefore, the priority selection of mangrove species in mangrove zone should use the capacity of salt secretion, accumulation and exclusion gland (Macintosh et al., 2002), mangrove density, growth rate, mangrove root, and another environment factors. The dominant species were (1) grade 1 was *Avicennia marina*, Avicennia alba, *Rhizophora stylosa*, *Sonneratia alba* and *Sonneratia caseolaris*, (2) grade 2 was *Rhizophora apiculata*, *Ceriops* spp., *Rhizophora mucronata*, (3) grade 3 was *Bruguiera gymnorrhiza*, *Bruguiera praviflora*, *Aegiceras* spp., and (4) grade 4 was *Xylocarpus* spp., and *Nypa frutican*.

IV. CONCLUSION

In Jakarta, the existence of mangrove and freshwater demand are the triggering factors for increasing seawater intrusion. The rate of seawater intrusion in Jakarta will reach 0.20 km year^{-1} (with mangrove) is lower than the rate of seawater intrusion approximately 0.3 – 0.4 km year^{-1} (without mangrove). The mangrove degradation reached 1000.05 ha (over 36 years) from 1165.33 ha (1980) to 165.28 ha (2016). The design of mangrove plantation is used to reduce seawater intrusion.

The width of mangrove greenbelt to reduce seawater intrusion is the width of mangrove greenbelt (m) = 781.76* exp(-0.002* seawater intrusion (m)). Based on this equation Jakarta needs a distance of mangrove greenbelt of more than 115 m with species priority of *Avicennia marina*, *Avicennia alba*, *Rhizophora apiculata*, *Rhizophora stylosa*, *Sonneratia alba* and *Sonneratia caseolaris*.

The activity of coastal rehabilitation to reduce seawater intrusion in Jakarta's coastal area is only using the ability of mangrove vegetations and the width of mangrove greenbelt as the main factors. Therefore, the next research should use the mangrove zone as the important factor to reduce high sea waves, seawater flooding and abrasion.

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