SUBMARINE GROUNDWATER DISCHARGE MEASUREMENT ON THE SANDY UNCONFINED AQUIFER AT THE CARNAVAL BEACH, ANCOL (JAKARTA BAY)

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Received: 12 July 2016 Accepted: 28 December 2016

ABSTRACT

Submarine groundwater discharge (SGD) is defined as all direct discharge of subsurface fluids into coastal zone. Components of SGD consist of fresh submarine groundwater discharge and recirculated saline seawater discharge. With respect to environmental studies, SGD could act as a pathway for the transport of anthropogenic contaminants and nutrients to coastal waters. In this study, we present SGD measurement at the Carnaval Beach, Ancol (Jakarta Bay) with focus on unconfined groundwater system. The SGD measurement was made using an automated seepage meter with installed conductivity-temperature-depth meter. Our study estimates that the SGD at the Carnaval Beach has an average rate of about 10^{-9} m/s and is more dominated by recirculated saline seawater than freshwater discharge. Variation of SGD at the Carnaval Beach is also influenced by the tides and precipitation.

Keywords: Submarine groundwater discharge, unconfined aquifer, Jakarta Bay, Indonesia

INTRODUCTION

Researches on submarine groundwater discharge (SGD) has been flourishing in the last few years, showing the importance of quantifying SGD in coastal environments. SGD represents all direct discharge of subsurface fluids across the land-ocean interface. SGD consists of submarine fresh groundwater discharge (SFGD) and recirculated saline groundwater discharge (RSGD), thus the total SGD includes both a terrestrial component of net fresh groundwater and an oceanic component of recirculated seawater (Taniguchi *et al.*, 2002; 2006).

Comprehensive understanding on SGD requires accurate direct measurements. In the field, SGD can be present as submarine springs and seepage (Burnett *et al.*, 2001; Taniguchi *et al.*, 2002). Taniguchi *et al.* (2002, 2006) suggest that the seepage is more important volumetrically than discrete springs as it is difficult to detect groundwater seepage through sediment layers. The magnitude of SGD and its generation mechanisms generally are still poorly understood mainly due to the lack of accurate measurement techniques, invisible sources, as well as slow moving, spatially and temporary varied flows (Jacob *et al.*, 2009). In Indonesia, Lubis *et al.* (2011) have identified and measured the magnitude of SGD in a few sites. More in-depth studies are widely needed in Indonesia.

The objective of this study is to characterize SGD on an unconfined sandy aquifer system by direct measurements at the Carnaval Beach, Ancol (Jakarta Bay) in order to accurately understand the phenomenon. The Jakarta Bay is located adjacent to Indonesia's capital, where marine pollution has been an ongoing environmental concerns. With respect to environmental studies, it is important to understand SGD as it may provide a significant pathway for the transport of anthropogenic contaminants and nutrients to coastal waters (e.g. Burnett and Dulaiova, 2003; Michael *et al.*, 2003; Martin *et al.*, 2004; Taniguchi *et al.* 2006).

Several works have been conducted in understanding SGD in Ancol. Umezawa *et al.* (2009) identified the presence of SGD by using Radon-222 as a natural tracer. The result showed very little detected Radon-222 at approximately 0.8-3.0 dpm/L. Therefore, they suggest to apply other methods for quantifying SGD continuously. Delinom *et al.* (2009) reported that the water resistivity at a 2.5 m depth in Ancol is around 0.5-5 Ohm-m and a resistivity anomaly occurs at 40-45 m from the coastline, which altogether is interpreted as the presence of fresh groundwater at the site.

MATERIALS AND METHODS

The Carnaval Beach, Ancol is located in Jakarta Bay, Indonesia (Figure 1). This coastal environment has average depths of 2-10 m. And some of the areas are the products of land reclamation.

The geological setting in the area consists of quaternary sediments of an alluvial system (Turkandi *et al.*, 1992). Sediment coring data from Ancol shows that the lithology of the aquifer at 0-32 m depths consists of alternate rock and tuffaceous clay with intercelated tuffaceous sand and sandy clay, and at 32-55 m consists of clay. Ancol marine sediments are made of mud, clay, and fine to coarse sands.

Monthly precipitation data taken from the Kemayoran Climate Station (located ~1 km to the south of the study site) ranged from 6.5 mm (Aug) to 529 mm (Jan) in 2009. While the monthly precipitation in 2010 ranged between 27.7 mm (Apr) to 382.4 mm (Oct).

This study applies direct and continuous measurements of SGD by using an automated seepage meter developed by Taniguchi and Iwakawa (2004). An automated seepage meter was laid about 45 m offshore from the minimum tide line (Figure 2). The automated seepage meter is made of a chamber with 56 cm diameter and 20 cm height. Two conductivity-temperature-depth (CTD) sensors were installed inside and outside the chamber to monitor SGD and coastal seawater, respectively. A barometric probe was installed 2 m above the surface level. Depth meter on the outer CTD serves to record tidal data after being corrected by pressure data from the barometric probe. All of these equipment recorded the data every 10 minutes. And, the electrical conductivity (EC) of fresh groundwater was measured on a ~1m-deep dug well about 50-100 m away from the chamber and on the shoreline.

The methodology to separate SGD components of SFGD and RSGD that flow into the seepage meter follows the formula outlined by Michael *et al.* (2003). The formula calculates the proportion of SFGD and RSGD from salinity and volume of discharge data. The equation of mass balance and salt balance is described in details by Hays and Ullman (2007) and Garison *et al.* (2003) as:

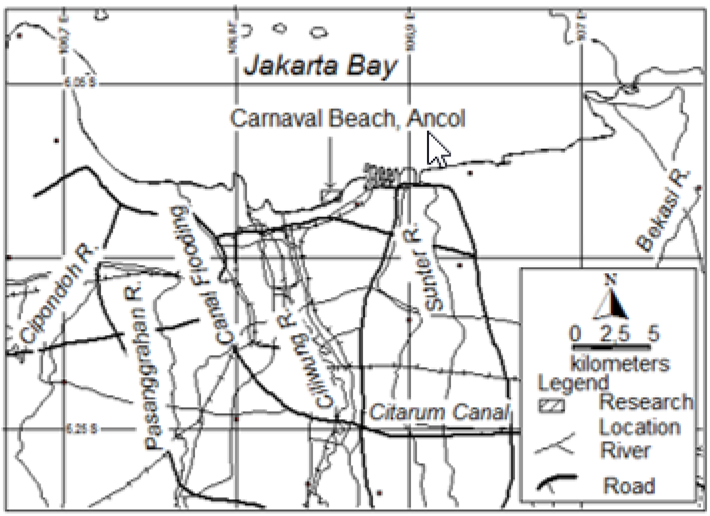


Figure 1. Map of study site (shaded box) at the Carnaval Beach, Ancol (Jakarta Bay).

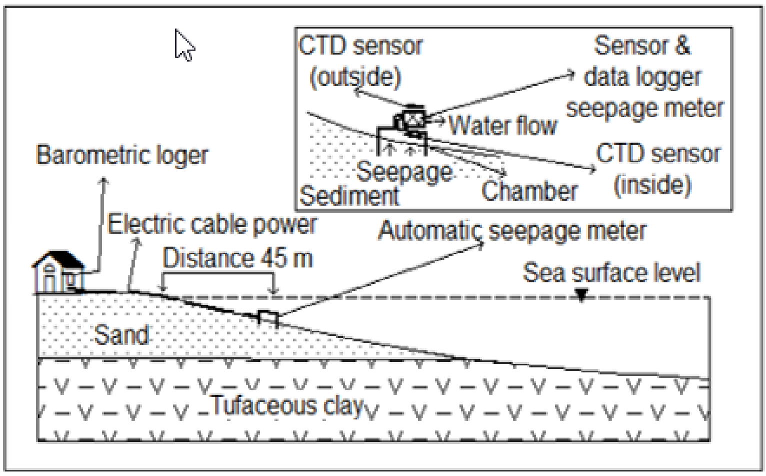


Figure 2. Design of the automated seepage meter at the study site. The chamber of the automated seepage meter dip into the sediment at about 18 cm depth.

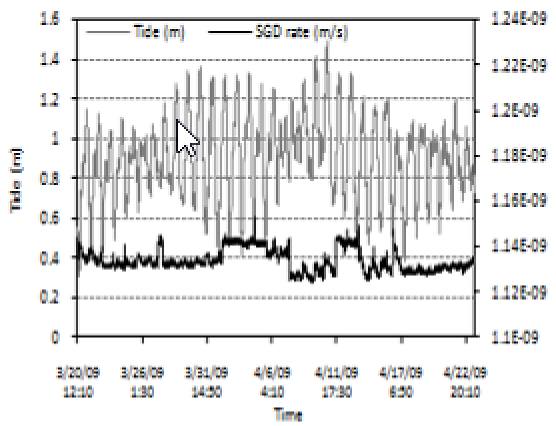
$$q_{fw} = q_t \{(S_{sw} - S_t)/(S_{sw} - S_{fw})\} \qquad (1)$$

where S_t is the salinity (or any other conservative property of water), S_{sw} is the salinity of the nearshore estuarine water, and S_{fw} is the salinity of the fresh groundwater. q_{fw} is the volume of freshwater and q_t is the volume of SGD from the chamber. We modified S_t, S_{sw} and S_{fw} in this study to the EC values.

RESULTS

SGD measurement and estimates of SGD component at the Carnaval Beach are shown in Table 1. Between March 20-July 9, 2009, the mean EC SGD (inside CTD) range between 52.21-55.68 mS/cm and the mean EC coastal seawater (outside CTD) range between 16.71-48.94 mS/cm. Between April 25-October 31, 2010, the mean EC coastal seawater range between 25.34-41.28 mS/cm. Furthermore, the average EC of fresh groundwater in the dug well is 1.0 mS/cm.

The observed SGD rate on the chamber is 10^{-9} m/s. The mean SGD rate in March-April 2009 is 1.13 10^{-9} m/s. Whereas the mean values between April and August 2010 range between 1.13 10^{-9}-1.16 10^{-9} m/s (Figure 3.). The product between SGD rate and the surface area of the chamber is the groundwater discharge that comes out of the chamber. The discharge values are between 24.98-24.99 ml/day during measurement periods in March and April 2009. And the values are between 24.93-25.51 ml/day in April to October 2010. The observed daily tidal variation at the study site is diurnal and less than 1 meter (Figure 3). Estimates of SGD component calculated between March 20 - April 23, 2009 is shown by Figure 4.



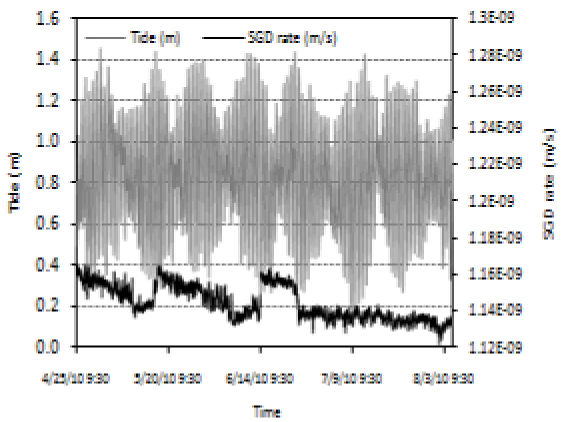


Figure 3. Tide variation and SGD rate measured every 10 minutes. (**Left**) From March 20, 2009 (12.10) to April 23, 2009 (13:00). (**Right**) From April 25, 2010 (09:30) to August 05, 2010 (16:00).

Table 1. Hydro-physicochemical of SGD and the estimation of SGD components at the Carnaval Beach, Ancol (Jakarta Bay).

	SGD EC (mS/cm)	EC seawater (mS/cm)	Tide (cm)	Total SGD (q_t) ml/day	SFGD (q_{fw}) ml/day	RSGD (q_{sw}) ml/day	SFGD (fw) %	RSGD (sw) %
March 20-31, 2009								
Maximum	55.66	55.47	136.50	25.21	5.55	21.54	22.15	86.04
Minimum	50.46	37.54	30.80	24.89	3.49	19.52	13.96	77.85
Average	53.07	48.94	87.57	24.98	4.50	20.47	18.04	81.96
April 1-23, 2009								
Maximum	55.91	55.43	149.70	25.40	4.73	21.70	19.05	86.43
Minimum	52.43	27.92	38.20	24.77	3.39	20.09	13.57	80.95
Average	54.16	41.71	92.32	24.99	4.08	20.91	16.32	83.68
May 1-31, 2009								
Maximum	57.29	31.20	175.90	-	-	-	-	-
Minimum	54.07	21.13	29.50	-	-	-	-	-
Average	55.68	24.93	89.48	-	-	-	-	-
June 1-30, 2009								
Maximum	55.94	43.23	156.9	-	-	-	-	-
Minimum	50.62	7.55	26.2	-	-	-	-	-
Average	52.45	16.71	93.86	-	-	-	-	-
July 1-9, 2009								
Maximum	53.10	20.43	137.50	-	-	-	-	-
Minimum	51.28	14.05	30.60	-	-	-	-	-
Average	52.21	17.40	85.28	-	-	-	-	-
25 - 30 April 2010								
Maximum	-	64.13	134.70	25.67	-	-	-	-
Minimum	-	37.50	35.80	25.26	-	-	-	-
Average	-	41.28	80.23	25.51	-	-	-	-
May 1-31, 2010								
Maximum	-	47.44	145.80	25.65	-	-	-	-
Minimum	-	38.21	28.90	25.03	-	-	-	-
Average	-	41.22	86.03	25.36	-	-	-	-
June 1-30, 2010								
Maximum	-	50.10	144.00	25.64	-	-	-	-
Minimum	-	2.34	25.80	24.84	-	-	-	-
Average	-	27.08	85.00	25.24	-	-	-	-
July 1-31, 2010								
Maximum	-	38.42	142.90	25.19	-	-	-	-
Minimum	-	12.25	16.30	24.84	-	-	-	-
Average	-	23.46	81.23	25.02	-	-	-	-
August 1-5, 2010								
Maximum	-	33.50	123.20	25.04	-	-	-	-
Minimum	-	17.97	33.10	24.71	-	-	-	-
Average	-	25.34	25.34	24.93	-	-	-	-
Sept 1-30, 2010								
Maximum	-	43.20	124.70	-	-	-	-	-
Minimum	-	26.16	15.60	-	-	-	-	-
Average	-	39.02	75.28	-	-	-	-	-
Oct 1-31, 2010								
Maximum	-	64.53	138.20	-	-	-	-	-
Minimum	-	25.06	34.40	-	-	-	-	-
Average	-	34.56	85.20	-	-	-	-	-

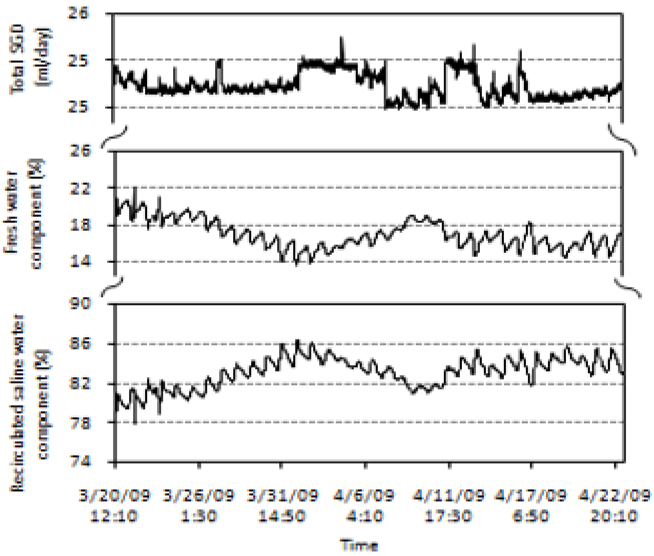


Figure 4. Total, freshwater and saline components of SGD showing recirculated saline water dominates SGD at the Carvanal Beach, Ancol (Jakarta Bay). Data were taken from March 20, 2009 (12.10) to April 23, 2009 (13:00).

The mean freshwater SGD component is 18.04% (March 20-31, 2009) and 16.32% (April 1-23, 2009). Longer measurement via EC SGD or total SGD is not available as the equipment breaks and get corroded by saline seawater easily.

DISCUSSION

Relatively stagnant EC SGD compared to EC coastal seawater suggests that coastal seawater is recharged from the rain as well as the supply the freshwater from nearby rivers (Ciliwung and Sunter Rivers are ~1 km and ~3 km away, respectively). The SGD is dominated by saline waters but also receives freshwater influence at our study site. Similar cases have also been observed elsewhere such as in the Waquoit Bay, USA (Michael et.al, 2003). Relatively high salinity SGD indicates that mixing and recirculation of sediment porewater are effective along several meters of its flow paths (Bokuniewicz et.al, 2008).

SGD at the Carnaval Beach, Ancol (Jakarta Bay) also shows sensitivity to tidal variation. When sea-level rises, the SGD rate decreases, and vice versa. Similar findings were reported by Garisson *et al.* (2003), Taniguchi *et al.* (2006) and Povinec *et al.* (2006). Furthermore, Bokuniewicz *et al.* (2008) suggest that the interaction is non-linear and the correlation is weak at tidal range less than 1 m. We also observe sharp SGD variations at the Carnaval Beach in mid-April 2009 and between April-June 2010. Whereas the SGD variation is relatively stable before and after those periods. We attribute this to precipitation influence as there is a strong correlation between monthly mean SGD rate and precipitation (r^2=0.84; Figure 5). Taniguchi (1995) also found a similar observation in Biwa Lake, Japan.

Component of SGD at the study site is dominated by recirculated saline. Similar findings have been observed in other sites such as in Tannowa, Osaka Bay, Japan with the freshwater component range between 4- 29% (Taniguchi and Iwakawa, 2004), and Cape Henlopen, Delaware Bay, USA (32%; Hays and Ullman, 2007). The domination of saline groundwater discharge may imply its importance to increase nutrient levels during recirculation (Burnett *et al.* 2003; Taniguchi *et al.* 2007). However, our study is an initial work in Jakarta Bay that records SGD over a relatively short period. Future works to understand the SGD spatially along the shoreline are needed.

CONCLUSIONS

Our study presents SGD measurements using an automated seepage meters and mini CTDs to provide accurate information on

SGD at the Carnaval Beach, Ancol (Jakarta Bay). Groundwater seepage during the study periods is sensitive to tidal and precipitation variations. If this observation applies to SGDs in coastal Jakarta, this would have an enormous consequence to environmental management in the area. Contaminants in groundwater could be carried into to coastal areas to further degrade the health of marine environments in Jakarta Bay. Therefore, pollution control of groundwater in the mainland would play an important role to mitigate coastal pollution issues.

ACKNOWLEDGEMENT

This research is part of a collaboration between the Research Center for Geotechnology, Indonesian Institute of Sciences (LIPI) and Research Institute for Humanity and Nature, Japan. We are grateful supports and fruitful discussions with Prof. Dr. Sudarto Notosiswoyo (Institut Teknologi Bandung), Dr. Shin-ichi Onodera (Hiroshima University), Dr. Mitsuyo Saito (Ehime University) and Dr. Sri Yudawati Cahyarini (LIPI).

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