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Identification of Diatoms in the Upstream Midstream and Downstream Sections of the Kalimalang River to Determine the Cause of Death by Drowning

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KEYWORDS

Diatoms, forensic medicine, drowning, Kalimalang River, bioindicator

ABSTRACT:

Drowning is one of the most frequent cases encountered in forensic medicine, yet determining the true cause of death often remains challenging through external examination alone. Diatom analysis serves as a reliable biological indicator for distinguishing between vital drowning and postmortem immersion. This study aims to identify the species and morphology of diatoms found in three segments of the Kalimalang River (upper, middle, and lower reaches) and to describe their potential role in determining the cause and site of drowning. This research employed a qualitative descriptive method, with water samples collected from Bendung Klari (upstream), Bendung Cikarang (midstream), and Jembatan Cipinang (downstream). Microscopic observations at 100x magnification were performed using 1% Lugol's solution as a preservative. The results revealed six genera of diatoms: Synedra sp., Navicula sp., Nitzschia sp., Asterionella sp., Cymbella sp., and Fragilaria sp.. The upstream segment was dominated by Synedra sp., Asterionella sp., and Cymbella sp., indicating oligotrophic conditions; the middle segment by Nitzschia sp. and Navicula sp. (mesotrophic); and the downstream segment by Navicula sp. and Nitzschia sp., representing eutrophic polluted waters. Morphological and compositional variations among segments reflected the ecological gradient of the river. These findings highlight the ecological and forensic value of diatom identification as supporting evidence for determining drowning sites and validating the cause of death scientifically.

1. Introduction

Death by drowning is one of the most frequently encountered cases in forensic medicine, particularly in archipelagic countries such as Indonesia, which has numerous bodies of water. According to the World Health Organization (WHO, 2023), approximately 236,000 deaths from drowning occur worldwide each year, with more than 90% of cases taking place in low- and middle-income countries—including Indonesia—where water safety supervision remains limited. Data from the National Disaster Management Agency (BNPB, 2022) indicate that drowning ranks among the top four causes of unintentional death in Indonesia, with a significant increase in cases occurring in rivers and irrigation channels where human activity is high.

In forensic medicine, the primary challenge in drowning cases lies in distinguishing between true drowning and post-mortem immersion. External examination alone is often insufficient to determine whether the victim was alive upon entering the water or had already died beforehand. Therefore, specific and reliable biological indicators are required—one of which is diatom analysis.

Diatoms are unicellular microalgae with silica-based cell walls (frustules) that exhibit unique shapes and morphological patterns characteristic of each species.[5] In cases of true drowning, water containing diatoms is inhaled into the lungs, passes through the alveoli, and enters the bloodstream, eventually reaching organs such as the liver, kidneys, and bone marrow. The presence of diatoms in these organs indicates that respiration was still occurring when the body entered the water, thus serving as a key biological marker of true drowning.

Beyond forensic applications, diatoms are also crucial as bioindicators of water quality because of their sensitivity to environmental changes such as temperature, pH, oxygen concentration, and pollution levels.[8] Differences in diatom types and abundance across water segments reflect the fertility and ecological condition of the aquatic environment. Consequently, identifying diatom species is useful not only in determining the cause of death by drowning, but also in

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estimating the probable site of drowning by comparing diatom profiles between water samples and the victim's internal organs.

The Kalimalang River (West Tarum Canal) is a man-made channel that transports water from the Walahar Dam in Karawang Regency to the Bekasi and East Jakarta regions. Its main functions are to provide raw water and irrigation, but as industrial and urban development has expanded, the water quality now varies significantly from upstream to downstream. The upstream section tends to have clear water with a strong current, while the downstream section shows higher turbidity and pollution levels due to domestic and industrial activities.

This study employs a descriptive experimental approach, involving the collection of water samples from three segments of the Kalimalang River—upstream, midstream, and downstream—followed by microscopic laboratory observation to identify diatom morphology and species variation. This experimental approach aims to obtain empirical data describing the relationship between aquatic environmental conditions and diatom diversity. Through this design, the study is expected to strengthen the application of diatomology in forensic medicine, particularly in supporting analyses of drowning-related deaths based on measurable biological evidence.

The aim of this study is to identify diatom species in three segments of the Kalimalang River—Bendung Klari, Bendung Cikarang, and Jembatan Cipinang—and to explain their potential forensic applications in determining the location and cause of death by drowning.

Methods

Research Design

This study employs a qualitative descriptive method aimed at identifying and characterizing the types of diatoms found in the upstream, midstream, and downstream sections of the Kalimalang River. The research also examines environmental factors that may influence diatom diversity in each section of the river. The observations are presented descriptively, based on actual field findings, without manipulation or experimental treatment.

Research Location and Duration

1 Research Location

Water samples were collected from three segments of the Kalimalang River, namely:

- Upstream: *Bendung Klari*, Karawang Regency
- Midstream: *Bendung Cikarang*, Bekasi Regency
- Downstream: *Jembatan Cipinang*, East Jakarta

Diatom observations were conducted at the Laboratory of the Faculty of Medicine, Universitas Kristen Indonesia (FK UKI).

2 Research Duration

This study was carried out in October 2025 over a total of 23 days.
Water sampling was performed on October 1, 2025, at the following times:

- Upstream: 09:50–10:50 WIB
- Midstream: 13:48–14:10 WIB
- Downstream: 16:01–17:30 WIB

Subsequently, microscopic examination of the samples was conducted over a period of 16 days.

Population and Sample

1 Population

The research population comprises the entire diatom community inhabiting the waters of the Kalimalang River, including its upstream, midstream, and downstream segments.

2 Sample

The study samples consist of river water containing diatoms, collected from three sampling sites. Each site includes four sampling points:

1. Left side of the river
2. Right side of the river
3. Middle surface of the water
4. Middle section at a depth of 1 meter from the surface

3 Sample Size

The total number of samples analyzed is 12, obtained as follows:

- Three river segments (upstream, midstream, downstream) × four sampling points per segment.
  Samples were taken at a depth of 0.3 meters for the left side, middle surface, and right side, while samples from the central river point were collected at a depth of 1 meter.

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Inclusion and Exclusion Criteria

1 Inclusion Criteria

1. Water samples collected from three segments of the Kalimalang River:
    - Upstream: *Bendung Klari*, Karawang Regency
    - Midstream: *Bendung Cikarang*, Bekasi Regency
    - Downstream: *Jembatan Cipinang*, East Jakarta
2. Each segment includes four sampling points: left side, right side, middle surface, and middle at 1-meter depth.
3. Sampling conducted under non-rainy conditions.

2 Exclusion Criteria

1. Water samples improperly preserved, leading to contamination.
2. Water samples damaged during transportation due to container leakage or breakage.

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2. Results

This study was conducted using water samples collected from three segments of the Kalimalang River: the upstream section at Bendung Klari in Karawang Regency, the midstream section at Bendung Cikarang in Bekasi Regency, and the downstream section at Jembatan Cipinang in East Jakarta. Water sampling was carried out on October 1, 2025, followed by laboratory observations at the Faculty of Medicine, Universitas Kristen Indonesia.

Figure 1 Research Location (Mapchart, 2025)

In the upstream section at Bendung Klari, the water appears clear with a relatively strong current and no noticeable odor. The surrounding environment remains natural, characterized by dense riparian vegetation and minimal human activity.

Figure 2 Klari Dam (Google Earth, 2025)

In the central part of the Cikarang Dam, the water appears somewhat murky with a moderate current and a slight odor. Residential and domestic activities in the area can potentially impact water quality.

Figure 3 Cikarang Dam (Google Earth, 2025)

Meanwhile, downstream at the Cipinang Bridge, the water appears murky and brownish, with a slow current and a foul odor. The surrounding area is dominated by industrial areas and dense residential areas, indicating increasing pollution and declining water quality downstream.

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Figure 4 Jembatan Cipinang (Google Earth, 2025)

Before collecting the water samples, measurements of the physico-chemical parameters—including pH and water temperature—were conducted using a water quality meter. Preliminary observations of the current, color, and odor of the water were made visually without any instruments for approximately five minutes prior to sampling at each research site. In general, the physical conditions of the Kalimalang River showed noticeable variations across the different sections of the river flow.

Table 1 Results of Temperature and pH Measurements

No.	Research Location	Measurement Point	Parameters measured
1.	Klari Dam	- Left Side	Temperature: 29.4°C pH :7.04
		- Middle	Temperature: 28.8°C pH : 6.75
		- Right Side	Temperature: 30.5°C pH : 7.00
2.	Cikarang Dam	- Left Side	Temperature: 29.0°C pH :6.57
		- Middle	Temperature: 30.0°C pH :6.89
		- Right Side	Temperature: 27.0°C pH :6.59
3.	Cipinang Bridge	- Left Side	Temperature: 29.6°C pH : 6.90
		- Middle	Temperature: 29.2°C pH :9.30
		- Right Side	Temperature: 28.8°C pH : 6.91

The measurement results showed that the water temperature at the three research sites ranged from 27°C to 30.5°C, reflecting warm and stable tropical aquatic conditions. The pH values ranged from 6.5 to 7.0, indicating neutral to slightly acidic conditions, which are still within the acceptable range for river water quality and conducive to the survival of aquatic organisms. Minor variations among the measurement points reflected differences in light intensity, water flow, and human activity around each location. Bendung Klari and Bendung Cikarang exhibited higher temperatures due to greater sunlight exposure and possible anthropogenic influences, whereas Jembatan Cipinang showed a slightly lower temperature, likely caused by faster water flow or post-rainfall conditions.

Table 2 Morphological Observation Results of Diatoms in the Upstream Section

Observation Location at Klari Dam				
	Left Side	Middle Surface	Middle Depth 1 meters	Right Side

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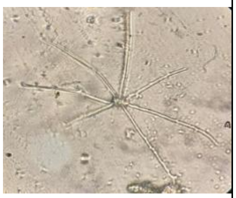
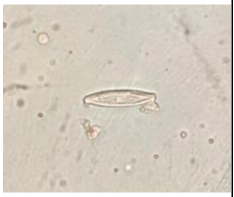
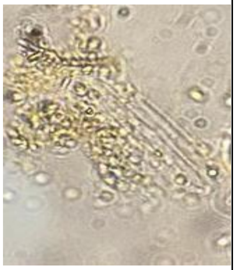
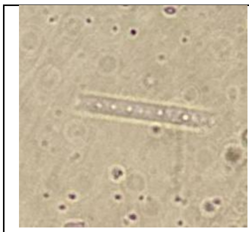
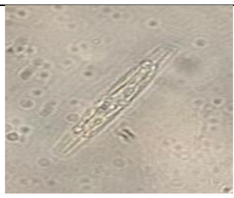
Ice Species	- *Synedra sp*   - *Nitzschia sp*  	- *Cymbella sp.*  - *Asterionella sp* 	- *Navicula sp* 	- *Navicula sp*    - *Fragilaria sp* 

Based on the results of diatom identification in the upstream part of the Kalimalang River (Klari Dam), six dominant genera were found, namely Synedra sp., Cymbella sp., Asterionella sp., Navicula sp., Nitzschia sp., and Fragilaria sp. High diversity and the dominance of sensitive species indicate clean, stable-flowing, and highly oxygenated waters. Forensically, this composition can be used to identify sinking sites in upstream waters with good ecological quality.

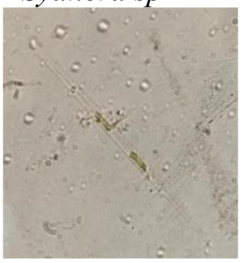
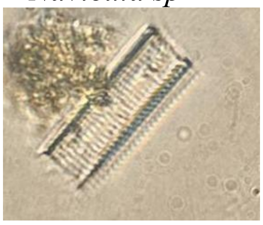
Table 3 Results of Observations on the Morphology of Diatoms in the Middle of the River

Observation Location at Cikarang Dam				
	Left Side	Middle Surface	Middle Depth 1 meter	Right Side
	- *Nitzschia sp.*	- *Navicula sp*	- *Synedra sp*	- *Navicula sp*

Ice Spe cies		 - *Sydnera sp* 		 

In the midstream section of the Kalimalang River (Bendung Cikarang), three main diatom genera were identified: Nitzschia sp., Navicula sp., and Synedra sp. The dominance of Nitzschia and Navicula indicates an increase in organic matter and human activity around the river, while the presence of Synedra sp. suggests that the water quality remains moderate. Overall, the midstream segment exhibits mesotrophic conditions, functioning as a transitional zone between the clean upstream waters and the more polluted downstream areas.

Table 3 Morphological Observation Results of Diatoms in the Downstream Section

	Observation Location on Cipinang Bridge			
	Left Side	Middle Surface	Middle Depth 1 meter	Side Right
Speies	- *Navicula sp* 	- *Sydnera sp*  	- *Navicula sp*  - *Nitzschia sp* 	-

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Observations in the downstream section of the Kalimalang River (Jembatan Cipinang) revealed a dominance of Navicula sp. and Nitzschia sp., both of which are strong indicators of polluted (eutrophic) waters. The number and diversity of diatoms were lower compared to the upstream and midstream sections, indicating a decline in water quality due to increased human activity. From a forensic perspective, the combination of these diatom species suggests a drowning site located in the downstream area, characterized by turbid water, slow flow, and high nutrient concentrations.

Table 4 Distribution of Diatoms at Five Sampling Points in the Upstream, Midstream, and Downstream Sections of the Kalimalang River

Location	Species Found	Left Side	Middle Surface	Middle Depth 1 m	Right Side
Klari Dam (Upstream)	*Synedra sp.*	+	–	–	–
	Nitzschia sp.	+	–	–	–
	Navicula sp.	–	+	+	+
	Asterionella sp.	–	+	–	–
	Cymbella sp.	–	+	–	–
	Fragilaria sp.	–	–	–	+
Cikarang Dam (Center)	*Nitzschia sp.*	+	–	–	–
	Navicula sp.	–	+	–	+
	Synedra sp.	–	+	+	–
Cipinang Bridge (Downstream)	*Navicula sp.*	+	–	+	–
	Synedra sp.	–	+	–	–
	Nitzschia sp.	–	–	+	–

Based on the microscopic identification results presented in Table 3.5, a total of six diatom species (genera) were identified across the three segments of the Kalimalang River: Synedra sp., Nitzschia sp., Navicula sp., Asterionella sp., Cymbella sp., and Fragilaria sp. The number and distribution of diatom species at each location indicate variations in biodiversity among the different river segments.

3. Discussion

Diversity of Diatoms at Bendung Klari

In the upstream section of the Kalimalang River, located at Bendung Klari, Karawang Regency, six dominant diatom genera were identified: Synedra sp., Nitzschia sp., Navicula sp., Cymbella sp., Asterionella sp., and Fragilaria sp. The high level of diversity indicates that the water conditions in the upstream area remain relatively good, characterized by strong

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currents, high dissolved oxygen levels, and minimal pollution.

The presence of Synedra and Asterionella suggests oligotrophic waters with low pollution levels and high light availability. Cymbella sp. is commonly found in waters with high silica content and stable flow, while Fragilaria sp. typically grows on hard substrates such as rocks, indicating ecosystem stability.

Morphologically, the diatoms in the upstream section exhibit elongated, slender forms, symmetrical frustule patterns, and distinct raphe structures, reflecting their adaptation to strong currents and oxygen-rich water. Based on both their composition and morphology, the upstream part of the Kalimalang River can be classified as oligotrophic water with good environmental quality.

From a forensic medicine perspective, the presence of oligotrophic diatoms such as Synedra and Asterionella holds significant diagnostic value. If these diatom species are found in a victim's organs (e.g., lungs, liver, or bone marrow), it can be interpreted that the drowning occurred in a clear, oxygen-rich water area, such as the upstream segment. This is because fine-frustule diatoms are more easily inhaled into the lungs while the victim is still alive, reinforcing the interpretation that the drowning was vital (vital drowning) rather than post-mortem immersion.

Diversity of Diatoms at Bendung Cikarang

In the midstream section of the Kalimalang River, located at Bendung Cikarang, Bekasi Regency, three main diatom genera were identified: Nitzschia sp., Navicula sp., and Synedra sp. The smaller number of genera compared to the upstream section indicates a decline in water quality, primarily due to domestic and industrial activities surrounding the river. *Nitzschia sp.* is known to tolerate high organic loads and is often found in mesotrophic to eutrophic waters.[13] *Navicula sp.* has a broad adaptive range and can thrive under varying environmental conditions depending on nitrate and phosphate levels.

Ecologically, this diatom composition reflects mesotrophic conditions, characterized by moderate productivity and increasing dissolved organic matter. The dominance of *Nitzschia sp.* and *Navicula sp.* suggests eutrophication caused by domestic waste and human activities near the sampling site.[14] From a forensic perspective, diatoms such as *Nitzschia sp.* have thicker frustules that are more resistant to tissue degradation, making them more likely to be found in the organs of drowning victims from waters with moderate to high organic content. If a forensic examination reveals the dominance of *Nitzschia sp.* and *Navicula sp.*, it likely indicates that the drowning occurred in a transitional water zone.

Diversity of Diatoms at Jembatan Cipinang

In the downstream section at Jembatan Cipinang, East Jakarta, both the number and diversity of diatoms decreased significantly. Only three genera were identified: Navicula sp., Synedra sp., and Nitzschia sp., with a strong dominance of Navicula sp. and Nitzschia sp. These two genera are classic indicators of eutrophic waters, representing heavily polluted conditions.

Navicula sp. is commonly found in slow-flowing waters with low oxygen levels and high organic matter, while *Nitzschia sp.* exhibits high tolerance to domestic waste and heavy metals. Morphologically, *Navicula* has a boat-like shape with a double raphe, whereas *Nitzschia* has a ribbon-like form with lateral raphe slits. These frustule patterns are characteristic of diatoms adapted to polluted aquatic environments.

In forensic investigations, the dominance of *Navicula* and *Nitzschia* is significant because diatoms from eutrophic environments are often more abundant and more easily inhaled into the respiratory system of a living victim before drowning. Therefore, if these genera are found in large numbers within the victim's organs, it may indicate vital drowning in polluted or slow-moving waters, such as the downstream segment of the Kalimalang River.

Relationship Between Diatom Distribution, Location, and Cause of Death by Drowning
The differing distribution of diatoms in each segment of the Kalimalang River demonstrates that diatom community variation can be used to estimate the probable drowning location:

a. The dominance of oligotrophic diatoms such as *Synedra sp.*, *Asterionella sp.*, and *Cymbella sp.* indicates a drowning event in the upstream area, characterized by clear water and high oxygen levels.
b. The dominance of tolerant diatoms such as *Nitzschia sp.* and *Navicula sp.* suggests drowning in the midstream or downstream sections, representing polluted and slow-flowing waters.

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From a forensic perspective, diatom analysis plays a vital role in distinguishing true drowning (vital drowning) from postmortem immersion. When diatoms are detected in internal organs such as the kidneys, liver, or bone marrow, it indicates water aspiration while the victim was still alive (Keerthi et al., 2021). In contrast, the absence of diatoms in vital organs suggests that the victim had died before entering the water.

Ecological Interpretation and Forensic Value of the Study

Ecologically, the Kalimalang River exhibits a declining water quality gradient from upstream to downstream—from oligotrophic (clean water) upstream, to mesotrophic (transitional) midstream, and eutrophic (polluted) downstream. This pattern corresponds with increasing human activities, including residential and industrial development, leading to higher organic and nutrient loads.

From a forensic medicine standpoint, these findings reinforce the concept that diatoms can serve as indicators of both drowning location and cause of death, as their structure and distribution reflect the ecological characteristics of the water environment. Differences in diatom composition and abundance across the three river segments provide not only ecological insights but also a forensic foundation for determining the cause and site of drowning. According to Ludes and Delabarde (2024), a match between the diatom species found in the victim's organs and those present at the water site strongly suggests that the victim drowned at that location before death. Thus, ecological data from the upstream, midstream, and downstream segments can strengthen forensic analysis, particularly in assessing whether a body drifted postmortem or drowned at the original site.

Furthermore, Rabiee et al. (2023) explained that an ecological understanding of diatom distribution significantly aids forensic interpretation, particularly in distinguishing antemortem from postmortem drowning. If diatom species found in a victim's tissues match the community composition of the water at the scene—whether upstream, midstream, or downstream—it is highly probable that the water entered the body's circulation while the victim was alive.[18] Conversely, species mismatches may indicate body displacement or postmortem contamination.

Previous studies by Zalat et al. (2023) also support the importance of an ecological approach in forensic analysis, demonstrating that variations in diatom communities across river sections are crucial for accurately determining the drowning site. Therefore, the integration of ecological and forensic data from all river segments is essential for a comprehensive understanding of environmental conditions and for scientifically verifying drowning as the cause of death.

The Role of Diatom Morphology, Species Variation, and Abundance in Forensic Medicine

Diatoms have high diagnostic value in forensic medicine due to their unique silica cell walls (frustules), which are resistant to decomposition and physicochemical changes. The variation in diatom forms and species reflects the ecological conditions of aquatic environments, forming a scientific basis for identifying the drowning location. According to Tambuzzi et al. (2024), the morphological differences among diatoms such as *Navicula*, *Nitzschia*, and *Synedra* are significant across freshwater, brackish, and marine habitats, allowing investigators to trace the water source in drowning cases.[20] Similarly, Dahiya et al. (2024) noted that each diatom species has specific environmental tolerances to temperature, pH, turbidity, and dissolved oxygen, making their morphological differences reliable environmental indicators.[21]

In the forensic context, the presence and diversity of diatoms in a victim's organs—particularly the lungs, kidneys, or bone marrow—are crucial in determining whether drowning occurred while alive (antemortem) or after death (postmortem). Ludes and Delabarde (2024) emphasized that the match between diatom species found in tissues and those present at the drowning site serves as strong evidence that water was actively aspirated into the circulation before death.[17] Conversely, species mismatches suggest body displacement or postmortem contamination. Similar findings by Yang et al. (2000) also confirmed that matching diatom communities between internal organs and water samples provides a scientific basis for pinpointing drowning sites.

The abundance of diatoms also holds forensic significance. Rabiee et al. (2023) explained that high diatom counts in a victim's tissues indicate active water inhalation while alive, whereas low counts may result from low diatom density at the drowning site or rapid death before significant inhalation occurred.[17] This pattern aligns with findings by Pellondo'u et al. (2023) in the Ciliwung River, showing that *Nitzschia* and *Navicula* abundance increases from upstream to downstream, correlating with higher organic matter and

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anthropogenic activity—confirming that diatom variation reflects pollution level and water flow.[23] Similar observations were reported by Zalat et al. (2023) in Egypt, where eutrophic-water diatoms were smaller and more fragile, while clean-water diatoms had larger, thicker frustules.[19]

Ecologically, diatom variation serves as a natural bioindicator, aiding the forensic interpretation of drowning environments. Prakash et al. (2022) found that elongated diatoms such as *Synedra ulna* commonly occur in fast-flowing, oxygen-rich waters, whereas *Navicula* and *Gomphonema* dominate slow, organic-rich environments.[25] Bhati and Walia (2025) further stated that the diversity and abundance of diatoms not only help identify drowning sites but also strengthen scientific evidence of cause of death when compared to control water samples. Hestiyani et al. (2024) demonstrated in animal models that diatom type and abundance in the organs of drowned rats corresponded to those found in the experimental water source.

Therefore, variations in diatom morphology, species, and abundance hold both ecological and forensic significance. Integrating diatom analysis with environmental data enhances the accuracy of drowning investigations. Mourez et al. (2025) emphasized that interpreting diatom test results must consider ecological distribution, potential contamination, and species abundance to ensure accuracy, establishing diatom analysis as one of the most effective methods for distinguishing vital drowning from postmortem immersion.

Conclusion

Based on the research conducted on the identification of diatoms in three segments of the Kalimalang River—Bendung Klari (upstream), Bendung Cikarang (midstream), and Jembatan Cipinang (downstream)—the following conclusions can be drawn:

1. The diatom species identified across the three segments of the Kalimalang River include *Synedra sp.*, *Navicula sp.*, *Nitzschia sp.*, *Cymbella sp.*, *Asterionella sp.*, and *Fragilaria sp.* The upstream section was dominated by *Synedra sp.*, *Cymbella sp.*, and *Asterionella sp.*; the midstream section by *Nitzschia sp.*, *Navicula sp.*, and *Synedra sp.*; while the downstream section was dominated by *Navicula sp.* and *Nitzschia sp.*, which are strong indicators of polluted (eutrophic) waters.
2. The morphological characteristics of the diatoms varied across river segments. Diatoms from the upstream area exhibited slender forms with symmetrical frustules, indicating clear and well-oxygenated waters with stable flow, whereas diatoms from the midstream and downstream areas had thicker structures with denser frustule patterns, reflecting higher organic content and pollution levels.
3. Comparison of diatom morphology and diversity among the river segments revealed differences in diatom communities influenced by environmental conditions. The highest diversity was found in the upstream section (oligotrophic), decreasing in the midstream section (mesotrophic), and lowest in the downstream section (eutrophic).
4. The identification of diatoms shows significant potential in forensic medicine, particularly as supporting biological evidence in determining the location and cause of death by drowning. The distinctive distribution of diatoms in each segment of the Kalimalang River can serve as a reference for analyzing the probable drowning site based on the correspondence between diatom species found in the victim's organs and those present in the surrounding water.

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