The ecological vulnerability of Semarang's coastal waters, a brief review

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Abstract. As the capital city of the Central Java Province, Semarang has a very unique regional profile. Economic activity in Semarang has accelerated rapidly and many industrial estates have been established, but the latent problem of inundation and subsidence has been a threat in the northern region of the city for almost a century. Under these conditions, the burden of pollution as a by-product of various activities in the coastal and upland areas becomes a threat magnification for ecological sustainability of coastal waters and surrounding areas. This review will reveal the ecological vulnerability of coastal waters based on biogeochemical aspects. The major references for the review were several research papers and reports based on the research activities of The Research Centre for Oceanography, Indonesian Science Institute (LIPI) in Semarang coastal waters on the last decade. Geological studies, heavy metal contamination and retrospective study using benthic foraminifera as proxies based on two core samples are the major aspects on the review. The results show that the eastern coastal of Semarang was more susceptible to ecological disasters such as accretion, pollution of several metals and total suspended solids compared to the western coastal waters. Retrospective study based on core sample showed that Pb and Zn contaminations were occurred higher at the East Flood Canal estuary since 1910, so was the imprint of hypoxia was found since 1939.

1. Introduction

The northern part of Semarang is a lowland area on the northern coast of Java Island. Industrial activities and urban public facilities such as office, trade, services, education, health and transportation facilities are in the area [1]. Flood inundation due to high tides and upstream flows have periodically threatened this region for more than a century [2]. The inundation has triggered another problem that is accretion in the coastal plain since Semarang has 21 rivers end up in Semarang coastal waters that two flood canals were built to control the flood.

Water waste run off was such a huge problem in coastal area, particularly in Semarang as the capital city of Centre Java Province. Therefore, pollution has always been a concern related to natural resources and environmental sustainability. The metal pollutants in the aquatic ecosystem is mainly introduced through various natural and anthropogenic sources [3]. Metals content in coastal sediments represent the total concentration of natural and anthropogenic metals content. Each region has a different geochemical characteristic, depend on the sedimentary rock source. The natural metals in the earth's crust has been compiled by several researchers such as [4], and [5].

Hypoxia is another impact of the pollution. As a direct and indirect effect of pollution, hypoxia has a magnified threat to the coastal ecological system. Hypoxia has occurred since the 1970s in some
Korean waters, such as in Jinhae and Shihwa Bay [6]. Hypoxia events were also indicated in Jakarta Bay since 1839 in western area (Tangerang) and since 1960 in eastern area (Cilingcing) [7].

The review of ecological vulnerability of Semarang’s coastal waters is crucial for mapping the threats and mitigation related to resources and coastal areas management. A retrospective study using core samples is an approach to trace several threats that the region has faced. Among of the threats were metal contamination, loading of suspension and silt from the up land and hypoxia over a long period of time.

2. Methods
This review was employing primary references from several research activities carried out by the Oceanographic Research Centre, Indonesian Science Institute in the coastal waters of Semarang in the last decade, and other supporting references. The research activity was conducted in 2009 by [8], [9] and [10]. The study of [8] and [10] particularly based on two core samples at the WFC (West Flood Canal) and EFC (East Flood Canal) estuary. Theses canals were used to accommodate the overflow of 21 rivers that end up to the Semarang coastal waters. While the study of [9] was particularly based on 13 stations in coastal waters of Semarang, two core stations at the WFC and EFC estuary were also deployed (Figure 1). Determination of lithology, chronological dating, metals and benthic foraminifera as a proxy were carried out through cores samples.

3. Result and Discussion
3.1. Geological setting
The geomorphology of Semarang coastal area is a low relief plain composed of alluvial deposits, marine beaches and swamps, while the lithology of coastal plain was clay, silt, sand, and mix of the three fractions that reaches more than 50 m thickness [11]. Based on the Geological Map of Semarang Sheet, the geology of northern part of Semarang was alluvium deposit (Qa). Alluvium deposits are divided into coastal, river and lake alluvium deposits [12]. This alluvium surface deposit covers almost the entire coastal area of Semarang, starting from Tugu, West Semarang, Central Semarang, North Semarang, South Semarang, East Semarang, Genuk, Gayamsari, and Pedurungan. The physical properties of alluvium deposits are loose clay, silt, sand, or gravel that has been deposited by running water in a stream bed, on a floodplain, or as alluvial fan.

The morphology of Semarang coastal area was almost a coastal plain unit, cover 45% distribution area. This plain is divided into several unit [13] after [14]:
1. Coastal alluvial plain, as a result of material deposition on beach area. The average elevation of the area was less than 200 above the sea level.
2. Natural Levee, formed due to the deposition of transported material by rivers and deposited on either side of the river during floods.

3. Fluvial Plain, found on the banks of rivers, which are formed by sedimentary material transported by rivers.

4. Delta Swamp, the delta swamps were occurred during the process of delta formed. Currently, the Semarang delta swamp is located in the field complex of Simpang Lima.

5. Tidal plains, the coastal plain of Semarang was alluvial plains which directly adjacent to the sea. This area has been converted into aquaculture, as well as settlements on current time. The average height of this area was less than 2 m, that at the high tide often causes inundation.

The lithological profiles of research area were based on two cores site, at the WFC estuary (Core1) and at the EFC estuary (Core 2). The length of Core 1 was 80 cm, consists of two layers. The deposition structure of the upper layer (0-64.5cm) was graded bedding, vertical gradation was coarse to fine fractions. The depositional structure of the next layer (65.5-80 cm) was massive strata [14]. According to [15] after [14] stratified layers were formed in constant energy (homogeneous) deposition, usually formed from suspensions without mechanical energy, while massive strata are formed due to rapid deposition of high-density deposits (Figure 2).

Figure 2. The lithological profile of Core 1 [13].

Lithological unit of Core 2 (103.5 cm long), consisted of four layers [14]. The depositional structure of the upper layer (0-45 cm) was stratified from fine to coarse fraction vertically. In the middle layer (45 - 64 cm), the lithology is divided into layer A (45 - 57 cm) and B (58 - 64). Layer A was the post-depositional sedimentary structures on load cast structure indicated by the downward curved formation due to loading of the material above. Layer B was erosional structures, indicated that sand...
layer inserted by clay as the imprint of depositional sedimentary changes, triggered by natural or anthropogenic factors. The depositional structure of base layer (65-103.5 cm) was stratified from fine grain to finer fractions (Figure. 3).

| Core 2, Lithology profile | Description |
|---------------------------|-------------|
| **0 - 44 cm**  | Gray clay, no bedding, lens sand at layer 34.5-38 cm. The erosional contact with the layer below |
| **45 - 57 cm**  | Sand, dark brown, shell fragments, coarse sand fraction, loose texture, poor sorting, firm contact with the underlying layer |
| **57 - 64 cm**  | Fine sand, light brown, laminated structure, medium-fine sand fraction, well sorted, firm contact with the underlying layer |
| **64 - 103 cm** | Brownish gray clay, black carbon clay lens in layers 93-94 cm and 103-104 cm |

**Figure 3.** The lithological profile of Core 2 [14].
3.2. Total suspended solid

The study of [16] has observed Total Suspend solid (TSS) in 2018 using satellite images 8 using algorithm analysis (after Budhiman) for six months, from March to August (Figure 5). The study showed that the concentration of TSS on the coast of Semarang from March (A) to August (F) 2018 ranged from 36 – 220 mg/L, according to the Alabaster and Lloyd classification, were categorized as class II to III. In the dry season (June-August), TSS concentrations ranged from 105-108 mg/L, lower than the transitional season (March-May) which ranged from 111-210 mg/L. Highest concentration of TSS was indicated in the coastal area of Genuk. Genuk area was located in the eastern of Semarang, bordering the Terboyo industrial area and the industrial areas along the Kaligawe highway. TSS concentrations during March to August remained constant, without significant fluctuations, only changed on the distribution area (Figure 4). This condition could be caused by the flat morphology of the river mount in Genuk District to the sea that inhibits river flow that caused inundation on such a long residence time on the estuary. This condition obviously caused the stagnant accumulation of TSS in the downstream.

3.3. Grain size distribution

Two core sample from WFC and EFC estuary revealed that sediment fraction characteristics in EFC was constantly finer than the WFC for 114 years [10]. The ratio between sand and fine fraction (silt and clay) in WFC was 14:86, and 7:95 in EFC. Sediment fractions in the West and East Flood Canal estuary were dominated by silt fractions.
Sedimentation rate based on core samples were determined at WFC and EFC in 2016 [10] using Pb\textsuperscript{210}. Sedimentation rate in the EFC estuary was higher than WCF (Figure 5), this was related to the stagnant and higher suspension inputs [14] as well as fine, silt fraction carried by EFC flow [10] to the estuary. The current in the coastal waters of Semarang dominated by tidal on 84.079\% value, and the percentage of residual current flows was 15.921\%. The maximum current velocity was 18.4 cm/second in the direction of 212.8 NE, and the minimum current velocity was 0.2 cm/second [17]. The large input of suspension and silt coupled with the dominance of tidal currents causes a high sedimentation rate in the EFC, with a range of 0.7 – 2.6 cm/year. While in WFC the sedimentation rate ranges between 0.11 – 0.65 cm/year (Fig. 5).

Sedimentation rate in the EFC estuary was 0.684 cm/year that was higher than the WFC (0.258 cm/year), indicated that sediment input to coastal waters in EFC was intensify. Genuk District, located on the eastern coast of Semarang has the wider erosion area, reaching 298.019 ha from 2003 – 2018 [18]. Erosion material in Semarang waters was transported to the open shore in various sediment fractions, particularly the finer fractions such as silt, clay and finer sand.

3.4. Heavy metal contamination
The concentration of Pb and Zn on sediment surface layer in almost stations of Semarang coastal waters on August 2010, exceeded the crustal abundance according to [4] after [9]. The Pb and Zn concentrations of surface sediments on 2010, indicated that Tanjung Mas Port was the highest concentration of those metals, and the WFC estuary was the lowest [19]. Both metals in surface sediments of 13 stations were higher than the crustal abundance, 70 ppm [4] after [9].

Meanwhile, the concentrations of Cd, Cu, and Ni were below the crustal abundance [4] after [9] (Table 1), that revealed these three metals has not been enriched nor contamination. In contrast the Cd, Cu and Zn concentrations in 2016 increased, that the Cd and Zn exceeded their natural concentrations but yet under PEL (Table 1). PEL (probable effects level) is a sediment quality index used by NOAA related to reducing the impact of metals on aquatic biota. Cd in the sediments can be sourced from the provenances and/or water system [20], aerosol [21] and anthropogenic [22].

| Metal | August 2010 [9] | March 2016 [10] | Crustal abundance [4] | PEL [23] |
|-------|----------------|----------------|-------------------|---------|
| Cu    | 18.26 – 36.64  | 27.8-55.3      |                   |         |
|       | 30.27          | 41.8           |                   |         |
| Pb    | 10.9 – 17.34   | 7.07-10.2      |                   | 91.3    |
|       | 13.7           | 8.16           | 12.5              |         |
| Cd    | 0.060 – 0.134  | 0.15-0.34      | 0.2               |         |
Retrospection study on metal contamination based on core sample of 2009 [8], showed that Cu concentration at the EFC estuary was higher the WFC since early 1870 (Fig. 6). The Cu concentration for more than a century varied between 31.7 – 46.2 ppm at the WFC estuary and between 35.7 – 71.2 ppm at EFC estuary [8]. Cu concentration at EFC tend to increase, during the pre-industrial to industrial era and reached 71 ppm on the recent sediment [8]. The Cu concentration in surface sediment layer dated 2009 of EFC was even higher on narrow concentration span than in the Jakarta Bay on June 2011 (11.8 – 68.3 ppm) [24].

Zn concentration in the EFC estuary always been higher than WFC for more than a century (Fig. 6). The Zn concentration at WFC estuary varied between 53 – 64 ppm and between 60 – 96 ppm at EFC [8]. Zn concentration tend to increase from pre-industrial era to industrial era, particularly at EFC that reached 119.2 ppm in 2010 [18]. Different pattern had shown on the variability of Hg concentration [8], which tend to be higher in EFC in the last century (1910).

![Figure 6](image)

*Figure 6. Cu, Zn and Hg concentration in Semarang coastal sediment for 160 years [8]. WFC in solid line and EFC in dash line.*

The 2016 core sampled by [10] indicates that the Cu, Pb, Cd, and Zn concentration in the EFC were higher than the WFC since 1896. The concentration range of those metals for 174 years based on 45 cm core length data in WFC, and 114 years based on 78 cm core length data in EFC, which were revealed in Table 2. Sedimentation rate in the EFC estuary was higher than the WFC, indicated that sediment input to coastal waters in EFC was intensify. Sedimentary material transported to shallow sea waters for more than a century was also carried various contaminants including metals from upland and coastal areas.
Table 2. Range of metal concentration in core sediment (ppm) at the West Flood Canal (WFC) and East Flood Canal (EFC) sampled in 2016.

| Site | Metal (ppm) | Cu  | Pb  | Cd  | Zn  |
|------|-------------|-----|-----|-----|-----|
| WFC  | Cu          | 25 - 35.5 | 3.5 - 10.8 | 0.13 - 0.43 | 70 - 115 |
|      | Pb          |       |     |     |     |
|      | Cd          |       |     |     |     |
|      | Zn          |       |     |     |     |
| EFC  | Cu          | 24 - 60 | 5 - 17.4 | 0.14 - 0.55 | 74 - 175 |
|      | Pb          |       |     |     |     |
|      | Cd          |       |     |     |     |
|      | Zn          |       |     |     |     |

3.5. Ammonia beccarii (Foraminifera benthic) as a proxy of coastal health

The most important component of the benthic foraminifera community at the observation site was *Ammonia beccarii*, that was one of an opportunist species that can survive in anoxia/hypoxia/eutrophic water [16]; [25]. Most of *Ammonia* species were adapted taxa to marginal marine environments such as coastal waters [26], this genus is found to dominate several coastal waters such as Jakarta Bay [27], Lampung Bay [28], Cirebon and Semarang coastal waters [27].

Abnormal test of *Ammonia beccarii* is one among the response to their habitat changes, in addition to its community structure and metabolism changes [29];[25]. The study of [19] had detected post mortem *Ammonia beccarii* abundance was concentrated in Tanjung Mas Harbour waters, but abnormal living forms were concentrated in the WFC estuary. Whereas deformed post mortem tests were concentrated in EFC. Living form of *Ammonia beccarii* that was found in the Semarang waters on August 2010 were higher than those found in the coastal waters of Cirebon and Jakarta Bay [27].

3.6. Hypoxia imprint

According to [30], used the A-E Index in coastal waters of Louisiana as a proxy for paleo hypoxia recorded in sediments. This index uses taxa that are widely distributed and well preserved in the sediments. Ammonia and Elphidium are benthic foraminifera that are living in almost all marine waters, particularly in shallow waters such as neritic waters. Ammonia has a better tolerance for decreasing dissolved oxygen in the waters compared to Elphidium [30].

The preserved foraminifera specimens in core sediment of WFC estuary were minuscule to identified (<0.063 mm), which also were categorized as juvenile form of benthic foraminifera, that were hardly can identified in genus level. On this case the AE index in WFC were not calculated. The single dominance and low density of Ammonia at the WCF indicated that these waters was not accommodated the physiological needs of almost taxa, except Ammonia which has opportunistic properties [23].

![Figure 7. A-E index at the EFC estuary [7].](image-url)
4. Conclusion
The vulnerability of Semarang coastal waters was risky, particularly in the EFC estuary. In addition to the periodic inundation problems recorded since 1920, accompanied by physical problems in the coastal areas, contamination in various forms has also become an ecological burden for this coastal area. The suspension and silt inputs which were higher than the WFC have also carried heavy metal contaminants. Retrospective studies using sediment cores have shown steadily increasing concentrations of some metals for more than a century, and a trend toward higher concentrations of these metals in the EFC. Through the benthic foraminifera proxy, *Ammonia beccarii*, it was indicated that ecological pressures have disturbed the benthic biota community, which is characterized by the emergence of single species dominance. Furthermore, the AE index has indicated a moderate to high hypoxia event in the EFC over a period of 72 years.

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