Physicochemical factors related to water quality improvement at Dongcheon stream in Busan, South Korea

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ABSTRACT

Dongcheon stream runs into the North port from the central urban area in Busan, South Korea. Since May, 2010, the seawater from the North port has been used to maintain the water quality improvement in Dongcheon stream. This had been effective until 2012, but since 2013 the water quality has gradually worsened because of water pollutants caused by sewage and sediment. The aim of this study is to improve the water quality through water and sediment monitoring in Dongcheon stream. The H₂S concentration, which had been the main cause of blue tide in Dongcheon stream was at a peak at the Beom4 bridge site from April to June due to the rising water temperature. From the particle size analysis of sediment, 0.02% of the streambeds of the midstream and upstream were covered with mud. The muddy area was about 10 times larger in the downstream than in the upstream. The COD(mg/g) and AVS(Acid Volatile Sulfide, mg·S/g·dry) in sediment as well as the SOD(Sediment Oxygen Demand) were at a peak concentration at Seongseo bridge site. With the rise in the water temperature, the salinity and ORP had an anti-symmetric relation with the pH decline caused by the decomposition of compounds in sediment.

Keywords: Water quality improvement, blue tide, salinity, SOD (Sediment Oxygen demand, g·O₂/m²·day), AVS (Acid volatile sulfide, mg·S/g·dry).

INTRODUCTION

Dongcheon stream, which flows into a residential area and a central urban area and borders Busan’s north port, has a basin area of 30.60 km² and a length of 8.77 km. A point in the downstream where it joins Jeonpo stream is a brackish water zone influenced by sea water (tidal gap of downstream in Dongcheon stream: full tide 113.6 cm, low tide 40.2 cm, average tidal gap 76.9 cm). Since 2010, discharging the sea water into Dongcheon stream in the first time had an effect on the water quality improvement, but the water pollution was aggravated by the accumulation of sewage and sediment in the streambed. As well, the stream water was congested by the frequent dredging of sediment from Dongcheon office site located at the exit of Jeonpo stream to the Beom4 bridge site. In summer, outbreaks of odor and algae resulted in an unpleasant environment for residents, causing them to stay away from the stream.

The aim of this study is to investigate pollutant factors in order to establish preventative measures and achieve a fundamental water quality improvement through the analysis of physicochemical factors. To study a transition process between the water and sediment, SOD(Sediment Oxygen Demand) measurement and the leaching test were performed at different times to investigate the cause of blue tide (Busan Metropolitan city, 2015) and to analyze the data in connection with the Multi-parameter Water Quality Monitoring System.

MATERIALS AND METHODS

Object

Dongcheon stream is 8.77 km in length, of which 2.8 km is
uncovered and the rest of the stream is covered. The sites used in this study are two sites in the upstream (Gwangmoo bridge site and Dongcheon office site), two sites in the midstream (Beom4 bridge site and Seongseo bridge site) and one site in downstream (Beomil bridge site). To check the water quality and sediment of each site, we investigated the water layers in full and low tide on a quarterly basis. Among the study sites, the water level was low (about 50 cm) at Gwangmoo bridge site and the water quality variation was only investigated for no sediment. Dongcheon office site (water depth approximately, 1 m), which was located at the exits of Bujeon stream and Jeonpo stream was investigated to check the water quality and sediment. The water levels of Beom4 bridge site, Seongseobridge site in the midstream and Beomilbridge site in the downstream were about 1.0 to 2.5 m, so it was possible to investigate the water quality variation and sediment. Figure 1 shows the map of study sites in Dongcheon stream (at 5 sites).

Methods

Investigation by water depth

For all sites other than Gwangmoo bridge site, temperature, DO, pH and salinity variations by depth were investigated and 16 items included in COD$_{Al}$, TOC, T-N, T-P and H$_2$S in overlying and underlying water of each site were also investigated. For Dongcheon stream, the maximum depth was only 1 m and we investigated only overlying and underlying water. A Van Dorn sampler was used to investigate H$_2$S by water layer, fixing a sample in the field with zinc acetate and moving it to the laboratory in a refrigerated container.

Water quality investigation

Water quality, which included tests of 17 items (COD$_{Al}$, TOC and DOC etc) at 5 sites was investigated on a monthly basis. Significantly, we referred to the results obtained by the Multi-parameter Water Quality Monitoring System that was installed at the Seongseo bridge site in October, 2014. To investigate pollutant factors, we analyzed in order to compare accumulated precipitation with the results of COD$_{Al}$, SO$_4^{2-}$, T-N, T-P, TOC/COD and DOC/TOC ratio.

Particle size and pollution level in the sediment

The particle size analysis of sediment was investigated by classifying sediment into silt(< 63 μm), very fine sand (< 100 μm), fine sand(< 250 μm), medium sand(< 500 μm), coarse sand(< 1,000 μm) and very coarse sand (> 1,000 μm). The grab sampler was used to take sediment samples at the same sites of water quality investigation. To check the sediment pollution level, COD(mg/g), AVS(Acid Volatile Sulfide, mg-S/g-dry), IL(Ignition Loss, %), MC(Moisture Content, %), TOC(Total Organic Carbon, mg/L) were analyzed in accordance with Korean Ocean Environmental Standard Methods. Also to understand the degree of sediment pollution, we carried out SOD (Peter et al., 1979) measurements in an incubator at 20°C.

Leaching test in the sediment

To examine leaching concentration of organic compounds in the sediment, we investigated the variation of pH, salinity(psu), ORP(mV), COD$_{Al}$, NH$_4^+$-N, T-N, H$_2$S, T-P by temperature(10, 20 and 30°C) and leaching time (0.5, 1.0, 2.0, 4.0, 8.0, 23, 48 and 96 h).

Mechanism of blue tide

To investigate factors related to the occurrence of blue tide in Dongcheon stream, H$_2$S concentration in the water mass was measured by temperature variation (10, 20 and 30°C) and quarterly in overlying and underlying water. Furthermore, in the laboratory the variation of SO$_4^{2-}$ and H$_2$S concentrations in the blue tide that was artificially created were investigated.

RESULTS AND DISCUSSION

Results of investigation in the water layers

There are no big changes in water quality in low and high tide at low water depth and a lot of stagnant watershed. In addition, the mean depth is just 1 m, while the salinity and DO values of overlying and underlying water barely changed. Looking at the changes of temperature, DO, pH, salinity by water depth (Figure 2) on May 26th, 2015 in full tide, seawater had an impact on the Seongseobridge site and DO values were changed slightly from a depth of 1 m. Figure 3 shows that the changes of temperature and DO values in Dongcheon stream slightly changed in low tide on July, 28th 2015.

TOC, DOC, COD$_{Al}$ and T-N were examined and it was observed that the pollution level is higher in overlying than in underlying water. At Gwangmoo bridge site, the water quality is under 2 mg/l but this increased by 2 to 3 times to 4.9 to 5.5 mg/L at Dongcheon office site, 4.0 to 5.0 mg/L at Beom4 bridge site and 3.9 to 5.7 mg/L at Seongseo bridge site. The DOC (Dissolved Organic Carbon) in TOC (Total Organic Carbon) is high at all investigation sites and it is known that sewage and non-point sources flowed into the Dongcheon stream.

Looking at annual variations, it was found that the degree of water pollution is high at Dongcheon office site and
Seongseo bridge site (Figure 4) because the exits of Bujeon and Jeonpo stream are located near Dongcheon office site, it is also similar at the Seongseo bridge site. This is considered to be the cause of sewage and non-point sources. In addition, 30,000 m³/day of sea water was conveyed at the Gwangmoo bridge site, 10,000 m³/day between Beom4 and Seongseo bridge sites and 10,000 m³/day between Seongseo and Beomil bridge sites in Dongcheon stream, which are influenced twice daily by low and high tide. But here, water quality improvement efforts were less effective; in particular, the odor and blue tide were often caused by the influence of sewage at Dongcheon office site and Beom4.
bridge site. As well, with the changes of H$_2$S concentration according to water depth (Figure 5), H$_2$S concentration is the highest in the second quarter (in May) was found to be 7.073 mg/L in the overlying water at Dongcheon office site and 5.364 mg/L in the underlying water at Seongseo bridge site.

**Results of water quality investigation**

We investigated the water quality of Dongcheon stream on a monthly basis at 5 investigation sites, which were the Gwangmoo bridge site, the Dongcheon office site, the Boem4 bridge site, the Seongseo bridge site and the Beomil bridge site. After dredging sediment in June, 2014, outbreaks of odor and blue tide declined significantly at Dongcheon office site and Boem4 bridge site, but at the space between Boem4 bridge and Seongseo bridge sites and the space between Seongseo bridge and Beomil bridge sites, sewage flowed into the Dongcheon stream and accumulated in a streambed, resulting in outbreaks of odor and blue tide. Figure 6 shows the findings produced through the Multi-parameter Water Quality Monitoring System (YSI 6600EDS) installed at Seongseo bridge site and it can be seen that the chlorophyll-a concentration (mg/m$^3$) increased from mid-March to June. Figure 7 shows the days of blue tide occurrence when there were more than 10 h of daylight by combining the findings with data generated by the Meteorological Administration from April to August, 2015. The intensive outbreaks of blue tide in April, May and August of all years were investigated and it was observed that dissolved oxygen was sharply increased by the excessive chlorophyll-a outbreak in August.

This study was performed to investigate the water quality changes caused by flowing 30,000 m$^3$/day of seawater and whether or not there were non-point sources flowing into the Dongcheon stream. In addition, to identify the causes of blue tide and odor in Dongcheon stream, we investigated 11 items included in COD$_{ML}$, H$_2$S, SO$_4^{2-}$, NH$_4^+$-N, TN, TP and in looking into TOC/COD, DOC/TOC ratio, we gained an understanding of the pollutant factors of each site. The COD changes in Dongcheon stream (Figure 8) were investigated and it was found that extreme changes could be ranked in the order of Dongcheon office site, Boem4 and Seongseo bridge sites. Thus, a lot of non-point sources were distributed and there were big changes in pollutant concentrations.

Figure 9 shows the TOC/COD and DOC/TOC ratios in Dongcheon stream and comparing rainfall, Dongcheon office, Boem4 bridge and Seongseo bridge sites have more
Figure 5: Annual variations of H₂S concentration by the overlying & underlying water in Dongcheon stream, 2015 (at 4 sites).

Figure 6: Annual variations of water pH, dissolved oxygen, temperature and chlorophyll-a in Dongcheon stream as of 2015, as recorded by the multi-parameter water quality monitoring system.
Figure 7: Outbreak of blue tide by tidal level from April to August in Dongcheon stream, 2015.

Figure 8: Annual variations in water quality (TOC, DOC, COD\textsubscript{Al} and TN) at study sites in Dongcheon stream.
external factors than internal. In other words, the DOC/TOC ratio declined rapidly with increased rainfall in April, August and September and in terms of the inflow of sewage and non-point sources, this contributed partially to a COD increase. After August, the DOC/TOC ratio declined sharply and inflow (unknown pollutants and non-point sources) other than pollutants in Dongcheon stream had a great effect on water quality variation. As such this has relevance to the sewage line and in general at the beginning of rainfall, the estimated discharge of the sewage line had to be 3Q(quantity), but in Busan a collecting design discharge was made to 1Q and if it rained over 6.7 mm/h, sewage and unknown pollutants from non-point sources flow into the stream. As such in the case of Dongcheon stream, when it rains, water pollution was caused by external rather than internal factors. The quantity of unknown pollutants and non-point sources that flowed into the Dongcheon stream is about 20,000 to 30,000 m³ (Gwangmoo bridge site: 31 psu, Dongcheon office site: 26 psu), calculated based on the difference in salinity.

Particle size analysis

Looking at the results of the particle size analysis of the sediment, silt (< 63 μm) made up 0.02% (average), very fine sand (< 100 μm) 0.3% (average), fine sand (< 250 μm) 5% (average), medium sand (< 500 μm) 19% (average) and the rest of the sand at the Dongcheon office site consisted of coarse sand (< 1,000 μm) and very coarse sand (> 1,000 μm). After dredging the sediment at the Dongcheon office site in 2014, it was found that the streambed consisted almost entirely of sand, which was similar to the Beom4 bridge site. Among the sites, the sediment pollution level was the highest at the Seongseo and Beomil bridge sites and the silt made up 2.6 and 2.2%, very fine sand 8.5 and 9.0%, fine sand 27.6 and 28.6%, medium sand 49.8 and 49.9%, respectively, while the rest of the sand (11.5 and 10.3%) consisted of coarse sand and very coarse sand.

Silt and mud were more than 10 times higher at Seongseo and Beomil bridge sites located on the midstream and downstream than at Dongcheon office site and Beom4 bridge site located on the upstream. This was caused by the dredging of the sediment at Dongcheon office site and Beom4 bridge site as the center that took place in 2014 and by the discharging of the water from a lowland waterproof storage tank installed in midstream and the flowing of unknown water from a neighborhood commercial center.

Sediment contamination level

Looking at the effect of stream water on the sediment in Dongcheon stream, based on the results of sediment investigation at 4 sites (Dongcheon office site, Beom4, Seongseo and Beomil bridge sites), the sediment condition in upstream and midstream was somewhat good but the results of quarterly investigation found an increase in sediment pollution. Meanwhile, the sediment pollution was at a serious level at the Seongseo bridge and Beomil bridge sites located at the mid- and down-stream in Dongcheon stream. In particular, the COD concentration in the sediment was found to be 107.7 mg/g(annual average) at Seongseo bridge site and it is higher than the sediment pollution level of Bosoo stream (73.1), Guduk stream (75.1), Oncheon stream (38.0), Chun stream (16.3) (Lee Jun-Ki et al., 2009) in Busan, South Korea. In addition, the AVS concentration (mg/S/g-dry) is the highest among 4 sites (Dongcheon office (0.40), Beom4 bridge (0.60), Seongseo bridge (2.15) and Beomil bridge (1.30).

SOD (Sediment Oxygen Demand) measurements

To study SOD measurements (Peter et al., 1979) in 4 sites, we carried out the test. To standardize the tests, the samples

Figure 9: Annual TOC/COD, DOC/TOC ratio variations of water quality and accumulation rainfall in Dongcheon stream, 2015.
in the field were taken to the laboratory, keeping the sediment in a freezer and homogenized with as little disturbance as possible (Figure 11). Also to minimize the effect of temperature, the tests were carried out in an incubator (20°C). Figure 10 shows the variations of pH and DO and temperature were tested at intervals of 0.5, 1, 2 and 4 h.

Through SOD measurements, it was shown that oxygen was depleted within 30 min after adding an aerated water column (Table 1). According to A SOD measurements report of sediment at Deer Creek Reservoir, Brigham Young University, USA (Derek, 2011), SOD measurements showed that DO was quickly depleted within 45 min after starting the test due to sample disturbance and then gradually stabilized. So in this study, DO was depleted within 30 min after starting the SOD measurements and was then gradually stabilized (Figure 12). Table 2 values were calculated using the formula (1).

Average SOD measurements values (g-O₂/m²·day) were investigated in 0.91(0.11 to 1.39) at Beom4 site and 2.81(1.13 to 4.87) at Seongseo bridge site. The formula below was the SOD measurement values calculation formula and Figure 13 provides a schematic diagram of the SOD measurement apparatus.

\[
\text{SOD} = \text{depletion factor (mgL/h)} \times \text{aerated water volume (L)} \times \text{reactor cross-section area (cm}^2\text{)} \times 240(1)
\]

### Table 1: Sediment oxygen demand values by streambed types (Chang-Mo Kim, 1999).

<table>
<thead>
<tr>
<th>Streambed types and sites</th>
<th>SOD(g·O₂/m²·day) at 20°C</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Range</td>
</tr>
<tr>
<td>Sewage inlet</td>
<td>2.0 - 10.0</td>
</tr>
<tr>
<td>Sewage downstream</td>
<td>1.0 - 2.0</td>
</tr>
<tr>
<td>Mud in estuary</td>
<td>1.0 - 2.0</td>
</tr>
<tr>
<td>Sand streambed</td>
<td>0.2 - 1.0</td>
</tr>
<tr>
<td>Minerals streambed</td>
<td>0.05 - 0.1</td>
</tr>
</tbody>
</table>

### Table 2: Quantities calculated from SOD measurements.

<table>
<thead>
<tr>
<th>Beom4 bridge</th>
<th>SOD(g·O₂/m²·day)</th>
<th>Seongseo bridge</th>
<th>SOD(g·O₂/m²·day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CORE #1</td>
<td>0.11</td>
<td>CORE #1</td>
<td>4.87</td>
</tr>
<tr>
<td>CORE #2</td>
<td>1.34</td>
<td>CORE #2</td>
<td>2.05</td>
</tr>
<tr>
<td>CORE #3</td>
<td>1.39</td>
<td>CORE #3</td>
<td>3.17</td>
</tr>
<tr>
<td>CORE #4</td>
<td>0.80</td>
<td>CORE #4</td>
<td>1.13</td>
</tr>
<tr>
<td>SOD AVG.</td>
<td>0.91</td>
<td>SOD AVG.</td>
<td>2.81</td>
</tr>
<tr>
<td>Standard deviation</td>
<td>0.60</td>
<td>Standard deviation</td>
<td>1.61</td>
</tr>
</tbody>
</table>
Figure 11: Pictures ① Dongcheon office, ② Beom4 bridge, ③ Seongseo bridge and ④ Beomil bridge of sediment from sampling sites in Dongcheon stream, before (a) and after (b) drying.

Figure 12: Annual COD, AVS, MC and IL concentrations of the sediment at sampling sites in Dongcheon stream, 2015.
Leaching test of sediment

In this study, to examine the leaching concentration of organic material according to the temperature of sediment, we investigated hourly pH, salinity and ORP using a portable measuring instrument (YSI 556MPS). Figure 14 shows variations in pH, salinity and ORP in the leaching test at Beom4 bridge and Seongseo bridge sites and it can be seen that the reaction was the fastest at 30°C. At higher temperatures, the H₂S generation in sediment was increased. Figure 15 showed that the item with the most changes was NH₄⁺-N. That is to say, when an organic material was decomposed, the earliest generated matter was NH₄⁺-N and was also considered to be the biggest generation of NH₄⁺-N by time.

Mechanism of blue tide

To investigate the pollutant transition between a water mass and a sediment in Dongcheon stream, we studied the variations of COD, TOC, AVS, NH₄⁺-N, T-N and T-P based on
pH and DO changes at 20°C (average water temperature of Dongcheon stream in summer season) (Figure 16). In particular, we investigated the changes in the concentration of H₂S and SO₄²⁻, which were cited as the cause of blue tide in Dongcheon stream. Also, we investigated the monthly variation of organic material, studied the inflow route of pollutants and considered cut-off methods. First of all, the organic materials transferred from sediment were absorbed or spread into a water mass and increased the water pollution level in Dongcheon stream. The following reactions were shown to a reaction formula (Shin et al., 2009) of H₂S generation process after sediment reacted to SO₄²⁻:

\[
\text{Sulfate reducing bacteria} \quad \text{SO}_4^{2\,-} + \text{organic material} \rightarrow \text{S}^{2\,-} + \text{H}_2\text{O} + \text{CO}_2 \tag{2}
\]

\[
\text{S}^{2\,-} + 2\text{H}^+ \rightarrow \text{H}_2\text{S} \quad \text{(hydrogen sulfide)} \tag{3}
\]

According to the reaction formulas, SO₄²⁻ ions which were plentiful in the seawater were resolved to H₂S in the sediment and the water (mostly underwater sediment) under anaerobic conditions when a sulfate reducing bacteria decomposed an organic material. Also, much of the H₂S generated was accumulated as dissolved sulfide (H₂S, HS⁻) in the underlying sediment and water.

\[
\text{H}_2\text{S} + 1/2\text{O}_2 \rightarrow \text{S} + \text{H}_2\text{O} \quad \text{(generation of sulfate colloid)} \tag{4}
\]

In these conditions, a water mass containing a lot of sulfide was rapidly oxidized in mixing the overlying water and this generated a sulfate colloid (white), which had a strong hydrogen sulfide odor while making a white turbidity. In the case of Dongcheon stream, hypoxic bottom water contained a lot of H₂S that came up to the water surface and the H₂S was oxidized by water oxygen to generate H₂SO₄ or a sulfur oxide particle. This was floating in the underwater, and caused an outbreak of blue tide or milky-looking water (Masayasu et al., 2009) in sun light.

As such if there were high concentrations of SO₄²⁻ ions

Figure 15: Variations of water pH, salinity and ORP in leaching test of Beom4 bridge (a) and Seongseo bridge (b) sediment samples.
Figure 16: Variations of water COD, NH₄+-N, T-N, T-P and H₂S in leaching test of Beom4bridge (a) and Seongseo bridge (b) sediment samples.

Figure 17: H₂S variations of Beom4bridge (a) and Seongseo bridge (b) sites in leaching test.

and low concentrations of DO in the water mass, the reaction velocity would be fast. Figure 17 shows the change in concentration of H₂S at different water temperatures. When the water temperature rose by 2°C the H₂S
concentration in the water increased more than two times. If the H$_2$S concentration in the water was increased, water color was changed to a white turbidity by light scattering at low tide. Figure 18 shows the outbreak of blue tide in Dongcheon stream and the quarterly concentration of H$_2$S in the water.

Blue tide often occurred in Dongcheon stream when water temperature was over 15°C, there was 10 h of sunlight and there was low tide. As sunlight hours increased, water temperature was rising and the anaerobic reaction in the water accelerated. In addition, oxygen was depleted in the water by these conditions and H$_2$S generation in the water increased. Below the pictures, the test is shown in which an artificial blue tide was created by producing similar conditions to Dongcheon stream (DO was under 1 mg/L).

Figure 19 shows the test under the same conditions of the outbreak of a blue tide in Dongcheon stream, which were temperature, DO, pH and ORP. Looking at H$_2$S concentrations by outbreak time and water conditions, the blue tide outbreak occurred when DO was under 1 mg/L and there was a certain inflow of sewage and an upwelling of sediment in the streambed. In other words, sediment upwelling, SO$_4^{2-}$ in the water and organic material were degraded, while H$_2$S and CO$_2$ were generated by a facultative anaerobic bacteria (Keiyu and Mizurou, 2012). In this process, the water color was shown to reach a white turbidity, increasing isolation. Table 3 shows the concentration change for each item (COD, T-N, T-P, SO$_4^{2-}$, H$_2$S and TOC) in the pilot test.

**Conclusions**

We studied the annual change of water quality in Dongcheon stream and the trend through and researched
the distribution characteristics of sediment in Dongcheon stream. Also, to investigate the cause of blue tide in Dongcheon stream, the SOD test, the leaching test by water temperature and the laboratory test on the mechanism of blue tide outbreak was performed and reached the following conclusions regarding how improvements in water quality could be achieved.

Looking at the results (TOC by water depth, mg/L) for 4 sites in Dongcheon stream, the water pollution level in the stream water was increased by about 2 to 3 times at Gwangmoo bridge site (under 2), Dongcheon office site (4.9 to 5.5), Beom4 bridge site (4.0 to 5.0) and Seongseo bridge site (3.9 to 5.7). It was also concluded that the effluent and sewage around Dongcheon stream was the source of its high concentration of organic matter. Meanwhile, looking at the results related to variation of H$_2$S concentration, along with the increase of the water temperature in April, May and August, blue tide and odor concentrically occurred at Seongseo bridge site.

Looking at the results of a particle analysis of Dongcheon stream sediment, it was found that silt was made up of 0.02% (average), very fine sand (3%), fine sand (5%), medium sand (19%) and the remaining (80%) consisted of coarse sand and very coarse sand. After the dredging of sediment that occurred in 2014, the streambed consisted of sand. Meanwhile, the sediment at Seongseo bridge and Beomil bridge sites located in the mid- and upstream consisted of silt (2.6 and 2.2%), very fine sand (8.5 and 9.0%), fine sand (27.6 and 28.6%), medium sand (49.8 and 49.9%) and the rest was coarse sand (11.5 and 10.3%) and the down-streambed was covered with as much as 10 times as much silt as in Dongcheon stream.

Looking at the results of the investigation of sediment pollution level (COD, mg/g) the sediment concentration (average 107.7) at the Seongseo bridge site was the highest among the study sites. It was higher than the sediment concentrations of Bosu stream (73.07), Guduk stream (75.07) in comparison with investigation results of sediment concentration in Busan, South Korea. Also, the results of AVS (mg/S/g/dry) in sediment were the highest at Seongseo bridge site (2.15). In the SOD (g/O$_2$/m$^2$/day) test, it was 0.91 at Beom4 bridge site and 2.81 at Seongseo bridge site.

Considering the variation of sediment concentration by water temperature, the investigation found that the higher the water temperature, the more an anti-symmetric relationship there was between the salinity and ORP in sediment. As the sediment pollution progressed, the ORP went down -200 mV, the organic material in sediment decomposed and the pH in the water decreased thus leading to the increase in leaching pollutants. Significantly, the higher the water temperature, the faster the reaction and H$_2$S generation was increasing rapidly after 8 h.

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