

Salinity Pattern in Semarang Coastal City: An Overview

Pola Salinitas di Pesisir Kota Semarang: Suatu Tinjauan

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ABSTRACT

Semarang Coastal City is one of cities in Indonesia which has experienced a long-term salt intrusion. Land subsidence and groundwater exploitation were identified as main factors accelerated salt intrusion in this area. Extended salt intrusion into the land from year to year cannot be neglected. Salinity pattern and land use affected by this intrusion must be identified. Salinity pattern could be identified by electrical conductance content. The purposes of this research are: a) to define spatial electrical conductance map from 1995 to 2008 and b) to identify salinity pattern in each land use. Primary data set of electrical conductance measurement in 2004 and 2008 was performed. Secondary data set of electrical conductance was collected in 1995 and 2000. Electrical conductance mapping was assigned by point interpolation using GIS Environment. Land use classification was interpreted from topographical map and IKONOS using GIS Environment. Field check of land use was also done in the study area. Geologically, the area setting consists of Damar, Kalibiuk, and Breccias Formations, where the Damar Formation is the recharge source for groundwater in Semarang City. Based on the result, it can be concluded that the salinity content in groundwater increased from 1995-2008. In 1995, there was only 2.4% of brackish groundwater in Semarang Coastal City, but in 2008, most of area in that region was classified as saline. Land use conversion into built up area increased from 1998 to 2008. The area intruded by salt water increased within 1995, 2004, and 2008 periods. About 68 % of the area contained brackish water and most of the area were built up area in 1995. In 2004, no fresh groundwater found in Semarang Coastal City and the area of brackish groundwater reached 77% and about 23% was saline groundwater which 82% of the built up area included brackish groundwater. In 2008, approximately 55% of Semarang Coastal City was occupied by saline groundwater. About 51% of groundwater built up area was saline.

Keywords: electrical conductance, land use, salinity pattern, Semarang Coastal City

ABSTRAK

Kota Pesisir Semarang adalah salah satu dari kota di Indonesia yang mengalami intrusi air asin dalam kurun waktu yang lama. Amblesan tanah, perubahan iklim, dan eksploitasi airtanah diidentifikasi dapat menjadi salah satu faktor semakin parahnya intrusi air asin di daerah tersebut. Persebaran intrusi air asin ke arah daratan dari tahun ke tahun tidak dapat diabaikan. Pola salinitas dan penggunaan lahan yang terkena dampak intrusi sebaiknya diidentifikasi. Pola salinitas dapat diidentifikasi dari kandungan DHL (Daya Hantar Listrik). Tujuan dari penelitian ini adalah untuk: a) menentukan peta DHL secara spasial dari tahun 1995 sampai 2008 dan b) menentukan pola salinitas pada tiap penggunaan lahan. Data primer berupa pengukuran DHL tahun 2004 dan 2008 telah dilakukan. Data sekunder pengukuran DHL di tahun 2004 dan 2008 telah dikumpulkan. Pemetaan DHL dianalisis melalui interpolasi titik menggunakan software SIG. Klasifikasi penggunaan lahan diinterpretasi dari peta topografi dan IKONOS menggunakan SIG. Cek lapangan untuk penggunaan lahan juga dilakukan di daerah penelitian. Kondisi geologi tersusun oleh Formasi Damar, Kalibiuk, dan Formasi Breksi, sementara Formasi Damar merupakan sumber recharge airtanah di

Kota Semarang. Berdasarkan hasil penelitian, dapat disimpulkan bahwa pola salinitas pada airtanah meningkat pada 1995-2008. Tahun 1995, hanya 2.4% areal di Kota Pesisir Semarang berair payau, tetapi di tahun 2008, sebagian besar Kota Pesisir Semarang termasuk dalam air asin. Konversi penggunaan lahan menjadi lahan terbangun meningkat dari 1998 sampai 2008. Daerah yang terintrusi air asin meningkat selama periode 1995, 2004, dan 2008. Sekitar 68% daerah penelitian merupakan air payau dan sebagian besar daerah tersebut merupakan lahan terbangun di 1995. Di tahun 2004, tidak terdapat air tawar di Kota Pesisir Semarang; dari luasan area air payau yang mencapai 77%, sekitar 23% adalah air asin dengan 82% arealnya adalah berair payau. Tahun 2008, sekitar 55% dari Kota Pesisir Semarang airtanahnya adalah air asin. Sekitar 51% dari lahan terbangun mempunyai airtanah asin.

Kata kunci: *Daya Hantar Listrik, land use, pola salinitas, Kota Pesisir Semarang*

INTRODUCTION

Background

There are several basic terms in this paper as a framework how geology correlates with the geomorphology and how they control groundwater flow. Landform is a natural asset of geomorphology in the context of geomorphological resources. Land use is an expression of anthropogenic activity that influences geomorphology and geomorphology also effects on land use change (Hugget, 2007). Morphometric in geomorphology influences groundwater flow in terms of kinetic energy and hydraulic boundaries (LaFleur, 1999). Various landforms affect spatial and temporal salt pathways (Summerell *et al.*, 2006). Landform can also modify salinity concentration in groundwater, as also paleo-material and slope as geomorphology features influence groundwater's salt concentration (Bennetts *et al.*, 2006). Perry *et al.* (2009) presented that fresh-water lens are controlled by geomorphology features (such as fault, and high permeability layer).

However, anthropological influence to groundwater by land use expression can affect groundwater condition. Moreover, land use can affect water recharge, water supply and water quality changes (Lerner and Harris, 2009). While, geological parameter controls groundwater chemistry and distribution (Hasan *et al.*, 2009).

Another term, hydrogeomorphology, can be defined as the studies of spatial and temporal dimension of hydrologic process and landform or interrelation between geomorphology process and surface and sub-surface water (Poole, 2010). Lenahan and Bristow (2010) studied about spatial and temporal saline groundwater in floodplain, whilst Baird and Horn (1996) studies groundwater flow in sandy beaches. Then Datema (1989) presents groundwater chemical pattern in Central Java and West Java.

Related to the above terms and basic framework, this paper will discuss the groundwater quality setting in Semarang, and how it changes through time. Semarang is one of coastal cities in Central Java that has experienced salt intrusion. Seawater intrusion in Semarang Coastal Area is identified since 1990 (Purnama, 2005). Various landforms in this area must influence the movement and distribution of salt intrusion. Jeong (2001) studies land use effects on hydrogeochemistry condition including electrical conductance in groundwater. Moreover, Cho *et al.* (2009) had reviewed effect of land use change with groundwater level. Therefore, this research reviewed spatial and temporal saline groundwater and land use in Semarang Coastal Area. Understanding the correlation between salt intrusion and land use is the key to manage groundwater resources in the area.

Site Description

Semarang is a capital city of Central Java Province, Indonesia. This capital city is located in coastal area and lowlands of the Semarang City. Semarang Coastal City comprises 16 subregencies that are Mijen, Gunungpati, Banyumanik, Gajah Mungkur, Semarang Selatan, Candisari, Tembalang, Pendurungan, Genuk, Gayamsari, Semarang Timur, Semarang Utara, Semarang Tengah, Semarang Barat, Tugu, and Ngalian. There are 1,544,358 inhabitants live within the area of 386.51 km² in Semarang City (BPS Kota Semarang, 2012). Administrative boundary of Semarang City can be shown in Figure 1. These are the subregencies included in this discussion: Gajah Mungkur, Semarang Selatan, Genuk, Semarang Timur, Gayamsari, Tembalang, Semarang Utara, Semarang Tengah, Semarang Barat, Tugu, and Ngaliyan.

Relative flat topographies in Semarang City that can reach 225.31 km² (Rahmawati, 2010) occupying most of the Semarang City is coastal and

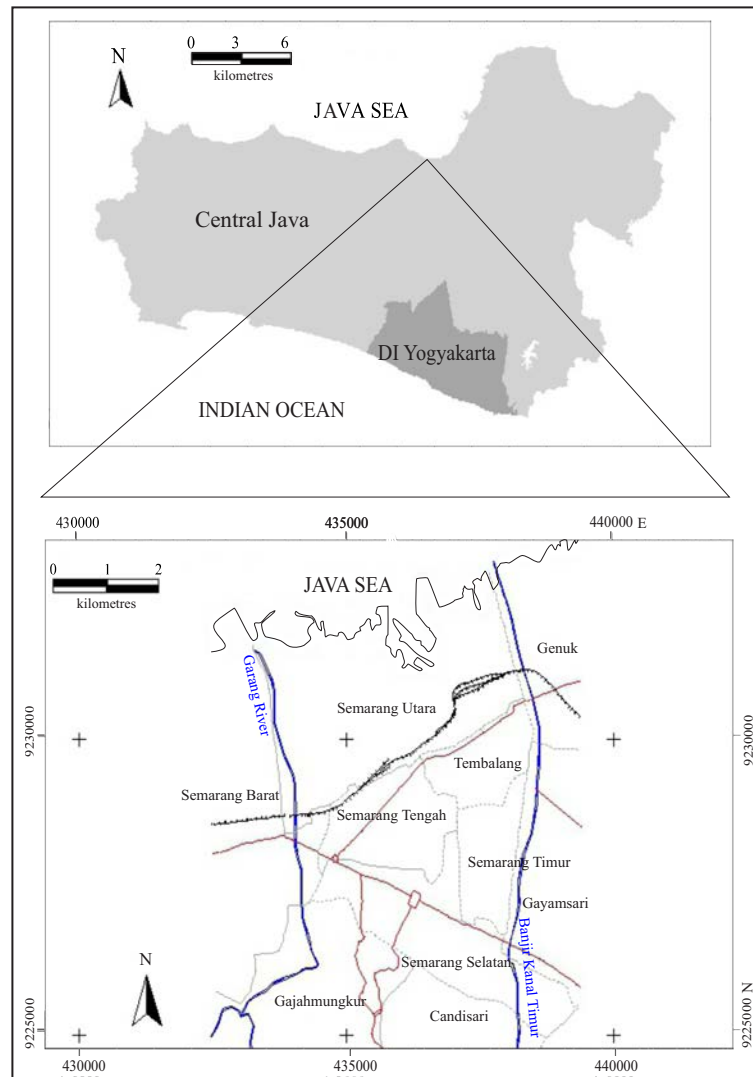


Figure 1. Locality map of Central Java and Yogyakarta Special Provinces that are focused on the study area in Semarang coastal city.

low land areas where the southern border of these areas are folded mountain. Geologically, setting of this coastal area is composed of alluvial sediment with alluvial soil. Alluvial sediment consists of sand, clay, and gravel. The age of this alluvial formation is Pleistocene. Based on Geological Map scale 1:100000, Magelang and Semarang Sheet (Thanden *et al.* 1996), the southern part of Semarang Coastal Area is bordered by fault line and hills. This hill is built by Damar, Kalibiuk and Breccias Formations. The Damar Formation comprises tuffaceous sandstone, conglomerats, volcanic breccias, and tuffs.

The Kalibiuk Formation consists of claystone, marl, and sandstone. The Breccias Formation is volcanic breccias, lava flows, tuffs, tuffaceous sandstone, and clay stone. According to Purnama (2005), groundwater recharge of Semarang City is from the Damar Formation. Depositional process dominated in this area since sedimentation rate from land was higher rate than from sea. According to Marfai *et al.* (2008), total sedimentation rate in a specific area of Semarang Coastal Area is 945 m from 1908 - 2003. Various abrasion and sedimentation face occurred in certain areas due to natural condition and reclama-

tion even though most of the years sedimentation face is higher than erosion rate. Moreover, wave activity in Java Sea located in north of Java Island was lower than in Hindia Ocean situated in south of Java Island. As a result, in this area deltas were formed. This area underwent land subsidence with the rate of subsidence is 2 cm/year to more than 8 cm/year closer to the sea (Kuehn *et al.*, 2010). Moreover, this city also has faced complicated problems in correlation with coastal flood. Total lost due to coastal flood can reach 1,812.8 million EUR, where the affected area can reach 1812.8 ha for not better case (Marfai and King, 2008).

Semarang Coastal City also is vulnerable for salt intrusion due to the contact with sea. Based on Purnama (2005) salt intrusion has occurred in coastal and low land areas in Semarang City. Moreover, since 1990, groundwater salinity in some areas has increased. Another issue was the increasing groundwater exploitation to 35.3 m³/year from 1990 - 1998 period (Marfai and King, 2007). Rahmawati (2010) presented that the groundwater exploitation activities in the coastal and low land areas make groundwater level drop significantly at the range of 0.5 - 1 m. Moreover, Hamandi (2007; in Kuehn *et al.*, 2010) stated that groundwater level decreased 15 m from 1984 to 2000. Many industrial, offices, and commercial buildings are set in this area. In addition, Tanjung Mas Harbour that is famous since Holland Colonization also exists in this area. This condition led to a higher pressure for groundwater exploitation to supply water demand. As a result, salt intrusion will be worse in the future.

METHODS

Time series primary and secondary data sets of groundwater sample were collected to identify salinity pattern in Semarang Coastal Area. Secondary data of groundwater sample was acquired in 1995 and 2000 from Ministry of Public Works. Primary data of groundwater was taken in 2004 and 2008. Saline groundwater classification was divided into three classes according to Todd and Mays (1970). Based on electrical conductance (EC) content, groundwater condition in the study area can be classified as fresh water, brackish water, and saline

water. EC value for fresh water is 0 - 600 $\mu\text{mhos/cm}$, for brackish water is 6,00 - 6,500 $\mu\text{mhos/cm}$, 6,500 - 65,000 $\mu\text{mhos/cm}$ is for saline water, and more than 65,000 $\mu\text{mhos/cm}$ is brine. Due to relative high resolution both in space and time, remote sensing data can be contributed to calibration and validation of hydrologic model such as landform, land use change, and land cover or climate change on hydrological system (Stisen *et al.*, 2008). This research used remote sensing and field checking to define a land use change in the study area. Land conversion is the type of land use change (Wang *et al.*, 2012). Time series aerial photographs were used to map land use by Hara *et al.* (2005). Spatial and temporal resolution of satellite imagery can be used for various cases and various researches (Marfai *et al.*, 2008). Multi data sources can be used for change detection analysis (Chalabi *et al.*, 2006). Marfai and King (2008) used topography map and IKONOS Image to detect land use changes. Therefore, this research used topography map and IKONOS for change detection of land use and water sampling. Land use analysis interpreted from topographic map published in 1998 which the field survey was on 1995, IKONOS 2004 and 2008. Universal Transverse Mercator (UTM) 49 S with WGS 1984 Spheroid was registered to IKONOS and topographic map. The material used for land use detection is explained in Table 1. Topographic map was used for base map. Manual digitations of land use in 2004 and 2008 were analyzed using ArcGIS 10. Field check was performed for land use in 2004 and 2008. Land use was classified into 6 main classes: bare land and garden, built up, fishpond, grass and shrub, rice field, and water body. This land use classification was adjusted to topographic map. The characteristic of land use was used to pattern behavior electrical conductance as an indication of salt intrusion such as the area influenced by salt intrusion.

Table 1. Data used for Land Use Classification

No	Type of data used	Scale/ Resolution	Year
1	digital topography map	1:25 000	1995/1998
2	IKONOS Image	1 m	2004
3	IKONOS Image	1 m	2008

RESULT AND DISCUSSION

Salinity Pattern

Salinity pattern in coastal area of the Semarang City illustrated further movement of saline water to landward. The value of electrical conductance increased continuously from 1995 to 2008. In 1995, western part of the Semarang Coastal City included Semarang Barat Regency suffered with brackish water. In southern and eastern parts of the Semarang Coastal City, their groundwater condition was fresh water even some of location was starting closely to brackish water. Figure 2 illustrates electrical conductivity map of the Semarang

Coastal City. Spatial salinity pattern in 2000 generally shows a rising value of electrical conductivity particularly Semarang Utara Subregency. It can be shown in Figure 3. The extend of saline water in 2004 is also broader than in 2000. The maximum value of electrical conductivity in this year could reach 24800 $\mu\text{mhos/cm}$ including saline groundwater. Most of the area of Semarang Coastal City was occupied by brackish water except in the southern part like Semarang Selatan Subregency. Figure 4 describes salinity pattern in the Semarang Coastal City. In 2008, electrical conductivity value was much higher than previous years that could be supported by an extensive salt intrusion. The maximum value

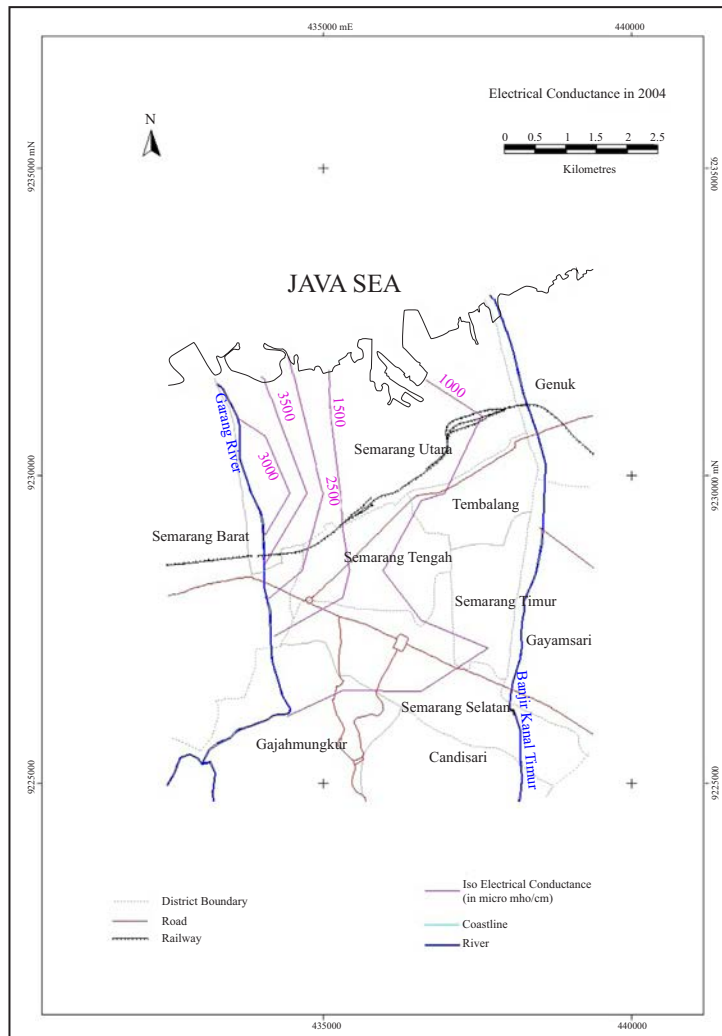


Figure 2. Electrical conductance in 1995.

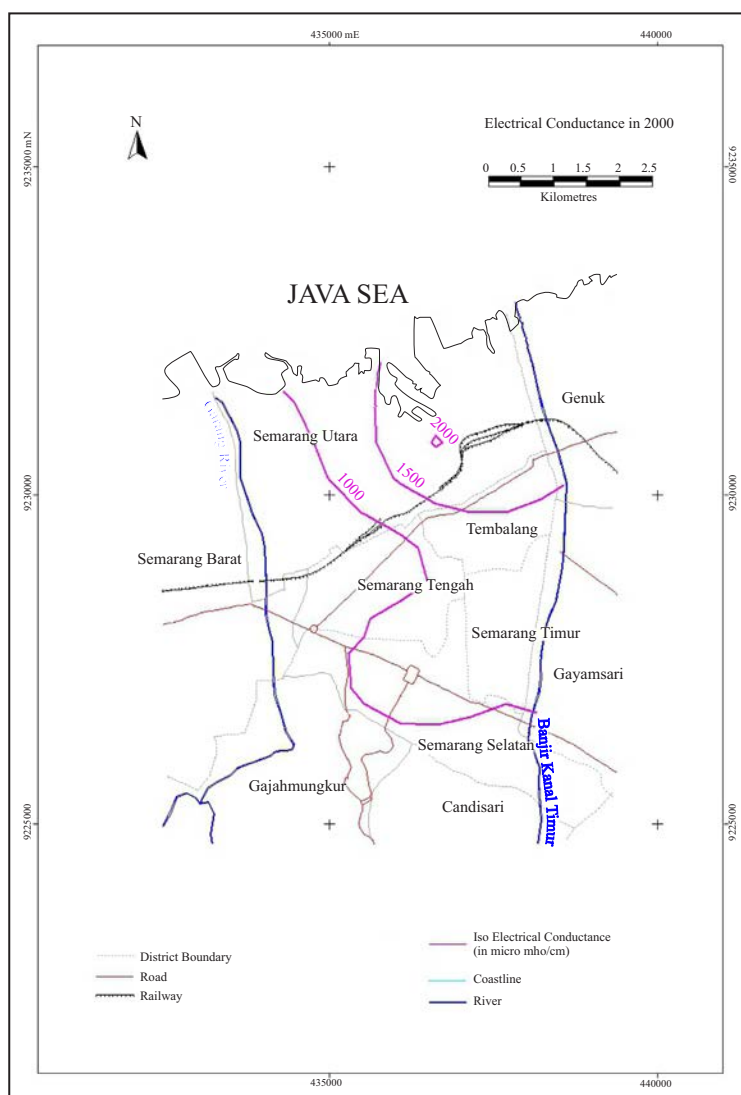


Figure 3. Illustration of electrical conductance map in 2000.

of electrical conductivity in this area was 61800 $\mu\text{mhos/cm}$. This value was close to brine water. The value of electrical conductance in eastern part was higher than western part of coastal area. Most of the area was brackish water. Some location-illustrated condition of groundwater was saline water particularly near Tanjung Mas Harbour. It can be shown in detail in Figure 5. Moreover, propagation of saline water in 1995 until 2008 in Semarang Coastal City can be illustrated clearly in Figures 6 and 7.

Since Semarang Coastal area was dominated by sedimentation of clay and silt materials derived from coastal depositional landform, this material make

possibility of higher salinity content because these materials can keep better salt concentration due to its porosity than other materials such as sand and breccias in the Damar Formation. In addition, since in the past trapped sedimentation created evaporated rocks such NaCl resulted in a higher electrical conductance value in coastal area of Semarang (Purnama, 2005). Moreover, in this area, a higher hydraulic conductivity of marine sediments and sedimentation process from river made the possibility of saline water move and spread faster than material of the Damar Formation in southern part that has a lower hydraulic conductivity. This case

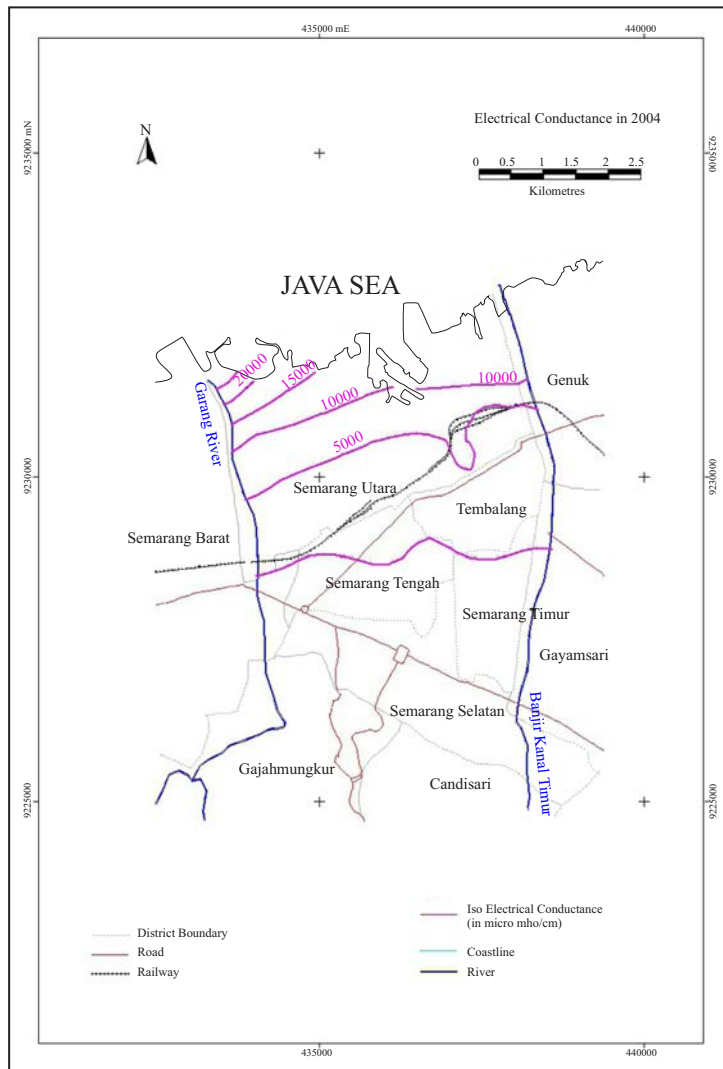


Figure 4. Map illustrates electrical conductance in 2004.

can be shown in Figures 6 and 7 that the movement of saline water is faster in eastern part where most of the area was alluvial sediment than in northwest where directly bordered by the Damar Formation. In 1995, groundwater was fresh water in eastern part consisting of alluvial sediment but in 2008, this area was saline water. However, it was different with the northwest part of this study area that was bordered by the Damar Formation where in 1995 and 2008 this area was brackish water. This paper overviewed salinity pattern in a shallow groundwater. If the movement flow further deep to the Kalibiuk Formation (Miocene and Pliocene periods), this salinity

contamination will trap in Semarang Coastal Area in a longer period, since this formation present as a horst separating the Damar Formation and Alluvial Deposit in Semarang Coastal Area with Volcanic Breccias Formation.

Salinity Pattern and Land Use

Land use changes in Semarang Coastal City were high from 1995 until 2008. Since 1995, generally built up area was dominated land use in the Semarang Coastal City. Most of land area was converted into built up area such as settlement, office building, commercial building, and road from 1998 to 2008.

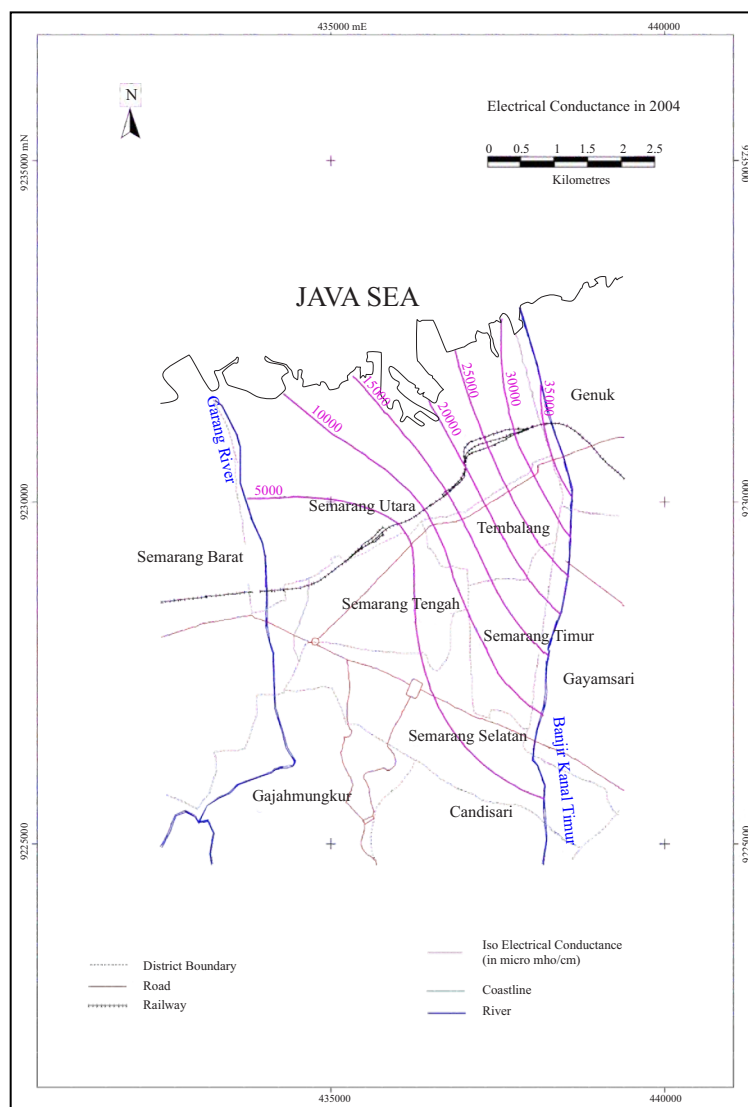


Figure 5. Illustration of electrical conductance in 2008.

Land area in the Semarang Coastal City was converted into built up area reaching about 698 ha. Land use change in Semarang Coastal City can be shown in Table 2. The different total area of the study area can be caused by different scale of the map, land reclamation, and higher sedimentation rate. Resolution of topography map was 5 m and IKONOS was 1 m. Marfai *et al.* (2008) confirmed higher sedimentation rate and land reclamation resulted additional land area in Semarang Coastal Area.

The effect of salt intrusion in Semarang Coastal City extended significantly to land use from 1998

Table 2. Data of Land Use Change in 1995 and 2008

Land Use	Area (ha)	
	1995	2008
Bare land, garden	37.42	32.42
Built up	2,006.17	2,704.74
Fish pond	102.81	148.46
Grass, shrub	670.85	
Rice field	29.99	
Water body	184.66	183.59
Total	3,031.90	3,069.22

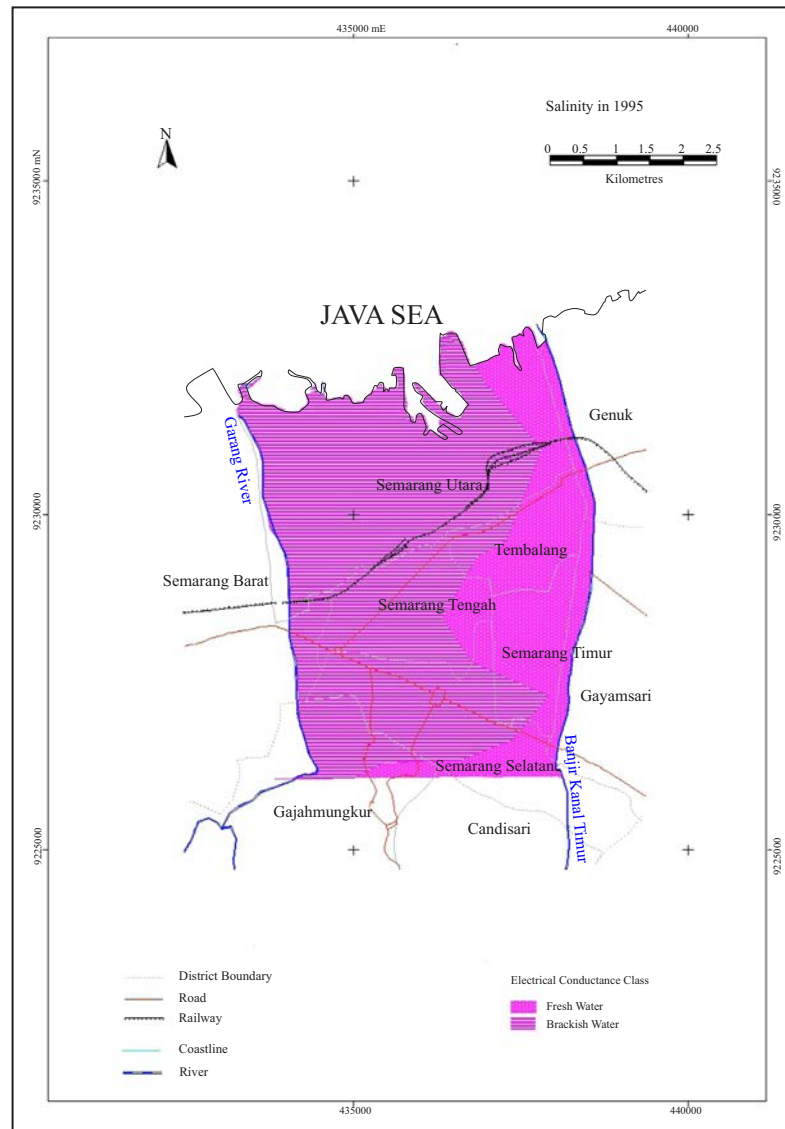


Figure 6. Map showing of salinity in 1995.

to 2008. In 1998, total area of fresh water reached 878.68 ha and brackish water extended 1,933.15 ha. The area affected by salt intrusion continuously 27.96 ha for bare land and garden; 1,417.77 ha for built up; 66 ha for fish pond; 335.08 ha for grass and shrub; 15.87 ha for rice field; and 70.47 ha for water body. Groundwater in these areas was brackish water, no saline water found in Year 1998. Moreover, in 2004, the area affected by salt intrusion increased significantly since in this year saline groundwater was identified and no fresh

groundwater in the Semarang Coastal City. Total area of brackish groundwater was 2,367.68 ha and total area of saline groundwater was 680.22 ha. The area of bare land and garden, built up, fish pond, grass and shrub, rice field, and water body that covered by brackish groundwater continuously was 20.59 ha; 2,209.88 ha; 11.61 ha; and 125.60 ha. Then, the area of saline water occurred in bare land and garden, built up, fish pond, and water body continuously was 12.22 ha; 473.08 ha; 136.86 ha; and 58.06 ha. Groundwater condition in built up

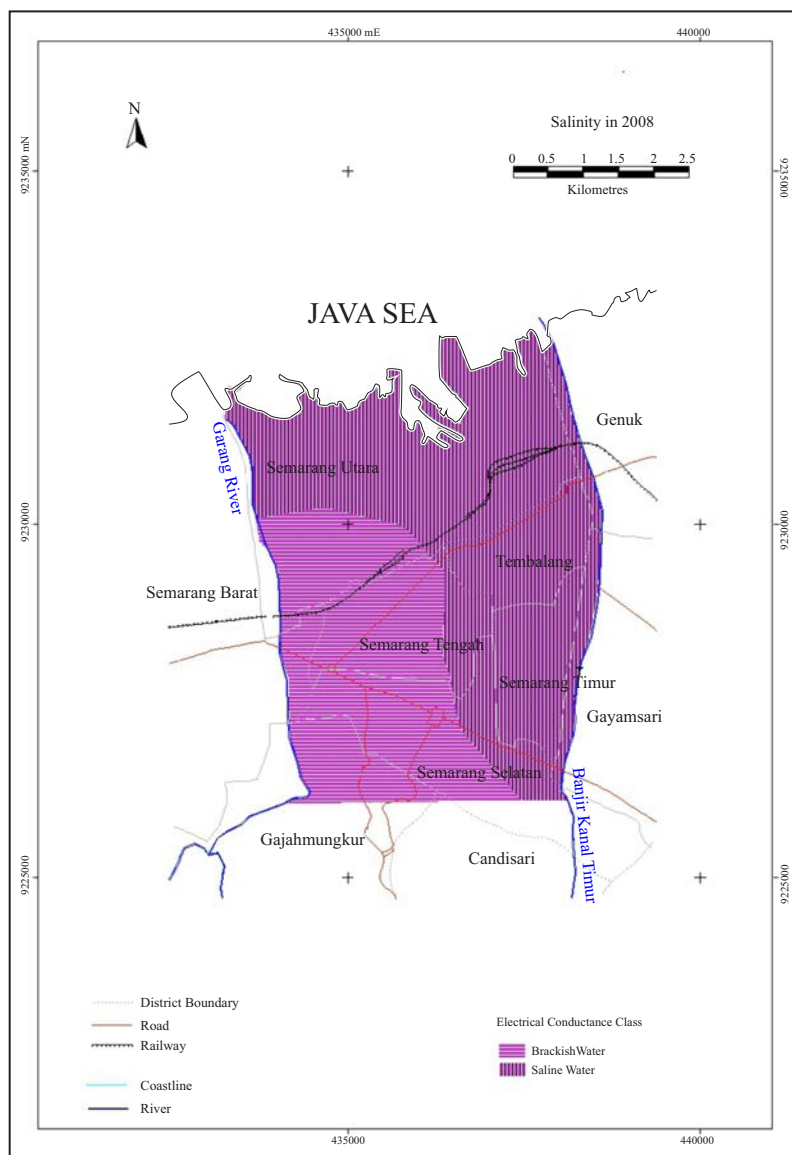


Figure 7. Illustrates salinity in 2008.

area including brackish groundwater that reached 80% and 20% of built up area was saline water. Area affected by salt intrusion in the Semarang Coastal City enhanced in 2008, where a half of the City area was occupied by saline groundwater. Groundwater condition in bare land and garden was saline. More than 50% of built up area in Semarang Coastal City was saline groundwater. The saline groundwater in the area of water body such as river and drainage system increased. Total area affected by brackish groundwater was 1,299.06 ha; 16.89 ha; and 42.79

ha continuously for built up, fish pond, and water body. The area affected by saline groundwater for bare land and garden, built up area, fish pond, and water body continuously was 32.81 ha; 1,405.69 ha; 131.58 ha; and 140.87 ha. The area of saline groundwater increased about 1,030.73 ha in 2008. The area affected by salt intrusion in the Semarang Coastal City can be illustrated in Table 3. One of the factors make saline water move forward to the land is groundwater exploitation. Example of groundwater exploitation records can be shown in Table 4.

Table 3. Data of Land Use affected by Salt Intrusion in Year 1995, 2004, and 2008

Land Use	Area (ha)								
	1995			2004			2008		
	Fresh	Brackish	Saline	Fresh	Brackish	Saline	Fresh	Brackish	Saline
Bare land, garden		27.96			20.59	12.22			32.81
Built up		1,417.77			2,209.88	473.08		1,299.06	1,405.69
Fish pond		66.00			11.61	136.86		16.89	131.58
Grass, shrub		335.08							
Rice field		15.87							
Water body		70.47			125.60	58.06		42.79	140.87
Total	878.68	1,933.15	0.00	0.00	2,367.68	680.22	0.00	1,358.73	1,710.95

Table 4. Groundwater Exploitation Record 1900 - 1998

Year	Groundwater abstraction (in million meter cubic per year)
1900	0.4
1910	0.5
1920	0.5
1932	0.6
1982	13.7
1985	16.1
1990	22.5
1995	26.7
1996	29.1
1997	34.9
1998	35.7

CONCLUSION

Salinity content of groundwater in the the Semarang Coastal City increased from 1995 to 2008 by 99% where the minimum level of salt content in 1995 was 601 $\mu\text{mhos/cm}$ then the maximum level of salt content in 2008 was 61800 $\mu\text{mhos/cm}$. Starting in 1995, groundwater in the Semarang Coastal City, particularly in Semarang Utara Subregency, was brackish water due to salt-water intrusion. This condition has continued until no fresh groundwater can be identified in the unconfined aquifers in 2004. In 2004 also, the groundwater has started to be classified as saline water in this year. This situation has continued until 2008, with increasing factor of 34% in 2004 to 2008 period. In the Semarang coast, 50% of built up area contained saline groundwater.

Increased saline groundwater in the Semarang Coastal City is mainly due to groundwater over exploitation. Intensive groundwater exploitation will make fresh-water interface move to landward. Moreover, land subsidence can lead salt-water move forward into the land.

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