# The Use of *Diopatra claparedii* Grube, 1878 (Onuphidae, Polychaeta) as a Bioindicator of Heavy Metal Contaminations in the Donan Creek, Cilacap, Central Java, Indonesia

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*Abstract*

*The Donan Creek is a coastal ecosystem in Central Java that is strongly affected by industrial activities. This study represents the first attempt to use the polychaete worms Diopatra claparedii Grube, 1878 (Onuphidae) as a bioindicator of heavy metal contaminations. The work was conducted between July and September 2023 at four sampling sites, designated from the farthest to the closest to the Indian Ocean. Samples of D. claparedii, sediment and water were collected at each site during low tide. The samples were analyzed for Cd, Cr and Pb concentration using Atomic Absorption Spectrophotometry. In addition, several other environmental parameters were also measured to examine the water quality of the creek. Our study highlights the capability of D. claparedii to accumulate all the three heavy metals. The concentrations of Cd, Cr and Pb in the body tissues of the worms ranged from 29.743 ± 0.011 mg.kg$^{-1}$ to 50.036 ± 0.028 mg.kg$^{-1}$, from 21.718 ± 0.024 mg.kg$^{-1}$ to 40.032 ± 0.052 mg.kg$^{-1}$, and from 20.068 ± 0.008 mg.kg$^{-1}$ to 44.030 ± 0.000 mg.kg$^{-1}$, respectively. These amounts were so far the highest among all other aquatic animals (i.e. bivalves, crustaceans and fishes) used as bioindicators in the Donan Creek. The heavy metal concentrations in D. claparedii were significantly correlated with those in the sediment ($p < 0.05$). In general, the levels of the metals were considerably higher in the more industrial area than those of the less industrial area ($P<0.05$). We further found that the concentrations of Cd, Cr and Pb as well as several other environmental parameters including BOD, COD, the total nitrate and phosphate in the water column of the creek did not meet the water quality standards stipulated by the Indonesian Government. These findings indicate that the ecosystem has been polluted by both heavy metals and organic matters. While environmental remediation is urgently required, a comprehensive review and improvement of industrial and domestic waste management practices in the region are equally essential to prevent further degradation.*

***Keywords:*** *Annelida, marine pollution, monitoring, water contamination*

## Introduction

The Donan Creek is an estuary administratively located in Cilacap Regency, Central Java Province, Indonesia. The creek, which is connected to the Indian Ocean, is often considered the easternmost part of the Segara Anakan Lagoon (SAL) and plays a crucial role in the local coastal ecosystem. Along with the mangrove area, it provides essential habitats for many estuarine species (*e.g.* Nordhaus *et al*. 2009; Pamungkas, 2013) and holds economic importance for the local residents, particularly in transportation, fisheries, recreational and industrial activities (pers. obs.).

Due to intensive anthropogenic activities on land, the Donan Creek has been reportedly receiving various contaminants, mainly through sewages. Dsikowitzky *et al*. (2011) reported the occurrence of more than 50 contaminants – they were mostly polycyclic aromatic compounds (PACs) consisted primarily of polycyclic aromatic hydrocarbons (PAHs) – in the water, sediment and macrobenthic fauna inhabiting the eastern part of the SAL, including the Donan Creek. Previous studies also indicated that the eastern part of the lagoon was contaminated by heavy metals (*e.g.* Hernawati, 2014; Widiyanto, 2014; Alam, 2015; Syakti *et al*., 2015; Piranti *et al*., 2020). The heavy metals, which typically come from

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industries, pose a significant threat to the coastal water ecosystem as well as human health as they cannot be degraded by organisms – the metals accumulate in the environment, mainly settling at the bottom of waters to form more complex compounds (*e.g.* Arifin *et al*., 2012; Piwowarska *et al*., 2024; Shintianata *et al*., 2024; Shetaia *et al*., 2025).

Benthic animals living at the bottom of aquatic ecosystems are commonly used as bioindicators due to their ability to accumulate heavy metals in their body tissues, being sessile with limited mobility, and ease of collection (Mir *et al*., 2021). Bioindicator species are commonly used in biomonitoring contaminant exposure. Locally, the bivalves *Geloina expansa* (Mousson, 1849) or '*kerang totok*' in the local name – the species is also known by the unaccepted species names *Geloina erosa* (*e.g.* Irawati *et al*., 2018) and *Polymesoda erosa* (*e.g.* Nordhaus *et al*., 2009) – have been used as a bioindicator for heavy metal contaminations in the eastern part of the SAL (Irawati *et al*., 2018) due to their widespread distribution in the lagoon and economic importance (the bivalves are consumed by the locals).

Another benthic species that has the potential for use as a bioindicator of heavy metal contaminations in the Donan Creek is the tubicolous polychaete worms *Diopatra claparedii* Grube, 1878 (Onuphidae). This species commonly occurs in several Southeast Asian countries and is often misidentified as *Diopatra neapolitana* Delle Chiaje, 1841 (*e.g.* Paxton, 2002; Idris and Arshad, 2013). The occurrence of this species in Indonesia, along with its economic importance, was first documented by Pamungkas *et al*. (2023) based on the specimens collected from the Donan Creek. Some biological aspects of this species have been studied by Wibowo *et al.* (2022; 2023; 2025). *Diopatra claparedii* is by far one of the biggest polychaete species in the SAL (pers. obs.), making it ideal for use as a bioindicator. While *D. neapolitana* has been reported to be a useful bioindicator for coastal contaminations (*e.g.* Mdaini *et al*., 2021; Arias *et al*., 2024) like some other polychaete species (*e.g.* Dean, 2008; Kies *et al*., 2020; Elías *et al*., 2021; Stefano *et al*., 2021), the potential of *D. claparedii* as an indicator species has not been investigated. In the present study, we used *D. claparedii* as an indicator species of heavy metal contaminations, especially Cd, Cr and Pb, and examined the water quality of the Donan Creek.

## Materials and Methods

The present study was carried out in the Donan Creek, Cilacap, Central Java, between July and September 2023. Four sampling sites were designated from the furthest to the closest site from the sea. Site 1 (7°39'54.6"S, 109°00'45.2"E), Site 2 (7°40'46.3"S, 109°00'23.2"E), Site 3 (7°42'22.5"S, 108°59'24.2"E) and Site 4 (7°43'40.2"S, 108°59'15.2"E) were situated near mangrove areas, a cement factory, an oil refinery and Sleko Harbour, respectively (Figure 1A). Site 1 and 4 are less industrial, whereas Site 2 and 3 are more industrial.

### *Sample collections*

At each sampling site, samples of *D. claparedii*, water and sediment were collected three times during a low tide. The worms were collected by a local experienced worm digger from the bottom of the Donan Creek. The tip of the animal's tube was first palpated using one foot. The tube, with the animal inside, was then taken out of the sediment using bare hands and was put on a thin wall container. The details on how a local digger collected the worms were documented by Pamungkas (2023) – see https://www.youtube.com/watch?v=1cBQx1yDOqU. On the boat, the worms obtained were removed from their tube by massaging the posterior part of the tube anterior wards. The worms were placed in a smaller thin wall container (Figure 2A). Water samples were taken using 1 L plastic bottles, and approximately 1 kg of sediment samples were taken using hands covered with plastic gloves and were put in plastic bags. Both samples were labelled and stored in a cool box for further analyses in the laboratory.

### *Species identification and other bioindicators*

The worms collected from the field were identified in the laboratory under both stereo and compound microscopes using the identification keys of Paxton (2002), Budaeva and Fauchald (2011), Idris and Arshad (2013), as well as the description of the local species by Pamungkas *et al*. (2023). This identification step was essential to ensure if the worms obtained were *D. claparedii* (Figure 2B). While the presence of spiralled branchiae and peristomial cirri confirmed the identity of the genus, the presence of distinct pectinate chaetae with funnel-like combs confirmed the identity of the species.

For comparison, we also compiled a list of all the species that have been used as bioindicators of heavy metal contaminations in the Donan Creek, along with the information about their capacity to accumulate the metals from relevant literature.

### *Environmental parameter measurements*

Three heavy metals, *i.e.* cadmium (Cd), chromium (Cr) and lead (Pb), were measured from the body of *D. claparedii,* as well as the water and the sediment of the Donan Creek. These three elements,

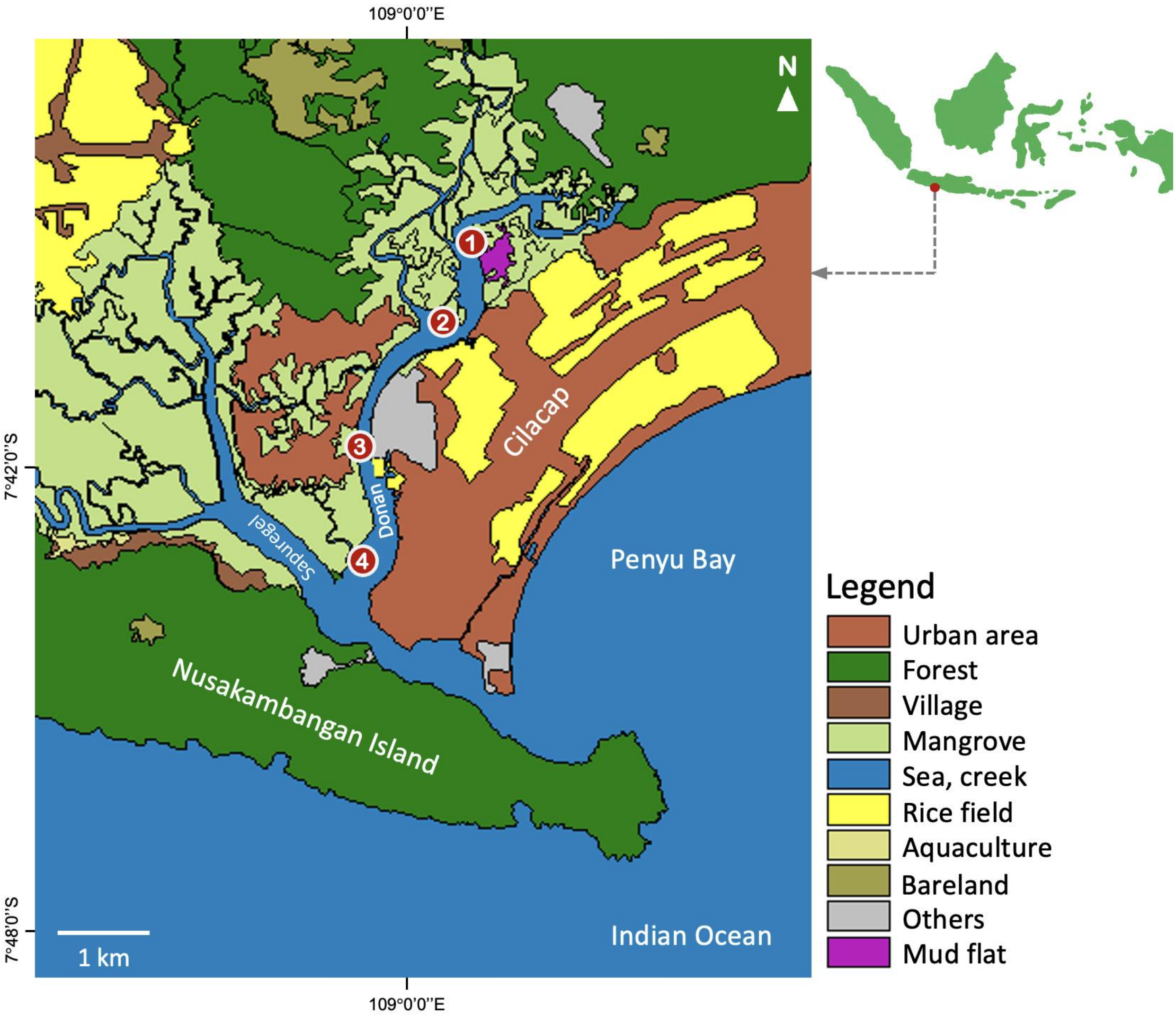


**Figure 1**. Map of the study area. Red circles with numbers indicate sampling sites (basic map was provided by Erwin R. Ardli)

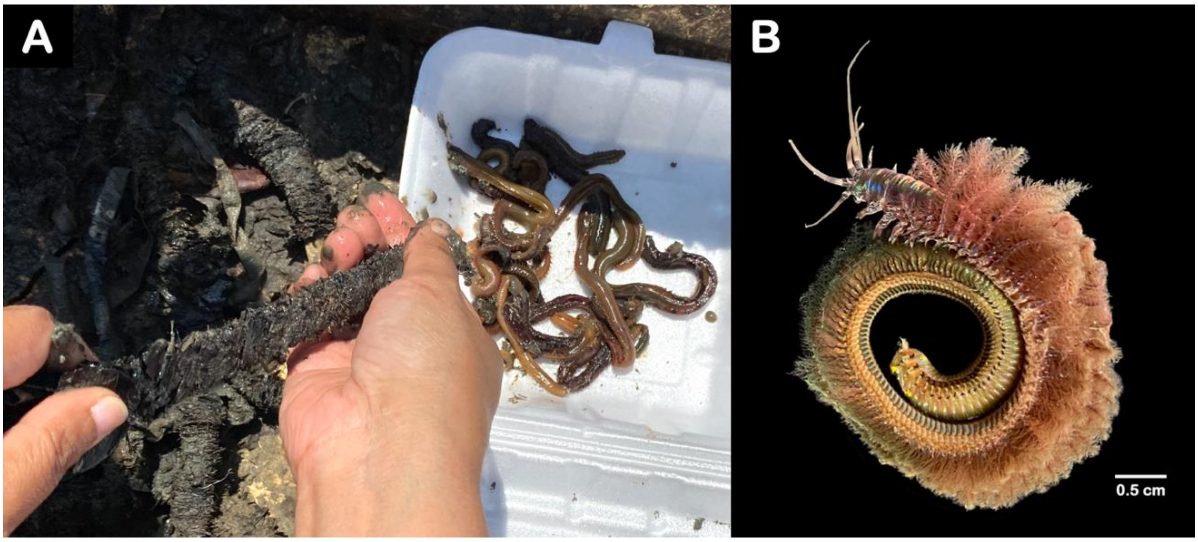


**Figure 2.** A. Worm removal from the tube. B. Morphology of a living *Diopatra claparedii* collected from the Donan Creek

along with arsenic (As) and mercury (Hg), are globally recognized as priority metals of public health concern due to their high toxicity (Tchounwou *et al*., 2012). Worm samples were first dried in the sun then air dried overnight. The drying process was then continued in the oven at a temperature of 60˚C for 24h. Thereafter, a 5 g worm sample was ashed using a furnace at a temperature of 600˚C for 4 h. The ash obtained was then cooled in a desiccator. The worm ash was put into a digestion flask and was added with 5 mL of concentrated $HNO_3$ and 2 mL of $H_2O_2$ until the ash was completely dissolved. The solution was then filtered using a Whatman grade 42 ashless filter paper (Badan Standarisasi Nasional, 2021). Using a 50 mL volumetric flask, the filtrate was diluted with distilled water to 50 mL. The filtrate was analyzed for Cd, Cr and Pb concentration using Atomic Absorption Spectrophotometry (AAS) with wavelengths of 228.8, 357.9 and 283.3 nm, respectively.

Sediment samples were first dried in the sun then air dried overnight. The drying process was then continued in the oven at a temperature of 105˚C for 24 h. Thereafter, the sediment was crushed in a porcelain cup, then sieved. A 20 g sediment sample was put into an Erlenmeyer tube added with 500 mL of distilled water, then was centrifuged at 2000 rpm for 30 min. The water phase was removed and the precipitate was dried in the oven at a temperature of 105˚C for 24 h. Afterwards, a 1 g sediment sample was put in a glass beaker added with 6 mL of aqua regia, then heated on a hotplate at a temperature of 103˚C until the solution was almost dry (Badan Standarisasi Nasional, 2021). After the sample was cooled, 1 mL of concentrated $HNO_3$ was added. The solution was then filtered using a Whatman grade 42 ashless filter paper. Using a 10 mL volumetric flask, the filtrate was diluted with distilled water to 10 mL. The filtrate was analyzed for Cd, Cr and Pb concentration using AAS with wavelengths of 228.8, 357.9 and 283.3 nm, respectively.

A 50 mL water sample was taken and put into a 100 mL glass beaker. The sample was added with 10 mL of concentrated $HNO_3$ and 5 mL of 20% HCl then was heated on a hotplate at a temperature of 120˚C until the solution became clear. Afterwards, the solution was filtered using a Whatman grade 42 ashless filter paper. Using a 50 mL volumetric flask, the filtrate was diluted with distilled water to 50 mL (Badan Standarisasi Nasional, 2019). The filtrate was analyzed for Cd, Cr and Pb concentration using AAS with wavelengths of 228.8, 357.9 and 283.3 nm, respectively.

Bioconcentration factor (BCF), *i.e.* the uptake of the heavy metals from both the sediment and the water by the worms was calculated using the equation BCF = $C_{dc}/C_{s\ or\ w}$. Here, $C_{dc}$ is the heavy metal concentration in *D. claparedii* ($mg.kg^{-1}$), whereas $C_s$ and $C_w$ are the heavy metal concentrations in the sediment ($mg.kg^{-1}$) and the water ($mg.L^{-1}$), respectively. BCF values smaller, equal and bigger than 1 indicate that the worms contain less, equal and higher metals than the environment, respectively. The BCF is an important concept in the environmental risk assessment since it gives quantitative information regarding the ability of a contaminant to be taken up by organisms from the water (Wang, 2016). In addition, concentration factor (CF), *i.e.* the uptake of the heavy metals from the water by the sediment, was calculated using the equation CF = $C_s/C_w$. CF values smaller, equal and bigger than 1 indicate that the sediment contains less, equal and higher metals than the water, respectively.

Various environmental parameters were measured to examine the water quality of the Donan Creek. The parameters included temperature, conductivity, salinity, pH, total dissolved solids (TDS), total suspended solids (TSS), dissolved oxygen (DO), biochemical oxygen demand (BOD), chemical oxygen demand (COD), total nitrate and total phosphate. Water quality parameters such as temperature, conductivity, salinity, pH, TDS, TSS, BOD and COD are essential to understand in relation to heavy metal analysis because they strongly influence the behavior, mobility, and bioavailability of metals in aquatic systems. all the data obtained were then compared to the Water Quality Standards for Marine Biota set in the Government Regulation No. 22 Year 2021, Appendix VIII.

### *Statistical analysis*

As the data obtained are not normally distributed (the Shapiro-Wilk test was performed to inspect the data normality), the non-parametric Spearman correlation analysis was used to evaluate the relationships among the heavy metal concentrations in the body tissues of *D. claparedii*, the water and the sediment. The Mann-Whitney U test was also performed to compare the concentrations of the metals between the less industrial area (Sites 1 and 4) and the more industrial area (Sites 2 and 3). The statistical analyses were conducted using R version 4.4.0. coupled with RStudio version 2024.04.1+748.

## Results and Discussion

This study demonstrated that the concentrations of Cd, Cr and Pb in the body of *D. claparedii*, as well as in the water and the sediment of the Donan Creek, varied among four sampling sites. However, they were generally higher in the more industrial area than those in the less industrial area ($P$< 0.05; Table 1; Figure 3).

The worms collected from Site 2 (near the cement factory) accumulated the highest amount of Cd (50.036 ± 0.028 mg.kg$^{-1}$), Cr (40.032 ± 0.052 mg.kg$^{-1}$) and Pb (44.030 ± 0.000 mg.kg$^{-1}$), followed by those collected from Site 3 (near the oil refinery). At the latter site, the amounts of Cd, Cr and Pb in the body of the worms were 33.050 ± 0.000 mg.kg$^{-1}$, 38.050 ± 0.047 mg.kg$^{-1}$ and 40.053 ± 0.005 mg.kg$^{-1}$, respectively. Lower levels of heavy metals were found at Sites 1 and 4, which were less industrial (Table 1 and Figure 3).

In the water column, the levels of Cd and Cr gradually increased from Site 1 to 4. Specifically, Cd increased from 2.808 ± 0.008 mg.L$^{-1}$ to 6.723 ± 0.007 mg.L$^{-1}$, and from 0.561 ± 0.025 mg.L$^{-1}$ to 2.042 ± 0.053 mg.L$^{-1}$ for Cr. Slightly different from these two metals, the level of Pb increased from Site 1 (0.601 ± 0.010 mg.L$^{-1}$) to 3 (2.751 ± 0.018 mg.L$^{-1}$), then declined to 1.845 ± 0.010 mg.L$^{-1}$ at Site 4 (Table 1 and Figure 3).

In the sediment, the metal concentrations increased from Site 1 to 3, then decreased at Site 4. The highest amounts of Cd (78.181 ± 0.058 mg.kg$^{-1}$), Cr (48.117 ± 0.022 mg.kg$^{-1}$) and Pb (72.899 ± 0.010 mg.kg$^{-1}$) were hence recorded at Site 3, whereas the lowest concentrations were at Site 1 (Table 1 and Figure 3).

The higher concentrations of the heavy metals in the more industrial area seem to be associated with the presence of the cement factory (near Site 2) and the oil refinery (near Site 3) that regularly discharge effluent into the creek (pers. obs). Typically, Cd, Cr and Pb resulted from the cement industry are sourced from limestone, clay, fly ash, additives such as steel slag, and fossil fuels, whereas in the oil refinery industry, Cd comes from crude oil or catalysts in the reforming, hydrocracking and desulfurization processes; Cr comes from pipe materials, tanks or metal catalysts; and Pb comes from heavy oil fractions and anti-knock additives in gasoline.

As can be seen in Table 1 and Figure 3, the amounts of Cd, Cr and Pb in the body of *D. claparedii* ranged from 29.743 ± 0.011 mg.kg$^{-1}$ to 50.036 ± 0.028 mg.kg$^{-1}$, from 21.718 ± 0.024 mg.kg$^{-1}$ to 40.032 ± 0.052 mg.kg$^{-1}$, and from 20.068 ± 0.008 mg.kg$^{-1}$ to 44.030 ± 0.000 mg.kg$^{-1}$, respectively. These findings show that the worms are resistant to the three metals and possess the ability to absorb metallic elements similar to the European species *D. neapolitana* (*e.g.* Freitas *et al*., 2012; Arias *et al*., 2024). The concentrations of metals accumulated in the body of *D. claparedii* were found to be much higher than those in other groups of aquatic animals inhabiting the Donan Creek such as bivalves, crustaceans and fishes (Table 2). These suggest that the species has the highest ability to absorb metal contaminations from the surrounding environment.

This study further showed that the heavy metal concentrations in the body of *D. claparedii* had a strong positive correlation with those of the sediment of the Donan Creek (R = 0.76; $P$= 9.6e-08; Figure 4A), but a weak positive correlation with those of the water ($P$>0.05; Figure 4B). The strong positive correlation between the metals in the body of *D. claparedii* and those in the sediment can be attributed to the life and the feeding habits of aquatic animals (*e.g.* Arifin *et al.*, 2012). The adult *D. claparedii* is benthic infaunal organisms dwelling in the sediment of the Donan Creek for their entire lives (Pamungkas *et al*., 2023). The worms are continuously exposed to heavy metal contaminants that settle in the sediment (the amount of the metals in the water column positively correlated (R= 0.45; $P$= 0.0059; Figure 4C) with that in the sediment), resulting in the accumulation of metals in their body tissues. The metals also enter the worms' body through their dietary uptake. While *Diopatra* worms are known to be omnivorous – they feed on aquatic organisms living on the tube cap, on neighbouring tube caps, and within nearby sediments (Berke, 2022) – several studies have showed that a number of aquatic animals in the Donan Creek were reportedly contaminated with heavy metals (see Table 2).

Understanding how *D. claparedii* resists the toxic effects of heavy metals requires a further investigation. However, previous studies show that some polychaete species have developed detoxification mechanisms. For example, they may produce metal-binding proteins such as metallothioneins (MTs) or metallothionein-like proteins (MTLPs), which chelate and neutralize toxic metals within their tissues (Zhao *et al*., 2020). They may also regulate their internal metal concentrations by inhibiting the uptake of metals or promoting their excretion (Sun and Zhou, 2007). Despite this, morphological abnormalities in *D. claparedii* inhabiting the Donan Creek – the abnormalities are likely to be linked to heavy metal exposure – were documented by Pamungkas *et al*. (2025), indicating that the deleterious effects of the metals may not be entirely avoidable.

This study further showed that the BCFs (dc–s) were close to 1, *i.e.* ranging from 0.547 to 1.770, suggesting that the concentrations of the heavy metals in both the body of the worms and the sediment were nearly equal (values below 1 may be linked to the young age of the animals). In general, these findings demonstrate that *D. claparedii* can be used as a bioindicator. The BCFs (dc–w) ranged from

**Table 1.** Environmental parameters at each sampling site

| Parameter | Site[1] 1 | 2 | 3 | 4 | GR[2] |
|---|---|---|---|---|---|
| Heavy metals | | | | | |
| Cd in worm ($mg.kg^{-1}$) | 32.064 ± 0.037 | 50.036 ± 0.028 | 33.050 ± 0.000 | 29.743 ± 0.011 | - |
| in sediment ($mg.kg^{-1}$) | 27.989 ± 0.008 | 57.875 ± 0.006 | 78.181 ± 0.058 | 27.081 ± 0.057 | - |
| in water ($mg.L^{-1}$) | **2.808 ± 0.008** | **4.512 ± 0.012** | **6.379 ± 0.008** | **6.723 ± 0.007** | 0.001 |
| Cr in worm ($mg.kg^{-1}$) | 22.065 ± 0.046 | 40.032 ± 0.052 | 38.050 ± 0.047 | 21.718 ± 0.024 | - |
| in sediment ($mg.kg^{-1}$) | 20.983 ± 0.104 | 47.818 ± 0.011 | 48.117 ± 0.022 | 37.838 ± 0.100 | - |
| in water ($mg.L^{-1}$) | **0.561 ± 0.025** | **0.981 ± 0.003** | **1.923 ± 0.010** | **2.042 ± 0.053** | 0.005 |
| Pb in worm ($mg.kg^{-1}$) | 20.068 ± 0.008 | 44.030 ± 0.000 | 40.053 ± 0.005 | 24.748 ± 0.007 | - |
| in sediment ($mg.kg^{-1}$) | 16.441 ± 0.032 | 48.27 ± 0.010 | 72.899 ± 0.010 | 13.979 ± 0.073 | - |
| in water ($mg.L^{-1}$) | **0.601 ± 0.010** | **1.030 ± 0.001** | **2.751 ± 0.018** | **1.845 ± 0.010** | 0.008 |
| Others | | | | | |
| Temperature (°C) | 29.233 ± 0.971 | 29.967 ± 0.586 | 29.633 ± 1.35 | 29.267 ± 0.551 | 28–32 |
| Conductivity ($\mu S.cm^{-1}$) | 41.9 ± 7.996 | 44.667 ± 13.65 | 47.5 ± 10.259 | 46.733 ± 13.683 | - |
| Salinity (ppt) | 22.967 ± 2.001 | 24.7 ± 7.856 | 25.2 ± 4.453 | 26.133 ± 7.727 | up to 34 |
| pH | 7.623 ± 0.186 | 7.75 ± 0.105 | 7.693 ± 0.047 | 7.773 ± 0.107 | 7–8.5 |
| TDS ($mg.L^{-1}$) | 22.233 ± 6.161 | 26.333 ± 10.42 | 24.933 ± 7.06 | 23.1 ± 7.206 | - |
| TSS ($mg.L^{-1}$) | 20.667 ± 3.215 | 20.667 ± 1.528 | 20.333 ± 3.215 | 20.667 ± 2.309 | 80 |
| DO ($mg.L^{-1}$) | 5.693 ± 0.508 | 8.083 ± 2.144 | 7.937 ± 1.842 | 8.02 ± 1.647 | > 5 |
| BOD ($mg.L^{-1}$) | **393 ± 136.121** | **381.667 ± 190.306** | **352.667 ± 195.677** | **291 ± 110.964** | 20 |
| COD ($mg.L^{-1}$) | 605.667 ± 231.738 | 596.333 ± 301.291 | 537.667 ± 295.392 | 450.333 ± 171.844 | - |
| Total nitrate ($mg.L^{-1}$)[3] | < 0.5/< 0.04/< 0.2 | < 0.5/< 0.04/< 0.2 | < 0.5/< 0.04/< 0.2 | < 0.5/< 0.04/< 0.2 | 0.06 |
| Total phosphate ($mg.L^{-1}$)[4] | < 0.04/< 0.5/< 0.06 | < 0.04/< 0.5/< 0.07 | 0.3/< 0.5/< 0.1 | < 0.4/< 0.5/< 0.06 | 0.015 |

[1] The data are presented as the average value ± standard deviation; values in bold have exceeded the threshold set by the Indonesian Government. [2] GR = Government Regulation No. 22 Year 2021, Appendix VIII. [3,4] The three values at each sampling site measured in July, August, September, respectively

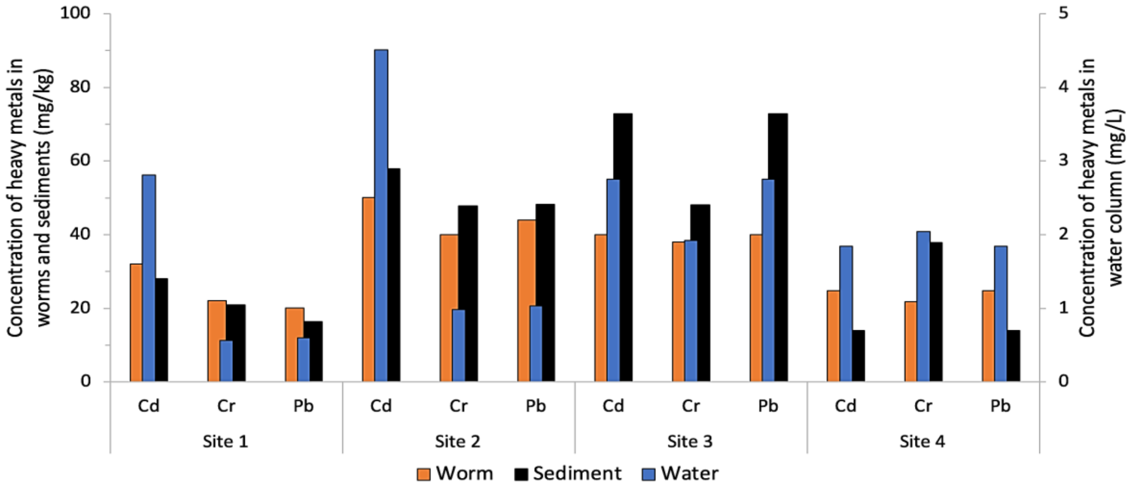


**Figure 3.** Concentrations of heavy metals at each sampling site

10.634 to 42.748, indicating that the concentrations of the metals in the body of the worms were considerably higher than those of the water column. Similarly, the CFs (s–w) ranged from 7.577 to 48.761, showing that the metal concentrations in the sediment were much higher than those of the water column (Table 3). Lower heavy metal concentrations in the water column appear to be related to their fate

**Table 2**. Heavy metal concentrations in the body of aquatic animals inhabiting the Donan Creek

| Species[1] | Common name | Local name | Heavy metals (mg.kg$^{-1}$)[3] Cd | Cr | Pb | Reference |
|---|---|---|---|---|---|---|
| **Bivalves** | | | | | | |
| *Geloina expansa* (Mousson 1849) | Broad geloina | *Kerang totok* | 0.0645 | 0.0495 | - | Annisa (2023) |
| *Geloina expansa* (Mousson 1849) | Broad geloina | *Kerang totok* | 0.117 ± 0.043 | - | 0.130 ± 0.059 | Irawati *et al*. (2018) |
| **Crustaceans** | | | | | | |
| *Alpheus* sp.[2] | Snapping/pistol shrimp | *Udang pletok* | Ud | - | Ud | Tumisem and Pusapawiningtiyas (2011) |
| *Macrobrachium equidens* (Dana 1852)[2] | Rough river prawn | *Udang wuku* | Ud | - | Ud | Tumisem and Pusapawiningtiyas (2011) |
| *Metapenaeus* sp.[2] | - | *Udang jahe* | Ud | - | Ud | Tumisem and Pusapawiningtiyas (2011) |
| *Metapenaeus* sp.[2] | - | *Udang peci* | Ud | - | Ud | Tumisem and Pusapawiningtiyas (2011) |
| *Oratosquilla fabricii* (Holthuis 1941)[2] | Mantis shrimp | *Udang sikat* | Ud | - | Ud | Tumisem and Pusapawiningtiyas (2011) |
| *Oratosquillina interrupta* (Kemp 1911)[2] | Blackspot mantis shrimp | *Udang sikat* | Ud | - | Ud | Tumisem and Pusapawiningtiyas (2011) |
| *Parapenaeopsis coromandelica* Alcock 1906[2] | Coromandel shrimp | *Udang jahe* | Ud | - | Ud | Tumisem and Pusapawiningtiyas (2011) |
| *Penaeus monodon* Fabricius 1798[2] | Asian tiger shrimp | *Udang tepus/windu* | Ud | - | Ud | Tumisem and Pusapawiningtiyas (2011) |
| *Scylla serrata* (Forskål 1775) | Mangrove crab | *Kepiting bakau* | 0.030 | - | < 0.001 | Sastranegara *et al*. (2021) |
| **Fishes** | | | | | | |
| *Mugil* sp. | Flathead grey mullet | *Ikan belanak* | 0.2115 | - | - | Afifah (2019) |
| *Mugil cephalus* Linnaeus 1758 | Flathead grey mullet | *Ikan belanak* | - | | 2.05 | Ningrum (2006) |
| *Sillago sihama* (Forskål 1775) | Northern whiting | *Ikan rejung* | 0.564 | - | 9.194 | Cahyani *et al*. (2016) |
| **Polychaetes** | | | | | | |
| *Diopatra claparedii* Grube 1878 | - | *Lur umah* | **50.036 ± 0.028** | **40.032 ± 0.052** | **44.030 ± 0.000** | This study |

[1] Based on the accepted species name on the World Register of Marine Species (www.marinespecies.org)
[2] The authors only provided local name; the scientific name was given by a crustacean taxonomist, Rena T. Hernawati, based merely on the photograph of the animal provided in the literature. Taxonomic investigations based on specimens collected from the Donan Creek may be required to verify the identification.
[3] Highest value in the animal provided in the literature; the symbol '-' indicates that the heavy metal was not measured; 'Ud' indicates undetected value measured using the thresholds 0.025 mg.kg$^{-1}$ (Pb) and 0.01 mg.kg$^{-1}$ (Cd); values in bold are the highest.

**Table 3.** Concentration factors at each sampling site

| Factor* | Site 1** Cd | Cr | Pb | Site 2*** Cd | Cr | Pb | Site 3*** Cd | Cr | Pb | Site 4** Cd | Cr | Pb |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| BCF (dc–s) | 1.146 | 1.052 | 1.221 | 0.865 | 0.837 | 0.912 | 0.549 | 0.791 | 0.549 | 1.770 | 0.574 | 1.770 |
| BCF (dc–w) | 11.420 | 39.318 | 33.410 | 11.089 | 40.821 | 42.748 | 14.561 | 19.790 | 14.561 | 13.413 | 10.634 | 13.413 |
| CF (s–w) | 9.969 | 37.389 | 27.372 | 12.826 | 48.761 | 46.864 | 26.502 | 25.026 | 26.502 | 7.577 | 18.527 | 7.577 |

* BCF = bioconcentration factor; CF = concentration factor; dc = *Diopatra claparedii*; s = sediment; w = water; ** Less industrial *** More industrial

in the water environment: the metals sink and accumulate in the sediment, or are absorbed by aquatic organisms.

This study further found that the levels of the three heavy metals in the water column of the Donan Creek at all sampling sites, *i.e.* ranging between 0.561 ± 0.025 mg.L$^{-1}$ and 6.723 ± 0.007 mg.L$^{-1}$, have significantly exceeded the threshold levels set by the Indonesian Government (Table 1). These findings are consistent with the results of the study conducted by Piranti *et al*. (2020) in the same area in 2018 – they

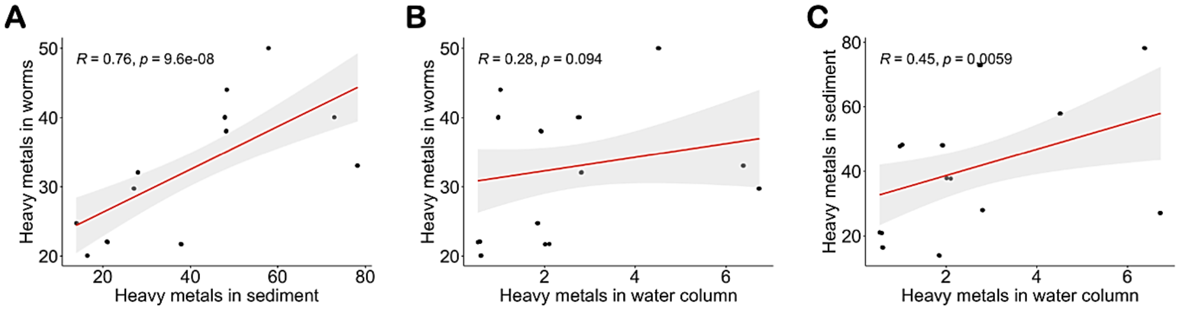


**Figure 4.** Spearman correlation analyses. *R* is the Spearman's correlation coefficient. The result is considered significant if *P*< 0.05. Solid red linear lines indicate positive correlation. Grey shading represents standard error

nonetheless reported lower concentrations of Cd (0.013–0.022 mg.L$^{-1}$), Cr (0.0165–0.0283 mg.L$^{-1}$) and Pb (0.02–0.03 mg.L$^{-1}$) – yet contradict Sastranegara *et al*. (2021). The latter authors, whose the investigation was done in 2015, suggested that the concentrations of Cd (0.001 mg.L$^{-1}$) and Pb (0.003 mg.L$^{-1}$) in the Donan Creek still met the national water quality standard. While the differences are in part because the sampling sites were not exactly the same, the data actually showed that the water quality of the creek has changed over the past decade: the coastal ecosystem has now been polluted by the metals, most likely from the effluent discharged by nearby factories.

Furthermore, whereas most of the other environmental parameters such as temperature, conductivity, salinity, pH, TDS, TSS and DO still met the national water quality standard, the high levels of both BOD (*i.e.* from 291 ± 110.964 mg.L$^{-1}$ to 393 ± 136.121 mg.L$^{-1}$) and COD (*i.e.* from 450.333 ± 171.844 mg.L$^{-1}$ to 605.667 ± 231.738 mg.L$^{-1}$) indicated high organic pollutions that occurred in the Donan Creek, most likely from anthropogenic activities on land. These findings are in line with what Dsikowitzky *et al*. (2011) documented that the eastern part of the SAL, including the Donan Creek, has been mainly contaminated by PAHs. The excessive amounts of both nitrate and phosphate in the present study (*i.e.* up to nearly 0.5 mg.L$^{-1}$), in particular, may accelerate eutrophication in the coastal ecosystem. These pollutants are mainly sourced from the locals' residential and agricultural areas as well as harbours and traditional markets situated right along the creek (see Figure 1), which discharge waste into the creek on a daily basis (pers. obs.).

## Conclusion

The present study sheds light on the capability of *D. claparedii* to absorb heavy metal contaminants from the environment. Being resistant to metal exposure, the species is a useful bioindicator in coastal waters and is by far a more effective species in accumulating metals than other aquatic organisms such as bivalves, crustaceans, and fishes. Further studies are nevertheless required to investigate where the metals are accumulated the most in the body of the species (*e.g.* digestive tract, skin, or even the tube – the analysis of heavy metal concentrations in the tube has been particularly challenging as the tube cannot be dried using the standard procedure). Our study also provides critical insights into the contamination occurring in the Donan Creek. The concentrations of three heavy metals, *i.e.* Cd, Cr and Pb, as well as several other environmental parameters including BOD, COD, and total nitrate and phosphate in the water column of the creek, did not meet the water quality standards set by the Indonesian Government. This suggests that the ecosystem has been polluted by both heavy metals and organic matter. As these metals are particularly toxic and can cause serious diseases in humans, environmental remediation is required. Furthermore, both industrial and domestic waste management systems in the area need to be thoroughly evaluated.

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