Assessment of Submarine Groundwater Discharge (SGD) as a Source of Nutrient at Jakarta Bay, Indonesia

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Abstract. Submarine groundwater discharge (SGD), the direct discharge of groundwater to the sea, is a ubiquitous phenomenon worldwide. While SGD is defined as "any and all flow of water on continental margins", this review focuses on the terrestrial fraction, also known as fresh SGD Jakarta Bay, which started from the late 1980s have had greatest impact on mangrove areas and coastal water quality due to the expanding of the city. In such an environment, inputs of nutrients will play an important role in sustaining primary productivity. Atmospheric deposition and riverine runoff have been traditionally considered the main external sources of nutrients to the bay, whereas the role of submarine groundwater discharge has been largely ignored. In this study, we used radon tracers and salinity to investigate SGD and associated nutrient inputs to Jakarta Bay especially from Citarum Estuary as the main river. The result shows that SGD becomes an important role in understanding the nutrient cycle at Jakarta Bay.

1. Introduction

Submarine groundwater discharge (SGD), the direct discharge of groundwater to the sea, is a ubiquitous phenomenon around the world. SGD is defined as the flow of water on continental margins from the seabed to the coastal ocean, regardless of fluid composition or driving force [1].

Research Centre for Geotechnology, Indonesian Institute of Sciences (LIPI) has already conducted the SGD study in Indonesia since 2006 in collaboration with the Research Institute for Humanity and Nature (RIHN), Kyoto, Japan. In Indonesia, SGD can be present as submarine springs and seepage [10], and seepage becomes more volumetrically important than discrete springs as it is difficult to detect groundwater seepage through sediment [16] [18].
Starting from the late 1980s, Jakarta Bay has had the greatest impact on mangrove areas and coastal water quality due to its expansion. In such an environment, inputs of nutrients will play an important role in sustaining primary productivity. Atmospheric deposition and riverine runoff have been traditionally considered the main external sources of nutrients to the bay, whereas the role of submarine groundwater discharge (SGD) has been largely ignored.

Many previous studies show that the transport of land-derived chemicals through SGD can contribute to nutrient-enriched coastal water. Dinoflagellate blooms occurring in the southern Sea of Korea appear to be related to nutrient-enriched groundwater supply [8][9]. Groundwater discharge has also been argued both to militate against [7] and stimulate [5] blooms of the "brown tide" pelagophyte Aureococcus anophagefferens in shallow estuaries on Long Island, NY (USA). SGD also affects phytoplankton production differs from one ecosystem to another because of variable hydrogeographical properties, such as the type of discharge [15]. In this study, we assess SGD as one of the nutrient inputs at Jakarta Bay, Indonesia.

2. Methods
The research covered the northern part of Jakarta city, dominated by alluvial flood plain and marine sediment over the volcanic rocks as a basement (Figure 1). Geology data is interpreted from a geological map by the Indonesian Geological Agency with a scale of 1:250.000. To understand the relation between groundwater-sea water relations through submarine groundwater discharge (SGD) base on the geology using Radon \(^{222}\text{Rn}\) measurement compared with in situ primary productivity using chlorophyll-a distribution mapping.

![Figure 1. Geology of Jakarta Bay](image)

Several studies have employed natural uranium decay-series nuclides such as Radon-222 is a good nature tracer for detecting and quantifying groundwater discharge into the seafloor [17]. Radon-222 has a high concentration (3-4 times) in groundwater when compared to seawater, conservative, relatively easy to measure, and has a relatively short half-life scale due to 3.82 day [3] [2] [12]. Therefore, Radon could be an excellent tool for locating seeps, springs, and other groundwater discharge points on the seafloor [2]. Radon data were collected directly from seawater along the coast of the East part of Jakarta Bay. Radon equipment used RAD-7 Durridge. The measurement in seawater was using a vessel with an average velocity of 4 kilometers per hour. Seawater was pump
from two meters below the sea surface, for ten minutes per cycle, for three times measurement.
Electric conductivity (EC) was assessed at the same time as radon measurement. The site's selection of seawater was based on each point's distance with an average of 2 kilometers. The average distance from the coastline is 50-200 meters. A battery of 12 volts utilizes energy sources for submersible pumps and RAD7.

Chlorophyll-a content in seawater is influenced by hydrology factors such as temperature, salinity, pH, DO, brightness, flow velocity, nitrate, and phosphate. The study's aim was ‘seeing’ or ‘to see’ the phytoplankton chlorophyll content and distribution in seawater correlated with radon value. Research about chlorophyll-a has been done since 1974. The sampling was done through the purposive sampling method with 1090 stations (Figure 2). Measurement methods by using chemical-physical parameters were done in situ. The measuring of phytoplankton chlorophyll was done using spectrophotometry[6] and Fluorometric [14][4]. Regression analysis was applied to see the relationship between hydrology factors add and chlorophyll content. Environment parameters measured are temperature, salinity, pH, Dissolved Oxygen (DO), and brightness to enrich the result.

Figure 2. Chlorophyll-a Observation Station at Jakarta Bay

3. Result and Discussion
Phytoplankton primary productivity in coastal seas is generally determined by temperature and light availability as well as nutrient concentration. In Indonesia, chlorophyll-a distribution will depend on the rainy and wet season due to the tropical climate, which is influenced the Jakarta Bay current.
Regional Chlorophyll-a Jakarta Bay distribution mapping and analysis started from 1974 until 1984 (Figure 3) and 2004 until 2015 (Figure 4) shows a significant increase in chlorophyll-a concentration in Jakarta's Bay. Chlorophyll-a concentration within 1974-1984 ranged from 0.37 - 21.00 mg.m\(^{-3}\), while in 2004-2015 the concentration ranged from 0.12 - 234.28 mg.m\(^{-3}\). The content and distribution of chlorophyll-a phytoplankton in Jakarta Bay's waters are strongly influenced by location and season. This is in line with [11] and [13]. The west season has a significant effect on the chlorophyll-a content of phytoplankton both on the surface and on the layer below it. Phytoplankton responses to increased nutrient concentrations cause the high chlorophyll-a content in the western season during the rainy season.
Radon measurements along the Jakarta bay already started from 2008 [19], which shows that many points have high radon concentration along the coastline (Figure 5). Based on that data, remeasurement at the eastern part from Marunda to Muara Bendera was carried out from 2015 until 2017. We also measured in the eastern part from Tanjung Pakis to Muarabungin (segment 2) on October 21, 2016, for-comparison data. During the measurement, radon counting interval was used every 10 minutes. The result of measurement tracing showed that $^{222}\text{Rn}$ varies from one point to another (Figure 6). The first segment ($n=31$) showed that radon average was in the range of $12 \pm 20$ Bqm$^{-3}$ to $140 \pm 48$ Bqm$^{-3}$, with an average of $68 \pm 35$ Bqm$^{-3}$. In this segment, the highest $^{222}\text{Rn}$ is found around Citarum estuary area eastern part of Jakarta Bay (Muara Bendera site) and the lowest in Jakarta city's central part (Marunda area). Meanwhile, the second segment has a radon range between $6 \pm 30$ Bqm$^{-3}$ to $73 \pm 56$ Bqm$^{-3}$ ($n = 56$) with an average of $32 \pm 42$ Bqm$^{-3}$. Detailing profiles were remeasured Radon more in a limited area as confirmation for the previous data (Figure 7). Measurements ($n = 25$) show the radon range between $12.5\pm34$ Bqm$^{-3}$ to $86.7\pm60$ Bqm$^{-3}$, with an average is $37.4\pm45.6$ Bqm$^{-3}$. Based on measurements at two different times, it appears that it does not show different radon activity during the different systems.

![Radon Distribution along Coast Line of Jakarta Bay](image)

**Figure 5.** Radon distribution along coast line of Jakarta Bay on 2009 (Umezawa et.al, 2009)

High Radon in seawater is indicating as the potential of submarine groundwater discharge. Base on radon value on 2009 [19] and recent measurements show that many points have high radon concentration along the coastline. The highest Radon distribution is located at the western and eastern part following the chlorophyll-a distribution pattern at Jakarta Bay coastal area. There was no clear spatial difference in salinity during all the measurements. The spatial variability in water temperature during both seasons was low (27.6–29.5°C in the wet season and 29.1–32.3°C in the dry season).
Figure 6. Jakarta Bay Radon distribution on 2015-2016

Average Chlorophyll-a ranged increase to the eastern part range from 5 to 220 mg m$^{-3}$. This distribution was correlated significantly with $^{222}$Rn concentration (Figure 8). It is shown that the relation between river and groundwater near the coastal area was an effluent system, and nutrient input was dependable on the season.

Figure 7. Radon distribution detailed at eastern part of Jakarta Bay
Figure 8. (A) $^{222}$Rn concentration and (B) Chlorophyll-a as in situ primary productivity on 2015-2017

4. Conclusions
Measurement of radon isotopes can identify some areas where groundwater inputs are qualitatively important and quantify SGD rates. As high radon shows, there's also abundances of chlorophyll-a. Therefore, there is a good correlation between radium (groundwater-derived) and nutrients. This is shown that submarine groundwater discharge has a significant contribution as a source of nutrient at Jakarta Bay.

Author Contributions
Lubis R.F is a main Contributor and others as support. Lubis, Delinom R, and Bakti H were in charge of the manuscript writing and took part in the sampling, measurements, and data analysis for Radon. Afdal was in charge of the sampling, measurement, and data analysis for primary productivity data. Onodera S and Taniguchi M was in charge of the overall manuscript structure and took part in the fieldwork.

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