TECHNICAL REPORT
RIVERINE STATUS ASSESSMENT
BELAGA OIL PALM ESTATES

for

GLENEALY PLANTATIONS SDN BHD
(*Sustainability Division*)

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WATER QUALITY
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EXECUTIVE SUMMARY

This comprehensive technical report presents the results of environmental assessments conducted at the Belaga oil palm estates in Sarawak, Malaysia, focusing on water quality, aquatic microflora and microfauna, and freshwater fish diversity.

Water Quality: The study evaluated water quality measuring key physical and chemical parameters such as pH, temperature, dissolved oxygen, conductivity, turbidity, total suspended solids (TSS), biological and chemical oxygen demand (BOD, COD), and ammonia nitrogen. Most parameters were within the Malaysian National Water Quality Standards (MNWQS) for Class IIA, indicating generally clean water. However, TSS and turbidity were elevated at stations closest to plantation activities, suggesting soil erosion and runoff impacts. The Water Quality Index (WQI) classified all sites as 'Clean,' but highlighted the need for continuous monitoring and improved management practices, especially regarding sediment control and riparian buffer maintenance.

Aquatic Microflora and Microfauna: A total of 60 species across four kingdoms (Animalia, Protozoa, Chromista, Plantae) were identified in the riverine system. The community was dominated by green algae (*Staurastrum* sp.1) and rotifers (*Brachionus* sp.1), with significant spatial variation in diversity and abundance. Station A exhibited the highest species diversity and ecological stability, while Station C showed reduced diversity due to the dominance of a single algal species, likely linked to nutrient enrichment from agricultural runoff. These findings underscore the importance of microflora and microfauna as bioindicators of river health and the need for targeted conservation measures in areas experiencing environmental stress.

Fish Composition: The fish survey at Glenealy Belaga Estate recorded seven native species from two families (Cyprinidae and Danionidae), with Cyprinidae being dominant. All species were classified as Least Concern on the IUCN Red List, except for *Tor douronensis*, which is Not Evaluated. The absence of invasive species and the presence of culturally significant native fish suggest a relatively intact aquatic ecosystem, though ongoing monitoring is recommended to detect future changes.

Overall, the report highlights that while the Belaga oil palm estates currently maintain generally good water quality and aquatic biodiversity, there are clear signs of localized environmental impacts, particularly related to sedimentation and nutrient enrichment. The baseline data provided by this assessment will support future monitoring, inform sustainable estate management, and contribute to regional conservation planning.

WATER QUALITY

INTRODUCTION

Oil palm (*Elaeis guineensis Jacq*.) is one of the most important commercial crops globally, particularly Malaysia and Indonesia. As of 2023, Malaysia alone accounted for about 25% of global palm oil production, with Sarawak being a significant contributor within the country (MPOB, 2023). The rapid expansion of oil palm plantations has brought about economic benefits, including job creation and rural development (Obidzinski et al., 2012). However, this expansion has also raised environmental concerns, particularly regarding water resources and their quality (Dislich et al., 2017). Water quality refers to the chemical, physical, and biological characteristics of water, usually in respect to its suitability for a particular purpose such as drinking, irrigation, or supporting aquatic life (WHO, 2017). In agricultural landscapes, water quality is influenced by land use practices, including the application of fertilizers, pesticides, and the management of effluents (FAO, 2011). The assessment of water quality is thus essential for ensuring the sustainability of agricultural production and the protection of surrounding ecosystems.

Oil palm cultivation indirectly may impact water quality through several pathways. The use of agrochemicals, soil erosion, and effluent discharge from palm oil mills are among the primary sources of water pollution (Cheng et al., 2017). Runoff from plantations can carry nutrients, sediments, and pesticides into nearby rivers and streams, leading to eutrophication, loss of biodiversity, and contamination of drinking water sources (Gaveau et al., 2014). In Malaysia, and particularly in Sarawak, the conversion of forests and peatlands to oil palm plantations has been associated with increased sedimentation and nutrient loading in water bodies (Miettinen et al., 2016). These changes can have far-reaching consequences for aquatic ecosystems, fisheries, and human health.

Thus, continuous water quality assessment and monitoring that involves systematic collection, analysis, and interpretation of data are critically important to determine river health status. This monitoring is crucial for several reasons that includes environmental (flora and fauna) protection, regulations compliance, sustainable plantation management, and human health. Regular assessment helps to detect pollution sources and pattern, enabling timely interventions to prevent ecosystem degradation (Yule et al., 2010). For example, studies in Sarawak have shown that streams adjacent to oil palm plantations often exhibit elevated nutrient concentrations, which can be mitigated through improved management practices (Kumaran et al., 2017).

Many countries, including Malaysia, have established water quality standards for agricultural effluents. Assessment ensures compliance and helps avoid legal penalties (DOE Malaysia, 2016). Regular water quality assessment ensures compliance with these standards, reducing the risk of fines and reputational damage. Understanding water quality dynamics allows estate managers to adopt best management practices, reducing negative environmental impacts while maintaining productivity. Water is a critical input for oil palm growth. Poor water quality can affect irrigation, reduce soil fertility, and ultimately lower yields (Corley & Tinker, 2016). By monitoring water quality, estate managers can ensure that water used for irrigation is free from harmful contaminants, supporting healthy crop growth.

Water quality assessment protects communities relying on surface and groundwater for drinking and domestic use (WHO, 2017). In addition, many oil palm estates are located near rural communities that depend on local water sources. Demonstrating a commitment to water quality monitoring and management can improve relations with local stakeholders and enhance the estate's social license to operate (Obidzinski et al., 2012).

Water quality assessment supports Malaysia's commitment to sustainable palm oil production, as outlined in the Malaysian Sustainable Palm Oil (MSPO) certification scheme and the Roundtable on Sustainable Palm Oil (RSPO) standards (MSPO, 2015; RSPO, 2018). These certifications require regular monitoring and reporting of water quality parameters.

Despite its importance, water quality assessment in oil palm estates faces several challenges such as limitation in monitoring equipment, data qaps, complex hydrology characteristic, and limit regulatory enforcement. Many estates lack the resources and expertise to conduct regular and comprehensive water quality monitoring (Dislich et al., 2017). There is often a lack of baseline data, making it difficult to assess changes over time (Gaveau et al., 2014). The hydrological complexity of tropical landscapes may complicate the interpretation of water quality data (Miettinen et al., 2016). Weak enforcement of environmental regulations can undermine the effectiveness of water quality assessment (DOE Malaysia, 2016).

Thus, this assessment aims to provide an up-to-date water quality data in the Belaga oil palm estates and compared the results with Malaysian National Water Quality Standards (MNWQS). In addition, the Water Quality Index (WQI) also to be computed to determine the level of river health status.

METHODOLOGY

Assessment Location

Sampling stations are usually conducted at different streams within the oil palm estates which include upstream and downstream, to assess the impact of oil palm activities (Cheng et al., 2017). Thus, this assessment involved 4 sampling stations, namely, Station A (Sg. Wai), Station B (Sg. Belaga), Station C (Sg. Iga Hilir), and Station D (Sg. Iga Hulu) (Figure 1 and 2). The GPS coordinates for these sampling stations are summarized in Table 1. Sampling period was conducted on 12 – 14 March 2025.

The selection of water quality sampling locations is critically important as oil palm estates often cover large and heterogeneous landscapes, with varying land uses, topography, and proximity to water bodies. Choosing the right sampling locations ensures that the collected data accurately represents the range of water quality conditions across the estate, including areas most likely to be impacted by estate activities.

Strategic sampling locations also help to enable detect early signs of ecological stress and guide conservation measures to support effective environmental management and conservation efforts. This is crucial for assessing the effectiveness of best management practices, understanding seasonal or climatic influences, and making informed decisions to minimize negative environmental impacts.

Generally, a careful selection of water quality sampling locations in oil palm estates is fundamental to obtaining accurate, actionable data for pollution control, regulatory compliance, environmental stewardship, and sustainable estate management.

Table 1: GPS coordination of the sampling points

Station	River/Stream Name	Latitude	Longitude
A	Sg. Wai	3° 02’ 08” N	114° 07’ 09” E
B	Sg. Belaga	3° 02’ 29” N	114° 03’ 08” E
C	Sg. Iga Hilir	3° 01’ 03” N	114° 04’ 25” E
D	Sg. Iga Hulu	3° 00’ 03” N	114° 05’ 51” E

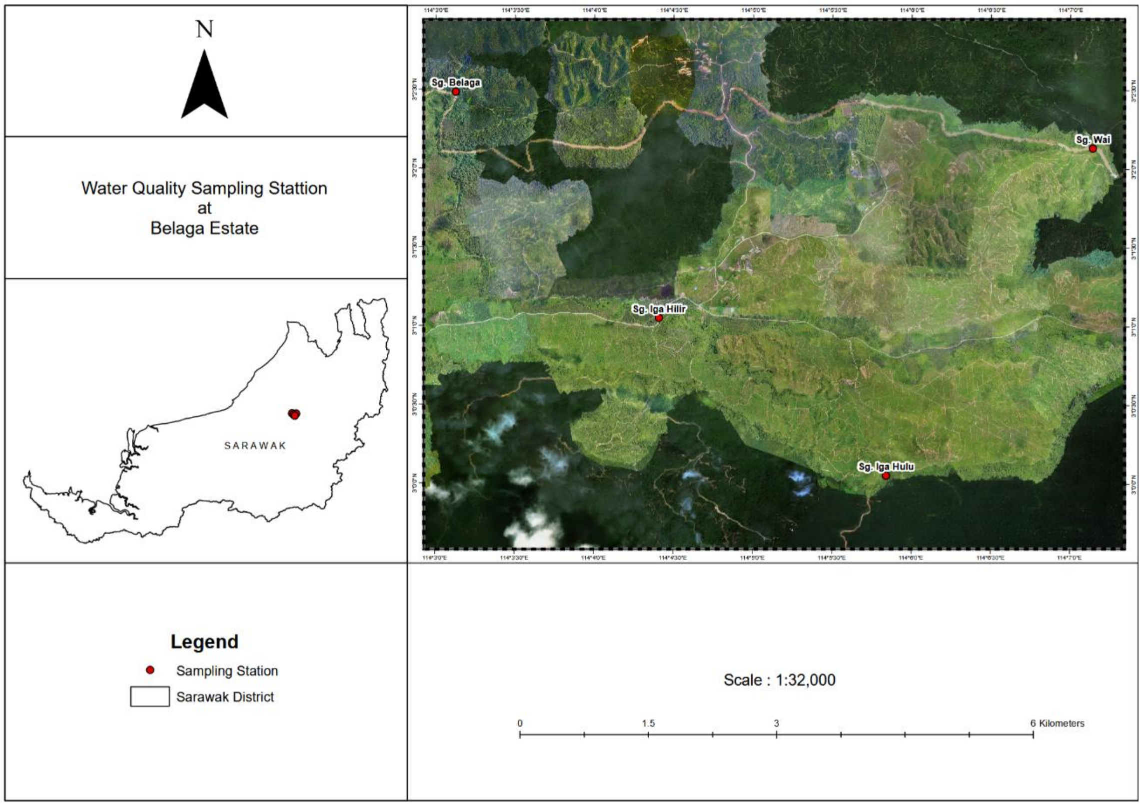

Figure 1: Locations of sampling stations in Belaga oil palm estates.

Water Quality Assessment Parameters

This water quality assessment for Belaga oil palm estates involves the measurement of physical and chemical parameters. The common indicators include temperature, turbidity, total suspended solids, conductivity as physical elements; and, pH, dissolved oxygen, biochemical oxygen demand, chemical oxygen demand, and ammoniacal nitrogen as chemical elements.

At each station, *in-situ* water quality data was recorded using DKK-TOA-WMS-24 multiparameter for temperature, pH, dissolved oxygen (DO), conductivity and turbidity (Figure 3). Additional surface water samples were collected to analyze for total suspended solids (TSS), biological oxygen demand (BOD), chemical oxygen demand (COD) and ammoniacal nitrogen (NH_3-N). The sampling and analytical procedures followed established protocols (APHA, 2017). Results were evaluated against the Malaysian National Water Quality Standards (MNWQS) and the Water Quality Index (WQI) to determine the status of each site.

a) Station A: Sg. Wai

b) Station B: Sg. Belaga

c) Station C: Sg. Iga Hilir

d) Station D: Sg. Iga Hulu

Figure 2: Pictures of sampling locations for water quality assessment at Belaga oil palm estates.

a) DKK-TOA-WMS-24 multiparameter

b) The scientific instrument being dipped into the river to measure water parameters.

Figure 3: Water quality *In-situ* sampling at Belaga oil palm estates.

RESULTS AND DISCUSSION

The water quality results obtained in this assessment is important to further understand river physiochemical pattern within Belaga oil palm estates. Those parameters serve as key indicators of both natural processes and anthropogenic influences associated with plantation management. The presented results of these measurements provide a detailed analysis of spatial variations in water quality of selected rivers within Belaga oil palm estates. The discussion integrates these findings with existing literature, offering a comparative perspective with other oil palm-dominated landscapes elsewhere.

pH

The pH level of water is a key indicator of its acidity or alkalinity, and it plays a crucial role in determining the health of river ecosystems. In this assessment, the observed pH values at the four stations show relatively consistent and slightly acidic conditions, with mean values ranging from 6.04 (Station D) to 6.34 (Station B). All means are below neutral pH 7, indicating mildly acidic water at all sites. The standard deviations and ranges are very small (all standard deviations below 0.04 and ranges below 0.06), suggesting minimal variation in pH within each station during the sampling period (Table 2 and Figure 4). The standard error values are also low, reflecting high precision in the mean estimates despite the small sample size ($n=3$ for each station). This finding is consistent with other studies conducted near oil palm plantations, which typically report pH values between 6.0 and 7.0. Such readings are often the result of various plantation-related activities that alter the natural chemical balance of the water.

This is within the typical range for tropical streams, which often exhibit pH values between 6.0 and 7.0 due to organic matter decomposition and soil leaching (Miettinen et al., 2012). The slight acidity may be attributed to organic acids from decaying vegetation and possible runoff from fertilizers used in oil palm plantations. Comparatively, studies in other Malaysian oil palm estates, such as those by Abdullah et al. (2015), reported pH values ranging from 5.8 to 6.5, suggesting that the Belaga estate's water bodies are consistent with regional trends. Maintaining pH within this range is crucial, as significant deviations can affect aquatic life, particularly sensitive species.

Table 2: pH descriptive analysis summary

Components	*Station A*	*Station B*	*Station C*	*Station D*
Mean	6.206	6.336	6.073	6.04
Standard Error	0.012	0.017	0.003	0.015
Median	6.2	6.33	6.07	6.05
Standard Deviation	0.0207	0.0305	0.0057	0.0264
Minimum	6.19	6.31	6.07	6.01
Maximum	6.23	6.37	6.08	6.06
Count	3	3	3	3
Confidence Level (95.0%)	0.051	0.075	0.014	0.065

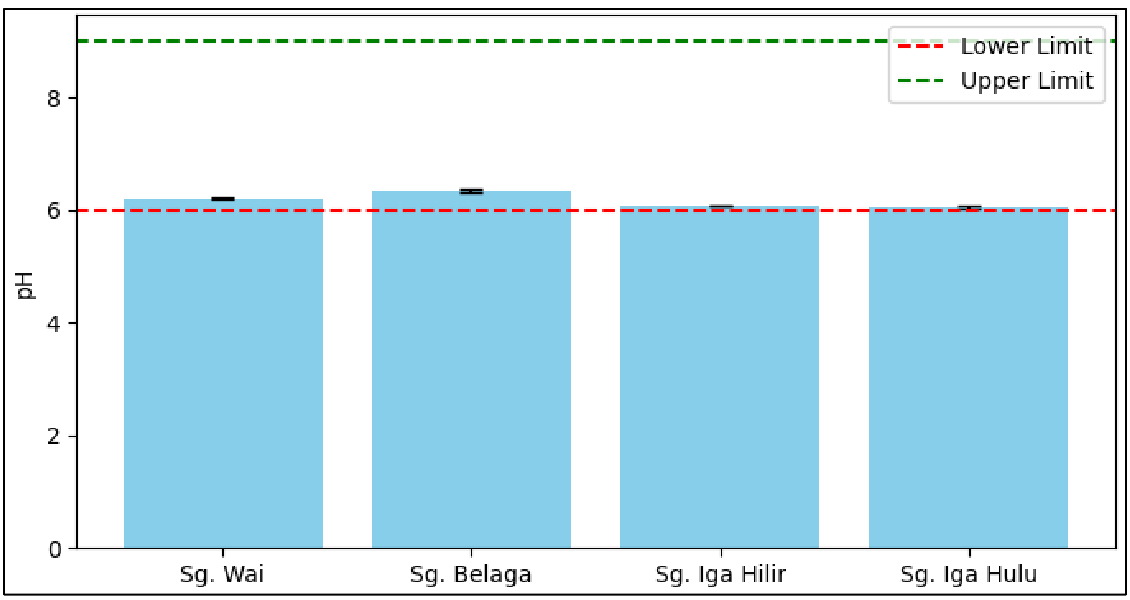

Figure 4: Indicating the water pH at each site falls within the acceptable range for MNWQS regulatory standards.

Temperature

The water temperature at the stations varied from 23.7°C to 27.3°C. Stations A and B recorded higher temperatures (27.1°C and 27.3°C), while C and D were cooler (24.2°C and 23.7°C) (Table 3 and Figure 5). The higher mean temperatures at Stations A and B (above 27°C) compared to Stations C and D (below 25°C) may reflect differences in microclimate, canopy cover, stream size, or proximity to oil palm activities. The relatively low variance and standard error suggests that the measurements are consistent and reliable for each station.

Studies across tropical Asia have consistently reported that streams draining oil palm plantations tend to be warmer than those in forested catchments. For example, research in Indonesia and Thailand has shown stream temperatures in oil palm areas often exceed 27°C, especially where riparian buffers are absent or degraded. In Peninsular Malaysia, studies (e.g., Luke et al., 2017; Giam et al., 2015) have found that streams in oil palm estates typically have mean temperatures ranging from 26°C to 29°C, compared to 23°C to 25°C in forested streams. The values from Stations A and B in your data align with these findings, while Stations C and D are closer to the lower end, possibly indicating better riparian management or less exposure. In addition, local condition factors, such as intact riparian buffers or shading, can mitigate temperature increases. This underscores the importance of riparian buffer conservation in oil palm landscapes to protect aquatic ecosystems from thermal stress.

Table 3: Temperature descriptive analysis summary

Components	*Station A*	*Station B*	*Station C*	*Station D*
Mean	27.1	27.2	24.1	23.7
Standard Error	0.033	0.088	0.033	0.033
Median	27.1	27.3	24.2	23.7
Standard Deviation	0.0577	0.1527	0.0577	0.0577
Minimum	27.1	27.1	24.1	23.7
Maximum	27.2	27.4	24.2	23.8
Count	3	3	3	3
Confidence Level(95.0%)	0.143	0.379	0.143	0.143

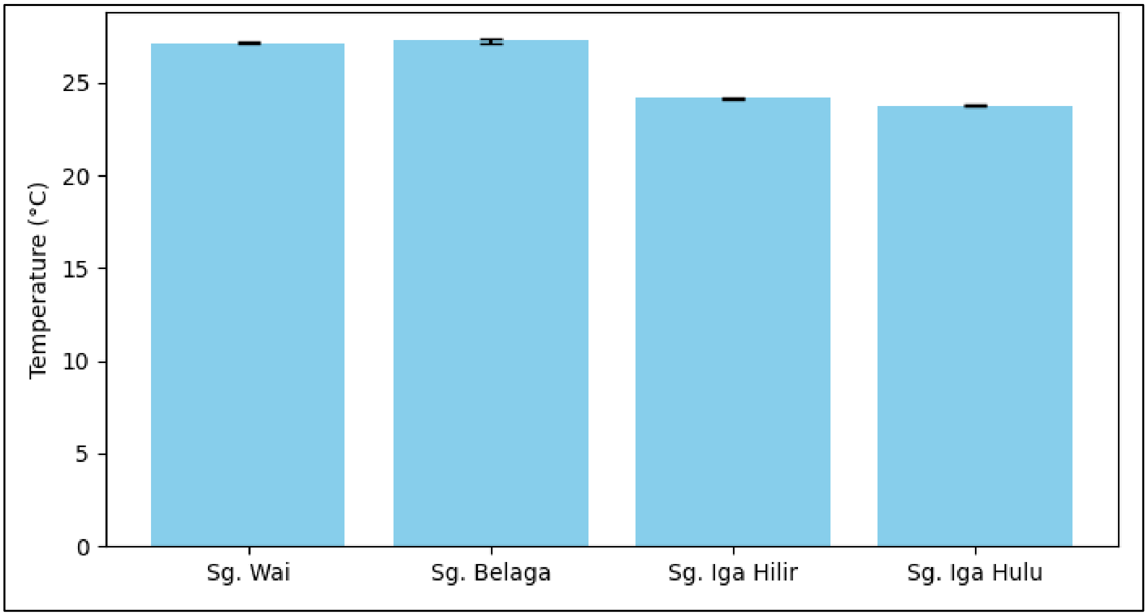

Figure 5: The diagram provides a visual comparison of water temperatures across the four river sites.

Dissolved Oxygen

The descriptive analysis of dissolved oxygen (DO) concentrations (mg/L) from four stations (A, B, C, D) in oil palm estates reveals mean values ranging from 6.83 mg/L (Station B) to 9.07 mg/L (Station D). The standard errors are low (0.03–0.09), indicating consistent measurements within each station (Table 4 and Figure 6). The 95% confidence intervals suggest that the true mean DO values are likely close to the observed means.

The observed DO levels (6.8–9.1 mg/L) are generally within the range considered healthy for most freshwater ecosystems. According to Chapman & Kimstach (1996), DO concentrations above 5 mg/L are typically sufficient to support diverse aquatic life, while values below this threshold can stress or even eliminate sensitive species. The results from these oil palm estates suggest that, at the time of sampling, the water bodies are not experiencing severe oxygen depletion.

Station D indicated the highest mean DO (9.07 mg/L), which may indicate better aeration, lower organic pollution, or less biological oxygen demand (BOD) in that area. In contrast, Station B has the lowest mean DO (6.83 mg/L), which, while still adequate, could reflect localized impacts such as organic runoff, higher temperatures, or reduced water flow. Studies by Melling et al. (2012) and Comte et al. (2012) have shown that oil palm cultivation can increase organic matter and nutrient runoff, potentially leading to localized reductions in DO, especially near effluent discharge points or areas with poor riparian buffer management. The low standard deviations and narrow ranges at each station suggest stable DO conditions during the sampling period.

Other study in Malaysian oil palm landscapes has reported similar DO values in streams with intact riparian buffers, but significantly lower DO in areas with poor management or direct effluent discharge. For example, Cheah et al. (2018) found that DO levels in oil palm-impacted streams ranged from 4.5 to 8.5 mg/L, with lower values associated with higher BOD and nutrient concentrations.

However, continued monitoring is essential, especially during periods of high rainfall or fertilizer application, to ensure that episodic events do not lead to harmful oxygen depletion. Maintaining or restoring riparian buffers and minimizing direct runoff are recommended best management practices to sustain healthy DO levels in oil palm landscapes.

Table 4: Dissolved oxygen (DO) descriptive analysis summary

Components	*Station A*	*Station B*	*Station C*	*Station D*
Mean	7.7	6.8	8.4	9.0
Standard Error	0.057	0.033	0.033	0.088
Median	7.7	6.8	8.4	9.1
Standard Deviation	0.1	0.0577	0.0577	0.1527
Minimum	7.6	6.8	8.4	8.9
Maximum	7.8	6.9	8.5	9.2
Count	3	3	3	3
Confidence Level(95.0%)	0.248	0.143	0.143	0.379

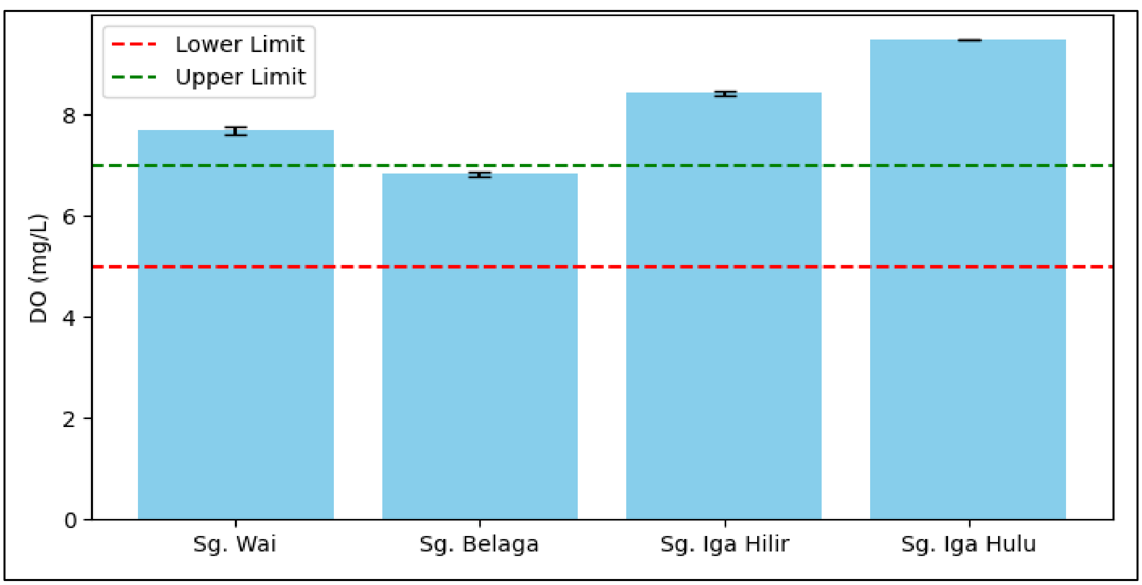

Figure 6: All sampling sItes meet the minimum requirement for dissolved oxygen, with some sites having particularly high levels.

Conductivity

Electrical conductivity is a measure of the water's ability to conduct electricity, which is directly related to the concentration of dissolved ions (such as nutrients and other charged particles). In freshwater systems, typical EC values range from 5 to 50 μS/cm, depending on geology, land use, and anthropogenic inputs (Chapman & Kimstach, 1996). The descriptive analysis of electrical conductivity (EC) in water samples from four stations (A, B, C, D) within oil palm estates shows mean values ranging from 17.3 μS/cm (Station D) to 23.7 μS/cm (Station B) (Table 5 and Figure 7). The standard errors are low (0.33–0.88), and the 95% confidence intervals indicate that the true mean values are likely close to the observed means.

The observed EC values in these oil palm estate stations (17–24 μS/cm) are within the expected range for tropical streams and rivers, suggesting moderate levels of dissolved ions. These values are not unusually high, indicating that there is no severe salinization or excessive input of dissolved solids. However, the slightly higher values at Stations A and B may reflect localized influences such as fertilizer runoff, soil leaching, or proximity to estate infrastructure.

Studies have shown that oil palm cultivation can increase the concentration of dissolved ions in adjacent water bodies, primarily due to fertilizer application, soil erosion, and runoff (Comte et al., 2012; Cheah et al., 2018). For example, Comte et al. (2012) found that streams draining oil palm plantations in Malaysia had higher EC values compared to those in forested catchments, with increases attributed to nutrient and sediment runoff. Similarly, Cheah et al. (2018) reported EC values in oil palm-impacted streams ranging from 10 to 40 μS/cm, with higher values linked to areas with intensive management and poor riparian buffer zones.

The EC values observed here are consistent with those reported in other studies of oil palm landscapes such as, Melling et al. (2012) found that EC in streams near oil palm plantations typically ranged from 15 to 35 μS/cm, with higher values associated with increased agricultural activity and reduced forest cover.

Continued monitoring is recommended, especially during periods of high rainfall or fertilizer application, to detect any episodic increases in dissolved ion concentrations. Implementing and maintaining effective riparian buffers and best management practices can help minimize the impact of oil palm cultivation on water quality.

Table 5: Conductivity descriptive analysis summary

Components	*Station A*	*Station B*	*Station C*	*Station D*
Mean	21.6	23.6	19.0	17.3
Standard Error	0.881	0.881	0.577	0.333
Median	22	24	19	17
Standard Deviation	1.5275	1.5275	1	0.5773
Minimum	20	22	18	17
Maximum	23	25	20	18
Count	3	3	3	3
Confidence Level (95.0%)	3.794	3.794	2.484	1.434

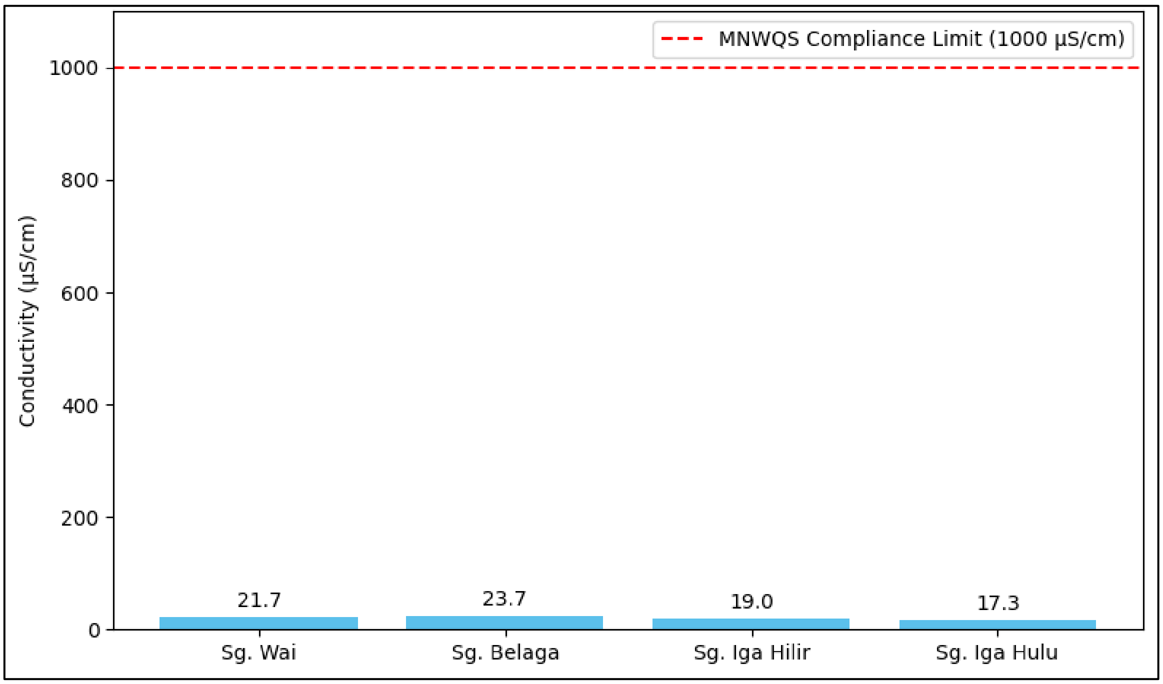

Figure 7: All measured values are within acceptable range, indicating that the water at all sites meets the standard for conductivity.

Turbidity

Turbidity is a critical indicator of water quality, reflecting the presence of suspended particles such as silt, clay, organic matter, and microorganisms. High turbidity reduces light penetration, affecting aquatic photosynthesis and habitat quality (Davies-Colley & Smith, 2001). In oil palm landscapes, land clearing, road construction, and fertilizer application increase soil erosion and runoff, leading to higher turbidity (Carlson et al., 2014; Gaveau et al., 2014). The turbidity measurements data revealed the mean values are as follows: Station A (39.3 NTU), Station B (43.7 NTU), Station C (21.3 NTU), and Station D (18.0 NTU) (Table 6 and Figure 8). The highest turbidity was recorded at Station B, while the lowest was at Station D. All stations show turbidity levels below the Malaysian National Water Quality Standard (MNWQS) Class IIA limit of 50 NTU.

These elevated turbidity values indicate substantial suspended solids in the water, likely due to soil erosion, surface runoff, and land disturbance associated with oil palm activities. The relatively high turbidity recorded at Station B, possibly linked to rainfall events or other land clearing upstream.
In tropical Asia, oil palm plantations are frequently associated with increased turbidity in adjacent water bodies. For example, Carlson et al. (2014) reported mean turbidity values of 20–60 NTU in streams draining oil palm plantations in Indonesia, especially after rainfall. Similarly, studies in Thailand and the Philippines have found that conversion of forest to oil palm or other agriculture increases turbidity due to soil exposure and reduced ground cover (Koh et al., 2011).

In Malaysia, several studies have documented the impact of oil palm on river turbidity. For instance, a study by Gaveau et al. (2014) in Peninsular Malaysia found that streams in oil palm catchments had turbidity values ranging from 15 to 70 NTU, with higher values during the wet season. Ling et al. (2017) reported that rivers in Sarawak draining oil palm areas had mean turbidity values between 25 and 45 NTU, which closely matches the values observed at Stations A and B. Sim et al. (2015) found that rivers in oil palm-dominated catchments had turbidity values of 20–50 NTU that linked to the expansion of oil palm plantations.

Table 6: Turbidity descriptive analysis summary

Components	*Station A*	*Station B*	*Station C*	*Station D*
Mean	39.3	43.6	21.3	18.0
Standard Error	0.881	1.667	0.334	0.577
Median	39	42	21	18
Standard Deviation	1.5275	2.8867	0.5773	1
Minimum	38	42	21	17
Maximum	41	47	22	19
Count	3	3	3	3
Confidence Level(95.0%)	3.794583	7.171088	1.434218	2.484138

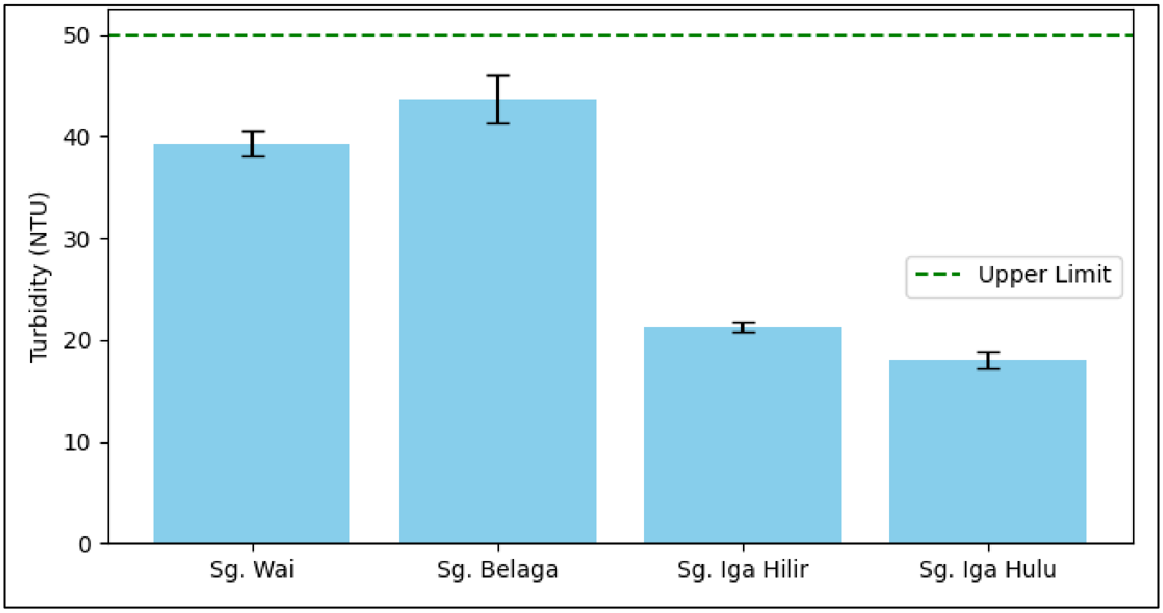

Figure 8: The chart shows that Sg. Wai and Sg. Belaga have higher turbidity values (close to 40 and 44 NTU, respectively), while Sg. Iga Hilir and Sg. Iga Hulu have lower values (around 21 and 18 NTU).

Total Suspended Solids

TSS represents the concentration of particulate matter suspended in water, including silt, clay, organic matter, and other debris. The mean total suspended solid (TSS) values recorded are, Station A (58 mg/L), Station B (70 mg/L), Station C (23.3 mg/L), and Station D (20 mg/L). The highest TSS was recorded at Station B, while the lowest was at Station D (Table 7 and Figure 9). Stations A and B exceed the threshold of class IIA (50 mg/l) based on Malaysian National Water Quality Standards (NWQS), indicating significant sediment pollution. Stations C and D, however, are below the guideline. Standard deviations indicate moderate to high variability, especially at Station B.

TSS is a critical indicator of water quality, affecting light penetration, aquatic habitat, and the transport of nutrients and pollutants (Davies-Colley & Smith, 2001). High TSS can smother aquatic habitats, reduce photosynthesis, and increase the risk of transporting attached pollutants. Among the factors that may contribute to TSS values are often associated with soil erosion, surface runoff, and land disturbance, all of which are common in oil palm landscapes due to land clearing, road construction, and poor ground cover management.

Carlson et al. (2014) reported TSS values of 30–120 mg/L in oil palm catchments in Indonesia, especially after rainfall. In Malaysia, studies have shown that oil palm plantations contribute to increased TSS in rivers. Ling et al. (2017) found TSS values ranging from 25 to 80 mg/L in rivers draining oil palm areas in Sarawak, with higher values during the wet season. Gaveau et al. (2014) reported similar findings in Peninsular Malaysia, with TSS in oil palm catchments often exceeding 50 mg/L, especially after heavy rain. Sim et al. (2015) observed TSS values of 20–60 mg/L in rivers within oil palm landscapes. Thus, best management practices, such as maintaining riparian buffers and minimizing soil disturbance, are recommended to reduce TSS impacts (Koh et al., 2011)

Table 7: Total Suspended Solid descriptive analysis summary

Components	*Station A*	*Station B*	*Station C*	*Station D*
Mean	58	70	23.33333	20
Standard Error	1.154	2.516	0.333	2.081
Median	58	68	23	21
Standard Deviation	2	4.3588	0.5773	3.6055
Minimum	56	67	23	16
Maximum	60	75	24	23
Count	3	3	3	3
Confidence Level(95.0%)	4.968	10.828	1.434	8.956

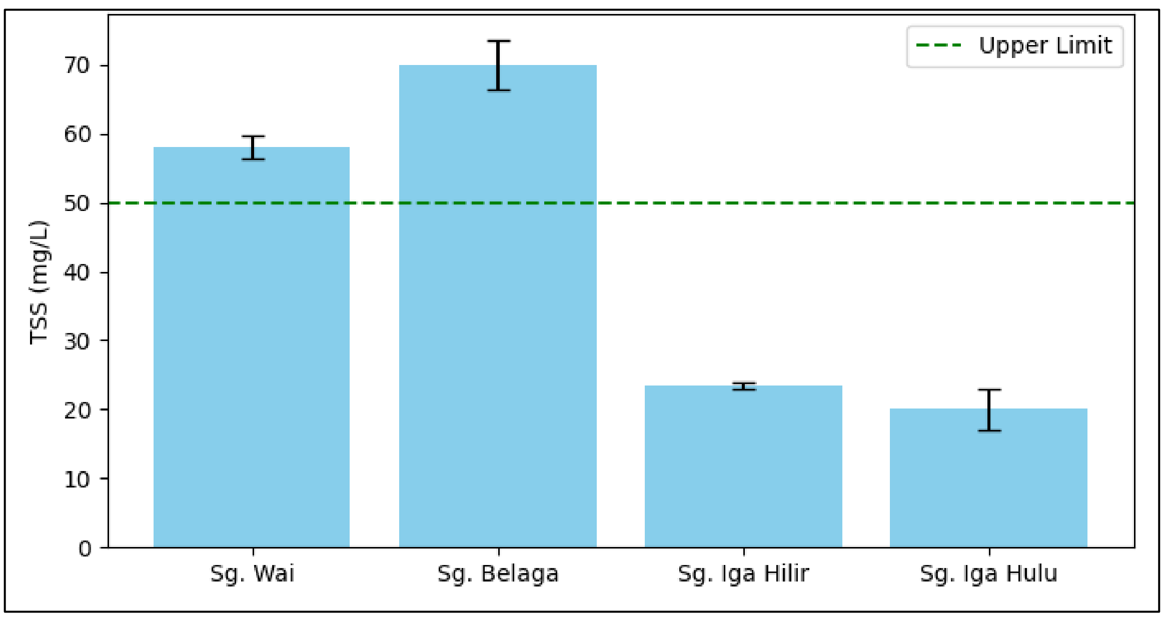

Figure 9: The chart shows that Sg. Wai and Sg. Belaga have TSS values above the upper limit, with Sg. Belaga having the highest TSS concentration. In contrast, Sg. Iga Hilir and Sg. Iga Hulu have TSS values well below the upper limit.

Biological Oxygen Demand

Biological oxygen demand (BOD) is a critical sign of water quality, reflecting the presence of biodegradable organic matter. It is a measure of the amount of oxygen required by microorganisms to decompose organic matter in water. It is a key indicator of organic pollution. Values below 3 mg/L are generally considered indicative of good water quality (Chapman, 1996). Elevated BOD can lead to oxygen depletion, affecting aquatic life and ecosystem health. The computed mean BOD values are: Station A (2.47 mg/L), Station B (2.56 mg/L), Station C (2.39 mg/L), and Station D (2.17 mg/L). The highest BOD was recorded at Station B, while the lowest was at Station D (Table 8 and Figure 10). The slightly higher BOD at Stations A and B may reflect organic inputs from plantation runoff or decaying vegetation. The standard deviations are very low, indicating stable BOD levels across sampling events. All stations revealed below MNWQS class IIA threshold (3 mg/l), indicating relatively good water quality with respect to organic pollution.

In tropical Asia, BOD values in streams draining agricultural and oil palm areas are often elevated. For example, Carlson et al. (2014) reported BOD values of 2–5 mg/L in oil palm catchments in Indonesia, with higher values after rainfall or fertilizer application. In Malaysia, studies have shown that oil palm plantations can increase BOD in rivers due to runoff containing organic matter and agrochemicals. Ling et al. (2017) found BOD values ranging from 2.5 to 4.0 mg/L in rivers draining oil palm areas in Sarawak, with higher values during the wet season. Gaveau et al. (2014) reported similar findings in Peninsular Malaysia, with BOD in oil palm catchments often between 2 and 4 mg/L.

The results from this assessment are consistent with these findings, indicating that oil palm cultivation contributes to moderate increases in BOD, but the values remain within acceptable limits for most uses. Again, best management practices, such as proper waste management and buffer zones, are recommended to minimize BOD impacts (Koh et al., 2011).

Table 8: Biological oxygen demand descriptive analysis summary

Components	*Station A*	*Station B*	*Station C*	*Station D*
Mean	2.4	2.5	2.3	2.1
Standard Error	0.018	0.029	0.012	0.021
Median	2.46	2.55	2.38	2.16
Standard Deviation	0.0321	0.0503	0.0208	0.0360
Minimum	2.45	2.51	2.37	2.14
Maximum	2.51	2.61	2.41	2.21
Count	3	3	3	3
Confidence Level(95.0%)	0.079854	0.125032	0.051711	0.089567

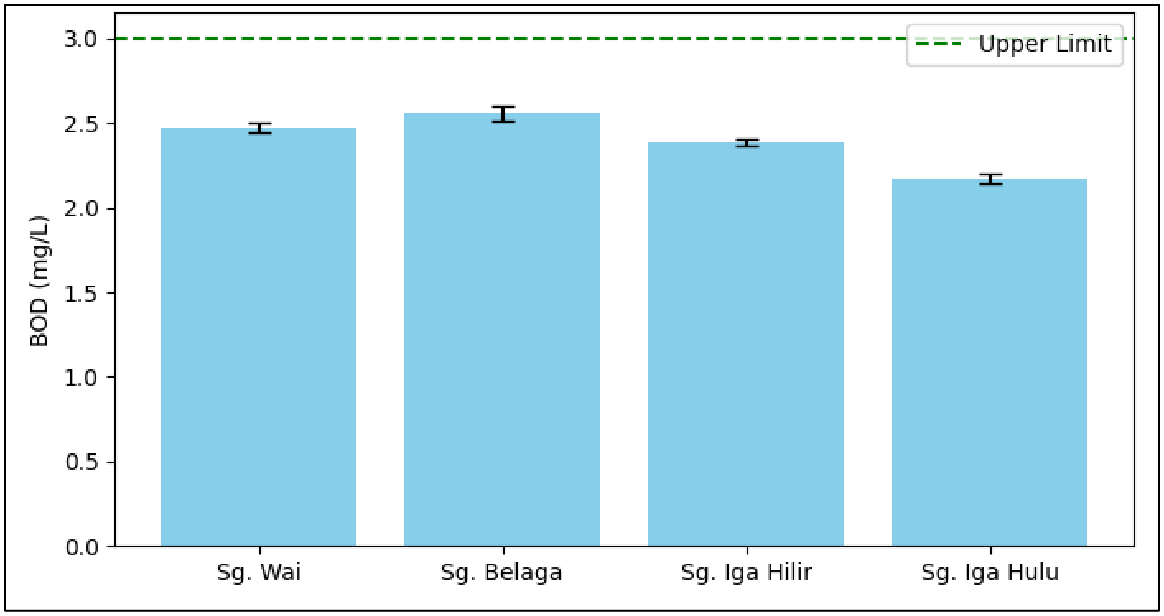

Figure 10: The chart shows that all four locations have BOD values below this upper limit, with Sg. Belaga having the highest BOD and Sg. Iga Hulu the lowest. This indicates that the BOD levels at all sites are within acceptable environmental standards.

Chemical Oxygen Demand

Chemical oxygen demand (COD) is a critical indicator of water quality, reflecting the presence of both biodegradable and non-biodegradable organic matter. Elevated COD can lead to oxygen depletion, affecting aquatic life and ecosystem health (Chapman, 1996). The computed mean COD values are: Station A (19.3 mg/L), Station B (22.1 mg/L), Station C (14.1 mg/L), and Station D (12.0 mg/L) (Table 9 and Figure 11). The highest COD was recorded at Station B, while the lowest was at Station D. Standard deviations indicate moderate variability, especially at Station A. All stations recorded below the threshold of COD below 25 mg/L (MNWQS), indicating that the water is within acceptable limits.

Ling et al. (2017) found COD values ranging from 15 to 30 mg/L in rivers draining oil palm areas in Sarawak, with higher values during the wet season. Sim et al. (2015) also observed COD values of 12–28 mg/L in rivers within oil palm landscapes. In addition, Gaveau et al. (2014) reported similar findings in Peninsular Malaysia, with COD in oil palm catchments often between 15 and 35 mg/L. Another study in Indonesia reported COD values of 15–40 mg/L in oil palm catchments in Indonesia, with higher values after rainfall or fertilizer application (Carlson et al., 2014). Best management practices, such as proper waste management and buffer zones, are recommended to minimize COD impacts (Koh et al., 2011).

Table 9: Chemical oxygen demand descriptive analysis summary

Component	*Station A*	*Station B*	*Station C*	*Station D*
Mean	19.3	22.1	14.1	12.0
Standard Error	1.644	0.519	0.712	0.435
Median	19.9	22.1	13.8	11.9
Standard Deviation	2.8478	0.9	1.2342	0.7549
Minimum	16.2	21.2	13.1	11.3
Maximum	21.8	23	15.5	12.8
Count	3	3	3	3
Confidence Level(95.0%)	7.074	2.235	3.066	1.875

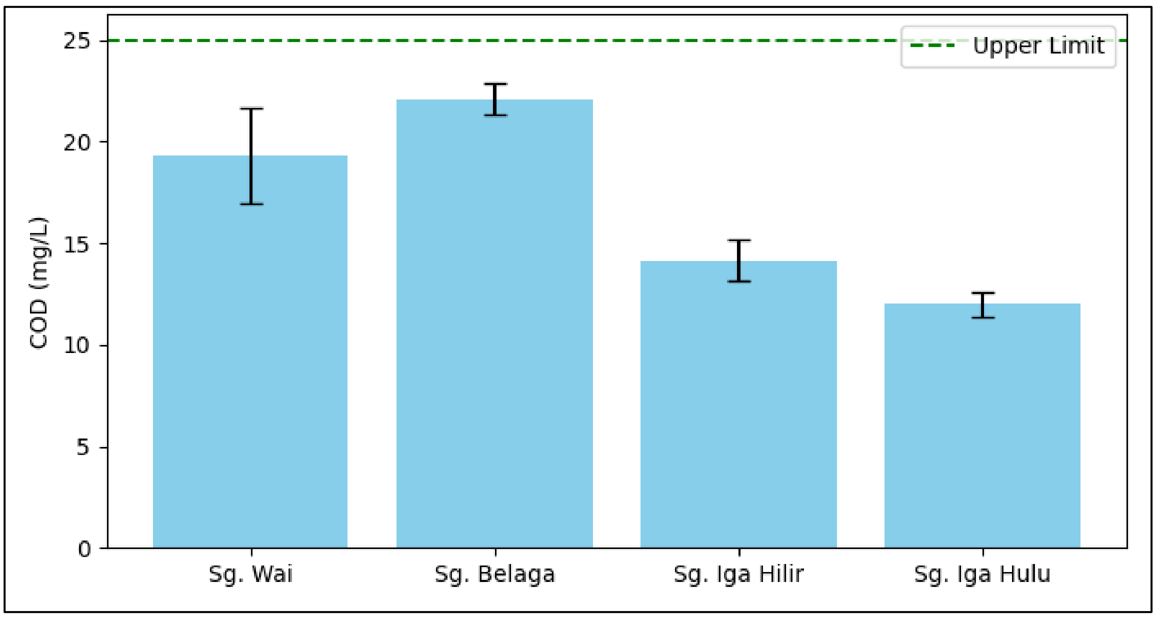

Figure 11: A green dashed horizontal line at 25 mg/L, labeled "Upper Limit," marks the maximum acceptable COD level. The chart shows that all four locations have COD values below this upper limit, with Sg. Belaga having the highest COD and Sg. Iga Hulu the lowest.

Ammonia Nitrogen

Ammonia nitrogen (NH_3-N) in surface waters is a product of microbial decomposition of organic nitrogen and direct input from fertilizers. NH_3-N is a key indicator of organic pollution and nutrient loading in river ecosystems. The computed NH_3-N concentrations from four sampling stations (A, B, C, D) in Belaga oil palm estates, with mean values ranging from 0.182 mg/L to 0.287 mg/L (Table 10 and Figure 12). These values suggest moderate nutrient enrichment, likely from fertilizer use and organic matter decomposition, but do not exceed thresholds associated with severe pollution or ecological risk. The standard deviations are low, indicating relatively stable readings across the samples.

Studies by Ling et al. (2017) found mean NH_3-N values of 0.10–0.50 mg/L in rivers adjacent to oil palm plantations in Sarawak. Similarly, a study by Goh et al. (2016) in Peninsular Malaysia reported NH_3-N concentrations between 0.25 and 0.40 mg/L in streams draining oil palm catchments. Elevated NH_3-N levels can result from fertilizers leaching and organic matter decomposition, which are common in oil palm plantations. Other finding has shown that NH_3-N levels can increase after rainfall events due to surface runoff (Tan et al., 2018). Prolonged exposure to elevated ammonia nitrogen can lead to eutrophication, oxygen depletion, and toxicity to aquatic organisms (USEPA, 2013).

Table 10: Ammonia Nitrogen descriptive analysis summary

Components	*Station A*	*Station B*	*Station C*	*Station D*
Mean	0.253	0.287	0.205	0.182
Standard Error	0.0008	0.0034	0.0085	0.0221
Median	0.254	0.288	0.211	0.201
Standard Deviation	0.0015	0.0061	0.0147	0.0382
Minimum	0.252	0.281	0.189	0.138
Maximum	0.255	0.293	0.217	0.207
Count	3	3	3	3
Confidence Level(95.0%)	0.003	0.014	0.036	0.094

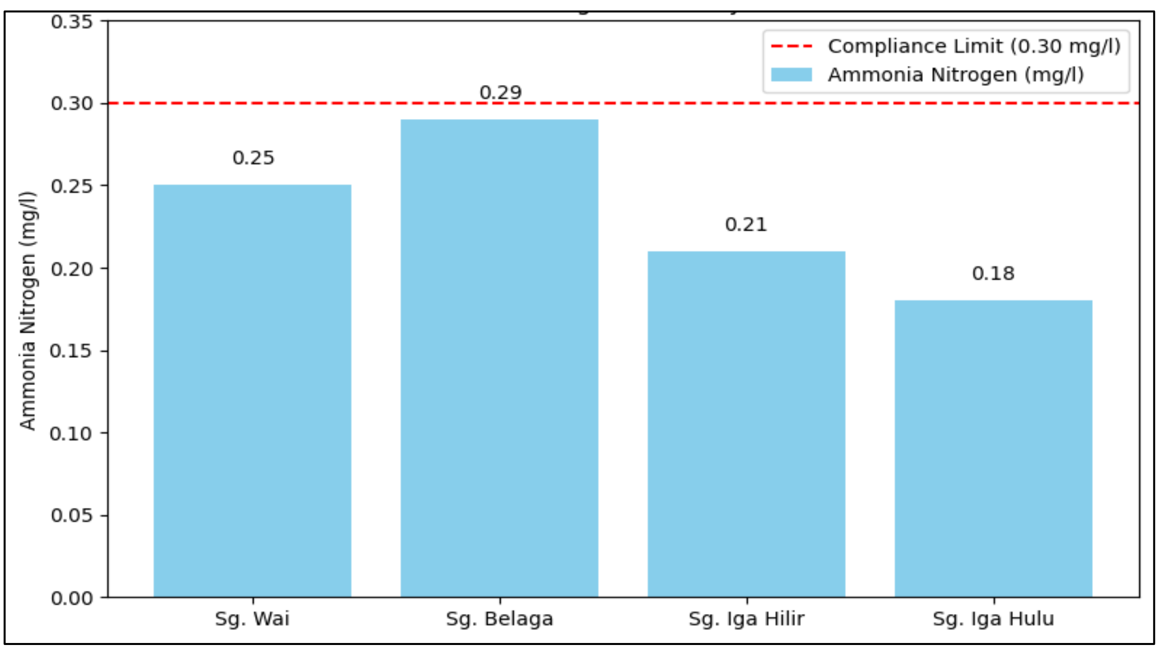

Figure 12: All measured values are within acceptable range of 0.3 mg/l.

Statistical Analysis

One-way ANOVA and post-hoc analysis revealed there are significant spatial variations in nine water quality parameters across four sampling stations within Belaga oil palm estates. All parameters exhibit statistically significant differences ($p < 0.05$), with most p-values lower than threshold p-value 0.05, indicating robust evidence against the null hypothesis of no differences between stations. The high F-values further confirm strong group variability. Post-hoc tests classify each station as a distinct statistical group, suggesting a gradient of water quality impact likely tied to proximity or intensity of oil palm activities.

Post-hoc test for pH revealed that Station B has the highest mean and is significantly different from the others. Station A is also significantly different from C and D. Stations C and D have the lowest means and are very close to each other; they may not be significantly different from each other, but both are lower than A and B (Table 11). Post-hoc test for Temperature revealed that Station B has the highest mean and is significantly different from the others. Station A is not significantly different from station B. However, both stations are significantly different compared to Stations C and D. No significant difference between Station C and D. However, post-hoc test for the other 7 parameters revealed that all stations are significantly different among each other's.

The general findings revealed oil palm cultivation may shift the water quality pattern if not well managed and maintain properly. Acidification, indicated by lower pH values downstream, is likely caused by organic acids from decomposing palm waste and fertilizer runoff, which can disrupt aquatic ecosystems by altering nutrient availability. Thermal differences between stations are pronounced with higher downstream temperatures. This may be attributed to reduced riparian canopy cover, which increases solar exposure. The dissolved oxygen (DO) levels in this assessment revealed good level of DO which the management need to maintain it.

Conductivity value reflects the present of ion concentrations from fertilizers, pesticides, and soil erosion, which can affect freshwater species. High turbidity and total suspended solids (TSS) indicate sediment runoff from eroded soils, especially during rainfall, reducing water clarity and may affect habitat quality. Biochemical and chemical oxygen demand, including ammonia (NH_3-N), signal organic and inorganic pollution, still below the threshold limits of Class IIA and thus, it is critically important for Belaga oil palm estates to maintain these values. The general impact of oil palm activities on water quality is driven by agrochemical runoff, soil erosion, organic pollution, and microclimatic changes. Recommended management strategies include continue to monitor and restoring riparian buffers, adopting precision agriculture, managing effluent treatment properly and implementing erosion control measures.

Table 11: Summary Table of Statistical Significance for Water Quality Parameters (ANOVA) and post-hoc test.

No	Parameter	Average reading at sampling points			
		F-value	**P-value**	**Station Grouping**	**Significance difference?**
1	pH	105.2011	9.1E-07	Station A^{1}; Station B^{2}; Station C^{3}; Station D^{3}	Yes
2	Temperature (°C)	1279.833	4.6E-11	Station A^{1}; Station B^{1}; Station C^{2}; Station D^{2}	Yes
3	Dissolved Oxygen (DO) (mg/l)	277.6389	2.01E-08	Station A^{1}; Station B^{2}; Station C^{3}; Station D^{4}	Yes
4	Conductivity (mS/m)	15.75926	0.001015	Station A^{1}; Station B^{2}; Station C^{3}; Station D^{4}	Yes
5	Turbidity (NTU)	163.8796	1.61E-07	Station A^{1}; Station B^{2}; Station C^{3}; Station D^{4}	YES
6	Total Suspended Solid (TSS) (mg/l)	205.8349	6.55E-08	Station A^{1}; Station B^{2}; Station C^{3}; Station D^{4}	YES
7	Biological Oxygen Demand (BOD) (mg/l)	62.60797	6.74E-06	Station A^{1}; Station B^{2}; Station C^{3}; Station D^{4}	Yes
8	Chemical Oxygen Demand (COD) (mg/l)	23.41283	0.000258	Station A^{1}; Station B^{2}; Station C^{3}; Station D^{4}	Yes
9	Ammonia Nitrogen (NH_3-N) (mg/l)	15.66583	0.001036	Station A^{1}; Station B^{2}; Station C^{3}; Station D^{4}	Yes

Note: The superscript value (1, 2, 3 and 4) denotes significant difference among station.

Water Quality Index

The WQI approach was applied to determine the status of water quality index of all four sampling stations at Belaga oil palm estates. There are SIX (6) basic water quality parameters used to compute the WQI which consists of pH, Total Suspended Solid (TSS), Dissolve Oxygen (DO), Biological Oxygen Demand (BOD), Chemical Oxygen Demand (BOD), and Ammonia Nitrogen (NH_3-N). The assessment finding based on WQI computation, Sg. Belaga (Station B) gained the lowest quality index with WQI - 81. This value is the threshold value for WQI status under CLEAN category (WQI – 81 -100). (Figure 13 and Table 12). TSS recorded poor condition with 70 mg/l during the assessment sampling period may be contributed from soil erosion located upstream. The WQI category for Sg. Iga Hulu (Station D) scored the highest WQI – 90, which categorized as CLEAN status. Similar categories were recorded for Sg. Wai (Station A) and Sg. Iga Hilir (Station C), with WQI – 84 and WQI – 89, respectively. Although the WQI presented in this study indicated the sampling rivers are CLEAN, continuous monitoring at all sampling stations are needed since it may pose significance effect to living biota in a long-term.

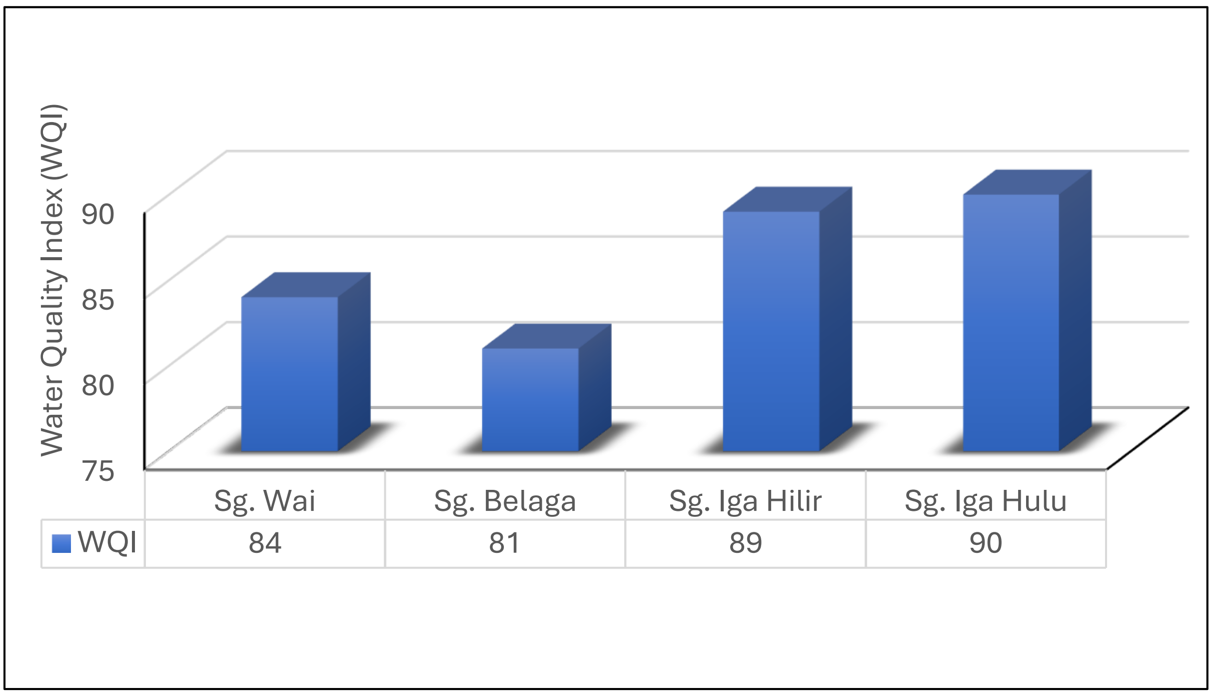

Figure 13: WQI performance index at all sampling stations at Belaga oil palm estates.

Table 12: The WQI categories of Sg. Wai, Sg. Belaga, Sg. Iga Hilir and Sg. Iga Hulu at Belaga oil palm estates.

Sampling Station	WQI value	WQI category	Remarks
Sg. Wai	84	Clean	TSS above limit 50 mg/l
Sg. Belaga	81	Clean	TSS above limit 50 mg/l
Sg. Iga Hilir	89	Clean	
Sg. Iga Hulu	90	Clean	

CONCLUSION

The water quality parameters at Belaga oil palm estates are generally within the ranges reported for other oil palm-dominated landscapes in Southeast Asia. However, Stations A and B consistently show higher values for parameters associated with soil erosion (turbidity and TSS), likely due to their proximity to plantation activities and possible point sources of contamination. In contrast, Stations C and D, which may be having a better buffered by vegetation, exhibit lower pollutant loads and better overall water quality.

These findings underscore the importance of implementing best management practices in oil palm estates, such as maintaining riparian buffer zones, minimizing soil disturbance, and optimizing fertilizer application to reduce runoff and protect aquatic ecosystems. The results also highlight the need for continuous monitoring to assess the long-term impacts of oil palm cultivation on water quality. Establishing long-term monitoring programs to track changes in water quality over time (Yule et al., 2010). Combining water quality assessment with other environmental indicators, such as soil health and biodiversity (Dislich et al., 2017). Strengthening policies and regulations to support effective water quality management (DOE Malaysia, 2016). Table 13 summary the general significance and advantages of continuous monitoring water quality in oil palm plantations.

Table 13: Importance and Benefits of Water Quality Assessment in Oil Palm Estates

Aspect	Description	Key References
Early Detection of Pollution	Enables timely intervention to prevent critical pollution levels	Cheng et al., 2017; Kumaran et al., 2017
Protection of Biodiversity	Maintains aquatic ecosystem health and species diversity	Yule et al., 2010; Che Salmah et al., 2014
Sustainable Yield	Ensures water used for irrigation is suitable, supporting healthy crop growth	Corley & Tinker, 2016
Regulatory Compliance	Ensures adherence to environmental laws and standards	DOE Malaysia, 2016
Community Relations	Protects local water sources, improving stakeholder relations	Obidzinski et al., 2012
Sustainability Certification	Supports compliance with MSPO and RSPO standards	MSPO, 2015; RSPO, 2018
Case Studies (Asia)	Documented impacts and mitigation strategies in Indonesia and Thailand	Carlson et al., 2014; Sukri et al., 2019
Case Studies (Malaysia)	Effects on water quality and biodiversity in Peninsular Malaysia	Che Salmah et al., 2014; Kumaran et al., 2017
Case Studies (Sarawak)	Unique challenges in peatland areas, increased acidity and nutrients	Miettinen et al., 2016; Evers et al., 2017
Challenges	Limited monitoring, data gaps, complex hydrology, weak enforcement	Dislich et al., 2017; Gaveau et al., 2014
Strategies	Capacity building, best practices, stakeholder engagement, technology use	MSPO, 2015; RSPO, 2018; Cheng et al., 2017

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AQUATIC MICROFLORA AND MICROFAUNA

INTRODUCTION

Freshwater ecosystems, particularly riverine systems, are vital ecological components that support diverse communities of organisms and provide essential ecosystem services. These systems are increasingly threatened by anthropogenic activities, including deforestation, agricultural expansion, and industrial development (Dudgeon et al., 2006). In Sarawak, Malaysia, the expansion of oil palm plantations and logging activities has raised significant concerns regarding their impacts on aquatic ecosystems and biodiversity (Mercer et al., 2014).

The Belaga riverine system in Sarawak represents a critical ecological zone that has experienced substantial environmental pressures in recent years. Located in the upper reaches of the Belaga River, this area has been subject to extensive land-use changes, including the conversion of native forests to oil palm plantations (Gaveau et al., 2016). Recent reports indicate significant environmental challenges in the region, including massive logjams that have choked major rivers such as Sungai Rajang and Sungai Katibas, with over 8,000 tonnes of timber debris removed from these waterways as of March 2024.

Aquatic microflora and microfauna serve as excellent bioindicators of water quality and ecosystem health due to their sensitivity to environmental changes, rapid reproduction rates, and specific habitat requirements (Bellinger & Sigee, 2015). These microscopic organisms form the foundation of aquatic food webs and play crucial roles in nutrient cycling, energy transfer, and maintaining ecological balance (Reynolds, 2006).

Riverine microflora and microfauna communities have been extensively studied worldwide due to their ecological significance and indicator value. Algae, particularly diatoms (Bacillariophyta), have been widely used as bioindicators of water quality in freshwater ecosystems (Kelly et al., 2008). Their community structure and abundance patterns can reflect various environmental conditions, including nutrient levels, organic pollution, and habitat modifications (Stevenson et al., 2010).

In tropical regions, studies have shown that microalgal communities in riverine systems are typically dominated by diatoms, green algae (Chlorophyta), and blue-green algae (Cyanobacteria), with their relative abundance varying seasonally and spatially in response to environmental factors such as light availability, temperature, and nutrient concentrations (Bere & Tundisi, 2010). In Malaysian freshwater ecosystems, previous research has documented diverse microalgal communities, with diatoms and green algae often being the predominant groups (Shuhaimi-Othman et al., 2007).

Microfaunal communities in riverine systems, including rotifers, protozoans, and microcrustaceans, also play vital ecological roles as primary consumers and decomposers. Rotifers, in particular, are known to be sensitive to environmental changes and have been used as indicators of water quality in various aquatic ecosystems (Sládeček, 1983). In tropical freshwater systems, rotifer communities often exhibit high diversity and abundance, with their distribution patterns influenced by factors such as water flow, substrate type, and food availability (Segers, 2008).

In Sarawak, studies on aquatic microorganisms in riverine systems have been relatively limited, particularly in areas affected by oil palm plantations. However, research in similar tropical regions has shown that land-use changes, such as forest conversion to agricultural lands, can significantly alter the composition and diversity of aquatic microflora and microfauna communities (Mercer et al., 2014). These alterations can have cascading effects on ecosystem functioning and services, highlighting the importance of monitoring and assessing these communities in areas undergoing rapid environmental changes.

The present study aims to provide a comprehensive assessment of the aquatic microflora and microfauna in the freshwater riverine system of Belaga Oil Palm Estate, Sarawak. By documenting the diversity, abundance, and ecological characteristics of these microscopic organisms, this study contributes valuable baseline data for understanding the current ecological status of the riverine system and for informing future conservation and management strategies in the region.

METHODOLOGY

Study Area

Sampling stations are usually conducted at different streams within the oil palm estates which include upstream and downstream, to assess the impact of oil palm activities (Cheng et al., 2017). Thus, this assessment involved 4 sampling stations, namely, Station A (Sg. Wai), Station B (Sg. Belaga), Station C (Sg. Iga Hilir), and Station D (Sg. Iga Hulu) (Figure 1). The GPS coordinates for these sampling stations are summarized in Table 1.

Sample Collection

At each monitoring station, water samples were collected for the analysis of aquatic microflora and microfauna. A total of 15 Liters of riverine water was filtered through a 20-µm plankton net to concentrate the microscopic organisms. The concentrated samples were then transferred to labelled containers and preserved with appropriate fixatives (Lugol's iodine) for laboratory analysis.

Laboratory Analysis

In the laboratory, the preserved samples were examined using light microscopy for the identification and enumeration of aquatic microflora and microfauna. Identification was performed to the lowest possible taxonomic level (typically genus or species) using standard taxonomic keys and reference materials (Bellinger & Sigee, 2015; John et al., 2011). For each sample, a known volume was placed on a Sedgewick-Rafter counting chamber, and organisms were identified and counted under appropriate magnification. Multiple subsamples were analysed to ensure adequate representation of the microflora and microfauna community.

Table 1: GPS coordination of the sampling points

Station	River/Stream Name	Latitude	Longitude
A	Sg. Wai	3° 02’ 08” N	114° 07’ 09” E
B	Sg. Belaga	3° 02’ 29” N	114° 03’ 08” E
C	Sg. Iga Hilir	3° 01’ 03” N	114° 04’ 25” E
D	Sg. Iga Hulu	3° 00’ 03” N	114° 05’ 51” E

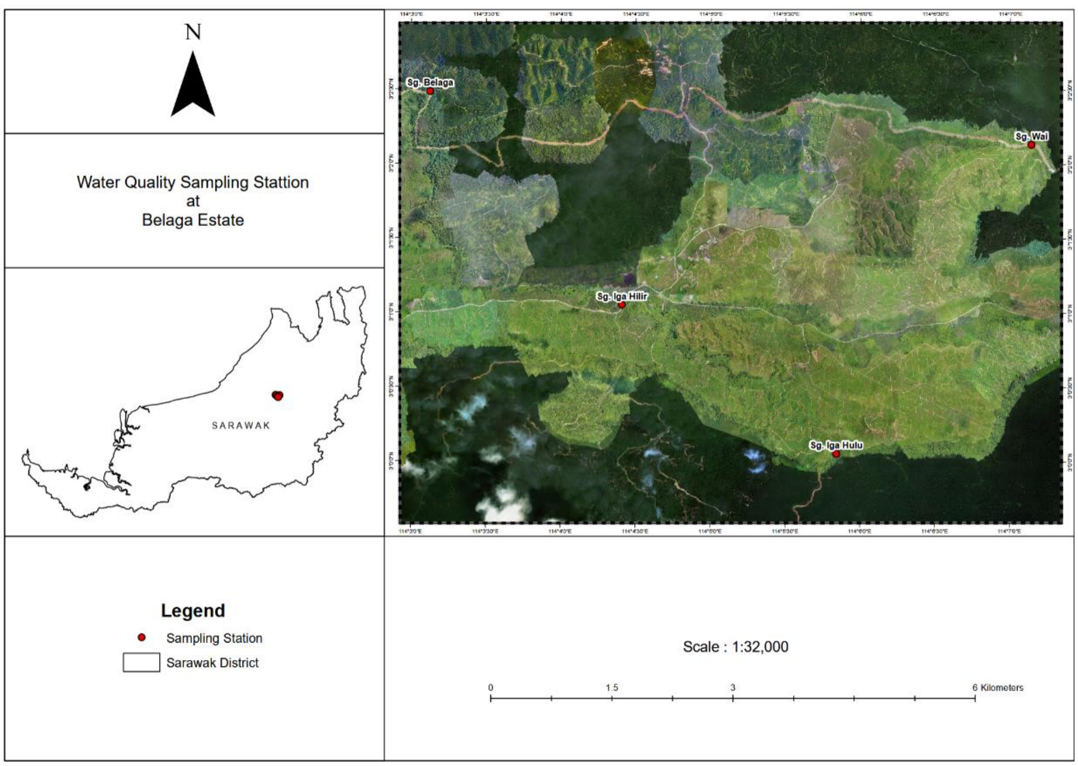

Figure 1: Locations of sampling stations in Belaga oil palm estates.

Data Analysis

The following parameters were calculated to characterize the aquatic microflora and microfauna communities:

1. **Relative Abundance (RA)**: The percentage of individuals of a particular species relative to the total number of individuals of all species.
2. **Frequency (F)**: The proportion of stations where a particular species was present.
3. **Important Species Index (ISI)**: Calculated as the product of mean relative abundance and frequency (ISI = RA × F).
4. **Shannon-Wiener Diversity Index (H')**: A measure of species diversity that accounts for both species richness and evenness.
5. **Evenness Index (E)**: A measure of how evenly individuals are distributed among different species.

The data were analyzed and presented according to taxonomic groups (Animalia, Protozoa, Chromista, and Plantae) and ecological significance (important species with ISI > 1.00).

RESULTS

Species Composition

The systematic list of aquatic microflora and microfauna identified from the Belaga riverine system is presented in Table 2. A total of 60 species belonging to four kingdoms were recorded: Animalia (21 species), Protozoa (8 species), Chromista (17 species), and Plantae (14 species). The Animalia kingdom was predominantly represented by rotifers (Phylum Rotifera) with 17 species, while the Chromista kingdom was dominated by diatoms (Phylum Bacillariophyta) with 15 species. All plant species belonged to the Phylum Chlorophyta (green algae).

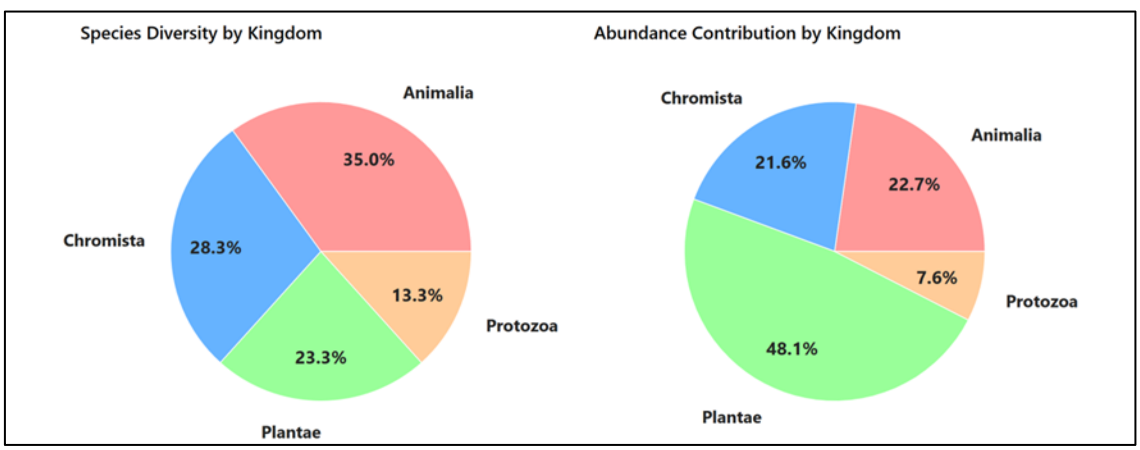

Figure 1a. Species Composition and Total Abundance of Aquatic Microflora and Microfauna at Belaga riverine system

As illustrated in Figure 1a, the overall species composition and abundance of aquatic microflora and microfauna in the Belaga riverine system showed a predominance of Plantae (green algae), particularly due to the high abundance of *Staurastrum* sp.1. The relative contributions of the four kingdoms to the total abundance were: Plantae (43.1%), Animalia (24.0%), Chromista (24.0%), and Protozoa (8.9%). This distribution pattern indicates a relatively balanced community structure with significant contributions from both autotrophic (Plantae and Chromista) and heterotrophic (Animalia and Protozoa) organisms.

Table 2. Systematic list of aquatic microflora and microfauna from riverine system at Belaga oil palm estate

No	Kingdom	Phylum	Species	No	Kingdom	Phylum	Species
1	Animalia	Annelida	Annelid	30	Chromista	Bacillariophyta	*Nitzschia sp.*
2	Animalia	Cnidaria	Hydrozoa	31	Chromista	Bacillariophyta	*Encyonema sp.*
3	Animalia	Gastrotricha	Gastrotricha	32	Chromista	Bacillariophyta	*Fragillaria sp.*
4	Animalia	Nematoda	Nematod	33	Chromista	Bacillariophyta	*Diatoma sp.*
5	Animalia	Rotifera	*Philodinavus sp.*	34	Chromista	Bacillariophyta	*Grammatophora sp.*
6	Animalia	Rotifera	*Dicranophorus sp.*	35	Chromista	Bacillariophyta	*Licomorpha sp.*
7	Animalia	Rotifera	*Asplancha sp.*	36	Chromista	Bacillariophyta	*Navicula sp.*
8	Animalia	Rotifera	*Anuraeopsis sp.*	37	Chromista	Bacillariophyta	*Pinnularia sp.*
9	Animalia	Rotifera	*Brachionus sp1.*	38	Chromista	Bacillariophyta	*Entomoneis*
10	Animalia	Rotifera	*Brachionus sp2.*	39	Chromista	Bacillariophyta	*Aulacoseira*
11	Animalia	Rotifera	*Bryceela sp.*	40	Chromista	Bacillariophyta	*Pleurosira sp.*
12	Animalia	Rotifera	*Lecane sp.*	41	Chromista	Bacillariophyta	*Melosira*
13	Animalia	Rotifera	*Lecane sp.2*	42	Chromista	Bacillariophyta	*Stephanodiscus sp.*
14	Animalia	Rotifera	*Colurella sp.*	43	Chromista	Bacillariophyta	*Lauderia sp.*
15	Animalia	Rotifera	*Notholca sp.*	44	Chromista	Bacillariophyta	*Thalassiosira*
16	Animalia	Rotifera	*Testudinella sp.1*	45	Chromista	Dinoflagellata	*Pyrocystis*
17	Animalia	Rotifera	*Testudinella sp.3*	46	Chromista	Dinoflagellata	*Peridinium sp.*
18	Animalia	Rotifera	*Testudinella sp.4*	47	Plantae	Chlorophyta	*Haematococcus sp.*
19	Animalia	Rotifera	*Trichocerca sp.*	48	Plantae	Chlorophyta	*Pleodorina*
20	Animalia	Rotifera	*Trichocerca sp1.*	49	Plantae	Chlorophyta	*Ulotrichales*
21	Animalia	Rotifera	*Trichocerca sp2.*	50	Plantae	Chlorophyta	*Closterium sp.*
22	Protozoa	Amoebozoa	*Difflugidae sp 2*	51	Plantae	Chlorophyta	*Closterium sp.1*
23	Protozoa	Amoebozoa	*Difflugidae sp1*	52	Plantae	Chlorophyta	*Closterium sp.2*
24	Protozoa	Amoebozoa	*Difflugidae sp3*	53	Plantae	Chlorophyta	*Cosmarium sp.1*
25	Protozoa	Amoebozoa	*Trinema sp.*	54	Plantae	Chlorophyta	*Cosmarium sp.2*
26	Protozoa	Ciliophora	*Lacrymaria sp.*	55	Plantae	Chlorophyta	*Cosmarium sp.3*
27	Protozoa	Ciliophora	*Vorticella*	56	Plantae	Chlorophyta	*Staurastrum sp.1*
28	Protozoa	Ciliophora	*Hypotrichia*	57	Plantae	Chlorophyta	*Staurastrum sp.2*
29	Protozoa	Euglenozoa	*Euglenozoa*	58	Plantae	Chlorophyta	*Gonatozygon sp.*
				59	Plantae	Chlorophyta	*Netrium sp.1*
				60	Plantae	Chlorophyta	*Roya sp.*

Animalia

Table 2 presents the relative abundance, frequency, and Important Species Index (ISI) of animal microfauna at the Belaga riverine system. A total of 21 animal species were identified, with rotifers (Phylum Rotifera) being the dominant group (19 species) (Figure 2 and Figure 3). The most abundant and widely distributed animal species was *Brachionus* sp.1 (Rotifera), with a mean relative abundance of 8.43%, a frequency of 1.00 (present at all stations), and an ISI value of 8.43. Other important animal species included *Brachionus* sp.2 (ISI = 2.94) and Nematoda (ISI = 0.96). The distribution of animal species varied across the four stations, with Station A having the highest number of species (10), followed by Station D (8), Station C (8), and Station B (7). Some species, such as *Brachionus* sp.1, were present at all stations, while others showed more restricted distributions. For instance, *Trichocerca* sp. was found only at Station B with a relatively high relative abundance (7.94%), while species like *Bryceela* sp., *Asplancha* sp., and *Colurella* sp. were exclusive to Station A.

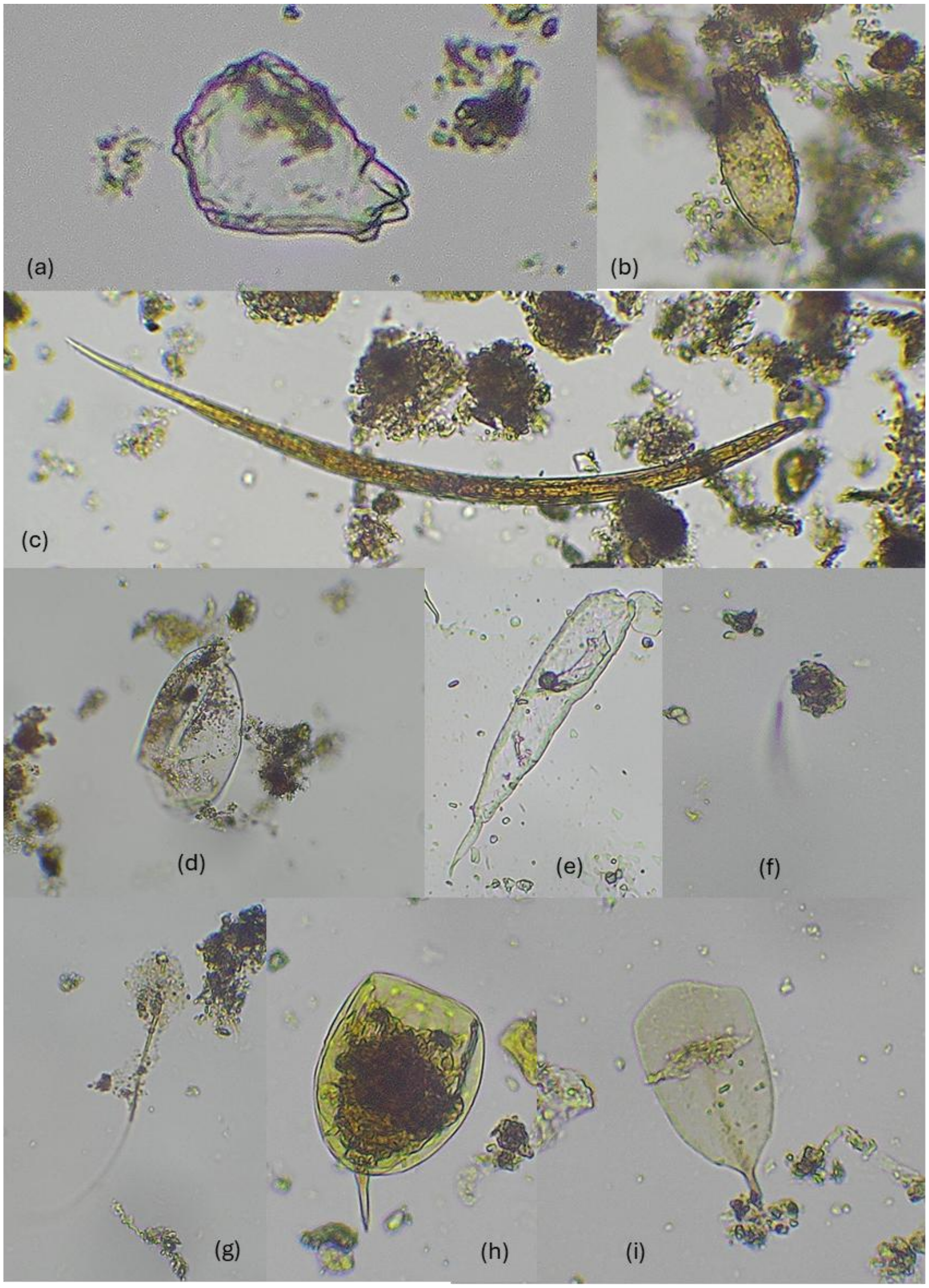

Figure 2. (a) *Brachionus* sp.1, (b) *Brachionus* sp.2, (c) Nematod, (d) *Anuraeopsis* sp. (e) *Trichocerca* sp., (f) *Trichocerca* sp.1, (g) *Trichocerca* sp.2, (h) *Lecane* sp. (i) *Lecane* sp.2

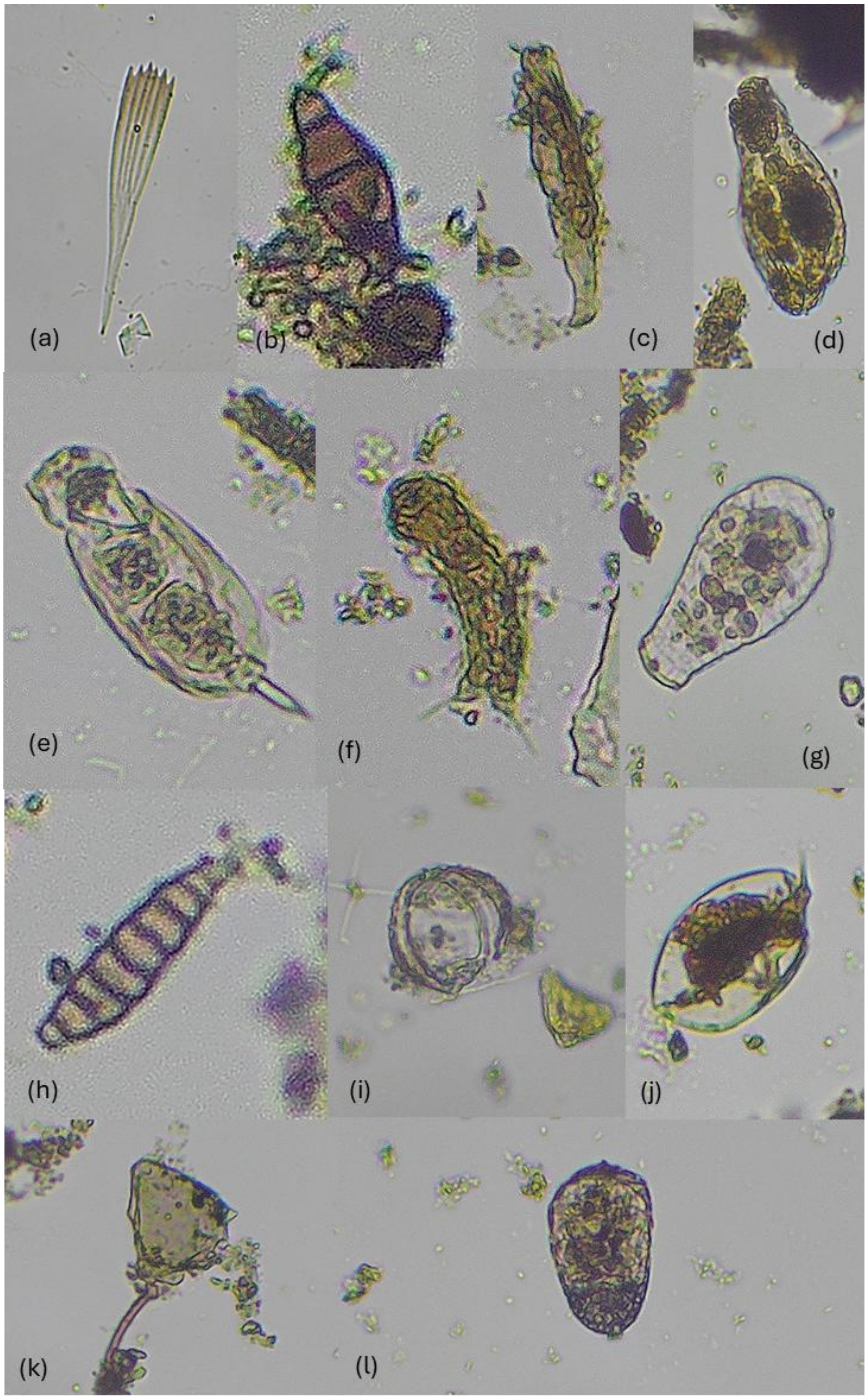

Figure 3. (a) *Notholca* sp., (b) *Bryceela sp.*, (c) Philodinavus sp., (d) *Testudinella sp.4,* (e) *Dicranophorus sp.*, (f) *Gastrotricha*, (g) *Asplancha sp.*, (h) Annelida*,* (i) *Hydrozoa,* (j) Colurella sp., (k) Testudinella sp.3, (l) Testudinella sp.

Table 2: Relative abundance (%) according to stations, mean relative abundance (RA), frequency and important species index of animalia microfauna

No	Kingdom	Phylum	Species	ST A	ST B	ST C	ST D	RA	F	ISI
1	Animalia	Rotifera	*Brachionus sp1.*	7.96	15.87	0.61	9.26	8.43	1.00	8.43
2	Animalia	Rotifera	*Brachionus sp2.*	4.42	0.00	8.48	2.78	3.92	0.75	2.94
3	Animalia	Nematoda	Nematod	2.65	0.00	0.61	1.85	1.28	0.75	0.96
4	Animalia	Rotifera	*Anuraeopsis sp.*	3.54	1.59	0.00	0.00	1.28	0.50	0.64
5	Animalia	Rotifera	*Trichocerca sp1.*	0.00	1.59	0.00	2.78	1.09	0.50	0.55
6	Animalia	Rotifera	*Lecane sp.*	0.00	0.00	1.21	2.78	1.00	0.50	0.50
7	Animalia	Rotifera	*Trichocerca sp.*	0.00	7.94	0.00	0.00	1.98	0.25	0.50
8	Animalia	Rotifera	*Notholca sp.*	0.00	0.00	0.61	2.78	0.85	0.50	0.42
9	Animalia	Rotifera	*Bryceela sp.*	3.54	0.00	0.00	0.00	0.88	0.25	0.22
10	Animalia	Rotifera	*Philodinavus sp.*	0.00	3.17	0.00	0.00	0.79	0.25	0.20
11	Animalia	Rotifera	*Dicranophorus sp.*	0.00	0.00	0.61	0.93	0.38	0.50	0.19
12	Animalia	Annelida	Annelid	2.65	0.00	0.00	0.00	0.66	0.25	0.17
13	Animalia	Rotifera	*Testudinella sp.3*	0.00	1.59	0.00	0.00	0.40	0.25	0.10
14	Animalia	Rotifera	*Trichocerca sp2.*	0.00	1.59	0.00	0.00	0.40	0.25	0.10
15	Animalia	Gastrotricha	Gastrotricha	0.00	0.00	1.21	0.00	0.30	0.25	0.08
16	Animalia	Rotifera	*Lecane sp.2*	0.00	0.00	0.00	0.93	0.23	0.25	0.06
17	Animalia	Cnidaria	Hydrozoa	0.88	0.00	0.00	0.00	0.22	0.25	0.06
18	Animalia	Rotifera	*Asplancha sp.*	0.88	0.00	0.00	0.00	0.22	0.25	0.06
19	Animalia	Rotifera	*Colurella sp.*	0.88	0.00	0.00	0.00	0.22	0.25	0.06
20	Animalia	Rotifera	*Testudinella sp.1*	0.88	0.00	0.00	0.00	0.22	0.25	0.06
21	Animalia	Rotifera	*Testudinella sp.4*	0.00	0.00	0.61	0.00	0.15	0.25	0.04
	Total number of species			**10**	**7**	**8**	**8**	**21**		

Protozoa

The protozoan microfauna in the Belaga riverine system comprised 8 species belonging to three phyla: Amoebozoa (4 species), Ciliophora (3 species), and Euglenozoa (1 species), as shown in Table 4 (Figure 4). The most important protozoan species were Difflugidae sp.1 (Amoebozoa) with an ISI value of 2.07 and *Vorticella* (Ciliophora) with an ISI value of 1.52. Both species were present at three out of four stations (F = 0.75). Station D supported the highest number of protozoan species (5), followed by Station B (4), Station C (3), and Station A (2). Some species showed specific distribution patterns; for example, Difflugidae sp.1 was particularly abundant at Station C (6.67%), while *Trinema* sp. was found only at Stations A and B.

Table 4. Relative abundance (%) according to stations, mean relative abundance (RA), frequency and important species index of protozoan microfauna

No	Kingdom	Phylum	Species	ST A	ST B	ST C	ST D	RA	F	ISI
1	Protozoa	Amoebozoa	*Difflugidae sp1*	0.00	1.59	6.67	2.78	2.76	0.75	2.07
2	Protozoa	Ciliophora	*Vorticella*	0.00	3.17	1.21	3.70	2.02	0.75	1.52
3	Protozoa	Amoebozoa	*Trinema sp.*	3.54	1.59	0.00	0.00	1.28	0.50	0.64
4	Protozoa	Euglenozoa	*Euglenozoa*	0.88	0.00	0.00	0.93	0.45	0.50	0.23
5	Protozoa	Ciliophora	*Hypotrichia*	0.00	1.59	0.00	0.00	0.40	0.25	0.10
6	Protozoa	Amoebozoa	*Difflugidae sp 2*	0.00	0.00	0.00	0.93	0.23	0.25	0.06
7	Protozoa	Amoebozoa	*Difflugidae sp3*	0.00	0.00	0.00	0.93	0.23	0.25	0.06
8	Protozoa	Ciliophora	*Lacrymaria sp.*	0.00	0.00	0.61	0.00	0.15	0.25	0.04
	Total number of species			**2**	**4**	**3**	**5**	**8**		

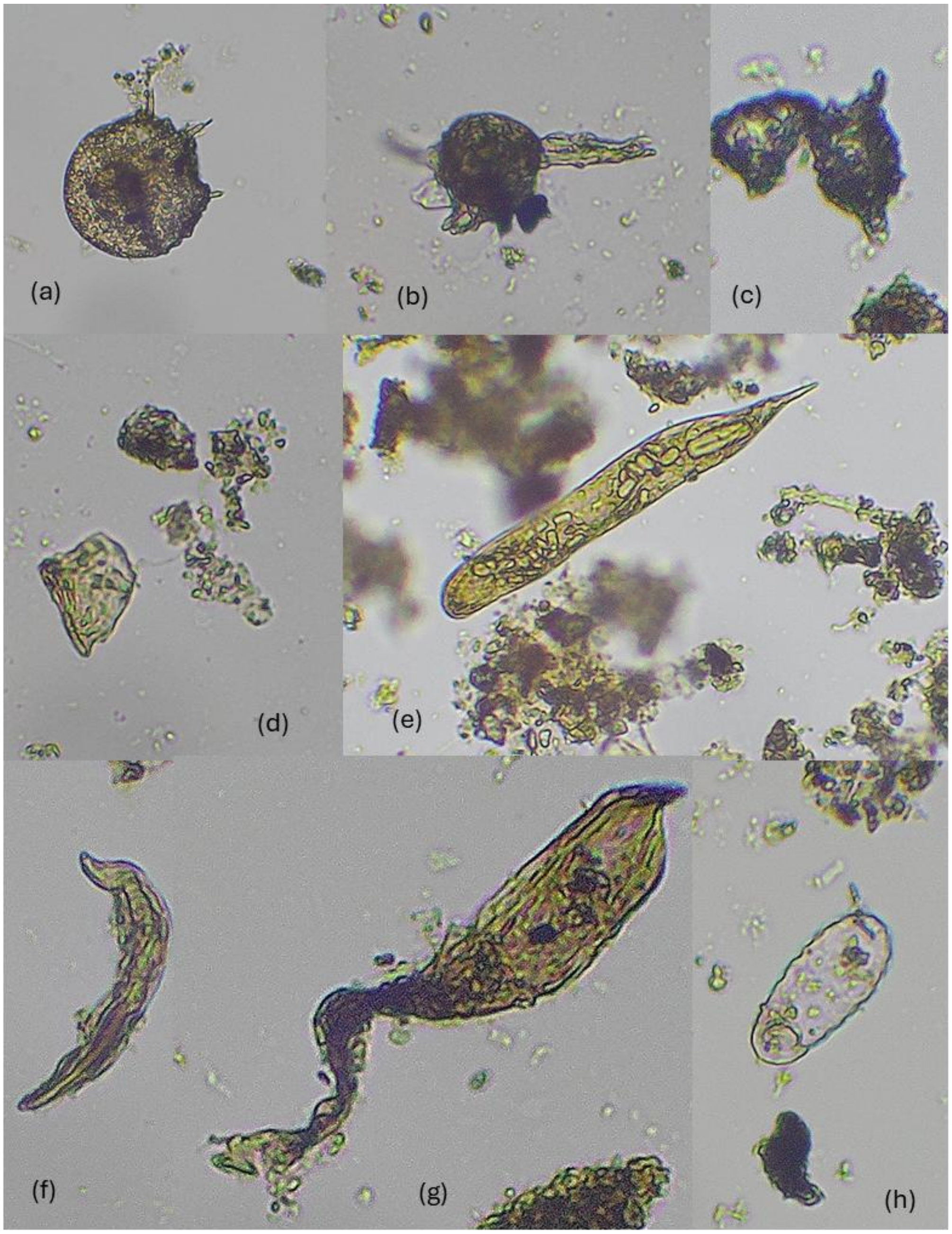

Figure 4. (a) *Difflugidae sp1*, (b) *Difflugidae sp2,* (c) Difflugidae sp3,
(d) *Vorticella,* (e) *Euglenozoa*, (f) *Hypotrichia*, (g) *Lacrymaria sp*. (h) Trinema sp.

Chromista

Table 5 presents the data for chromist microflora, which included 17 species predominantly from the Phylum Bacillariophyta (diatoms, 15 species) and two species from Dinoflagellata (Figure 5 and Figure 6). The most important chromist species were *Licomorpha* sp. (ISI = 4.84), *Navicula* sp. (ISI = 2.63), *Lauderia* sp. (ISI = 2.43), and *Peridinium* sp. (ISI = 1.85).

Station A supported the highest number of chromist species (14), indicating a diverse diatom community at this location. In contrast, Stations B, C, and D had 5, 6, and 7 species, respectively. Some species, such as *Licomorpha* sp. and *Lauderia* sp., were present at all stations (F = 1.00), while others showed more restricted distributions. For instance, *Peridinium* sp. was abundant at Stations A and B but absent from Stations C and D.

Table 5. Relative abundance (%) according to stations, mean relative abundance (RA), frequency and important species index of chromist microflora

No	Kingdom	Phylum	Species	ST A	ST B	ST C	ST D	RA	F	ISI
1	Chromista	Bacillariophyta	*Licomorpha sp.*	0.88	9.52	0.61	8.33	4.84	1.00	4.84
2	Chromista	Bacillariophyta	*Navicula sp.*	8.85	0.00	2.42	2.78	3.51	0.75	2.63
3	Chromista	Bacillariophyta	*Lauderia sp.*	4.42	3.17	1.21	0.93	2.43	1.00	2.43
4	Chromista	Dinoflagellata	*Peridinium sp.*	5.31	9.52	0.00	0.00	3.71	0.50	1.85
5	Chromista	Bacillariophyta	*Fragillaria sp.*	2.65	6.35	0.00	0.00	2.25	0.50	1.13
6	Chromista	Bacillariophyta	*Melosira*	1.77	0.00	1.21	0.93	0.98	0.75	0.73
7	Chromista	Bacillariophyta	*Stephanodiscus sp.*	4.42	0.00	1.21	0.00	1.41	0.50	0.70
8	Chromista	Bacillariophyta	*Encyonema sp.*	3.54	0.00	0.61	0.00	1.04	0.50	0.52
9	Chromista	Bacillariophyta	*Pinnularia sp.*	0.88	1.59	0.00	0.00	0.62	0.50	0.31
10	Chromista	Bacillariophyta	*Aulacoseira*	0.00	0.00	0.00	3.70	0.93	0.25	0.23
11	Chromista	Bacillariophyta	*Entomoneis*	0.00	0.00	0.00	2.78	0.69	0.25	0.17
12	Chromista	Bacillariophyta	*Thalassiosira*	2.65	0.00	0.00	0.00	0.66	0.25	0.17
13	Chromista	Bacillariophyta	*Grammatophora sp.*	0.00	0.00	0.00	0.93	0.23	0.25	0.06
14	Chromista	Bacillariophyta	*Nitzschia sp.*	0.88	0.00	0.00	0.00	0.22	0.25	0.06
15	Chromista	Bacillariophyta	*Diatoma sp.*	0.88	0.00	0.00	0.00	0.22	0.25	0.06
16	Chromista	Bacillariophyta	*Pleurosira sp.*	0.88	0.00	0.00	0.00	0.22	0.25	0.06
17	Chromista	Dinoflagellata	*Pyrocystis*	0.88	0.00	0.00	0.00	0.22	0.25	0.06
	Total number of species			**14**	**5**	**6**	**7**	**17**		

Plantae

The plant microflora in the Belaga riverine system consisted of 14 species, all belonging to the Phylum Chlorophyta (green algae), as shown in Table 6 (Figure 7). *Staurastrum* sp.1 was by far the most dominant plant species, with an exceptionally high mean relative abundance of 35.09% and an ISI value of 35.09. This species was present at all stations and showed particularly high abundance at Station C (70.30%).

Other notable plant species included *Netrium* sp.1 (ISI = 1.82) and *Roya* sp. (ISI = 0.53). The distribution of plant species varied across stations, with Stations A and D each supporting 8 species, Station B supporting 3 species, and Station C having only 1 species (*Staurastrum* sp.1). This pattern suggests that Station C might be experiencing environmental conditions that favour the dominance of *Staurastrum* sp.1 at the expense of other green algae species.

Figure 5. (a) *Licomorpha sp.*, (b) *Navicula*, (c) Lauderia sp., (d) *Peridinium sp.,* (e) *Fragillaria sp.*, (f) *Encyonema sp.*, (g) *Melosira* (h) Aulacoseira (i) Nitzschia sp.

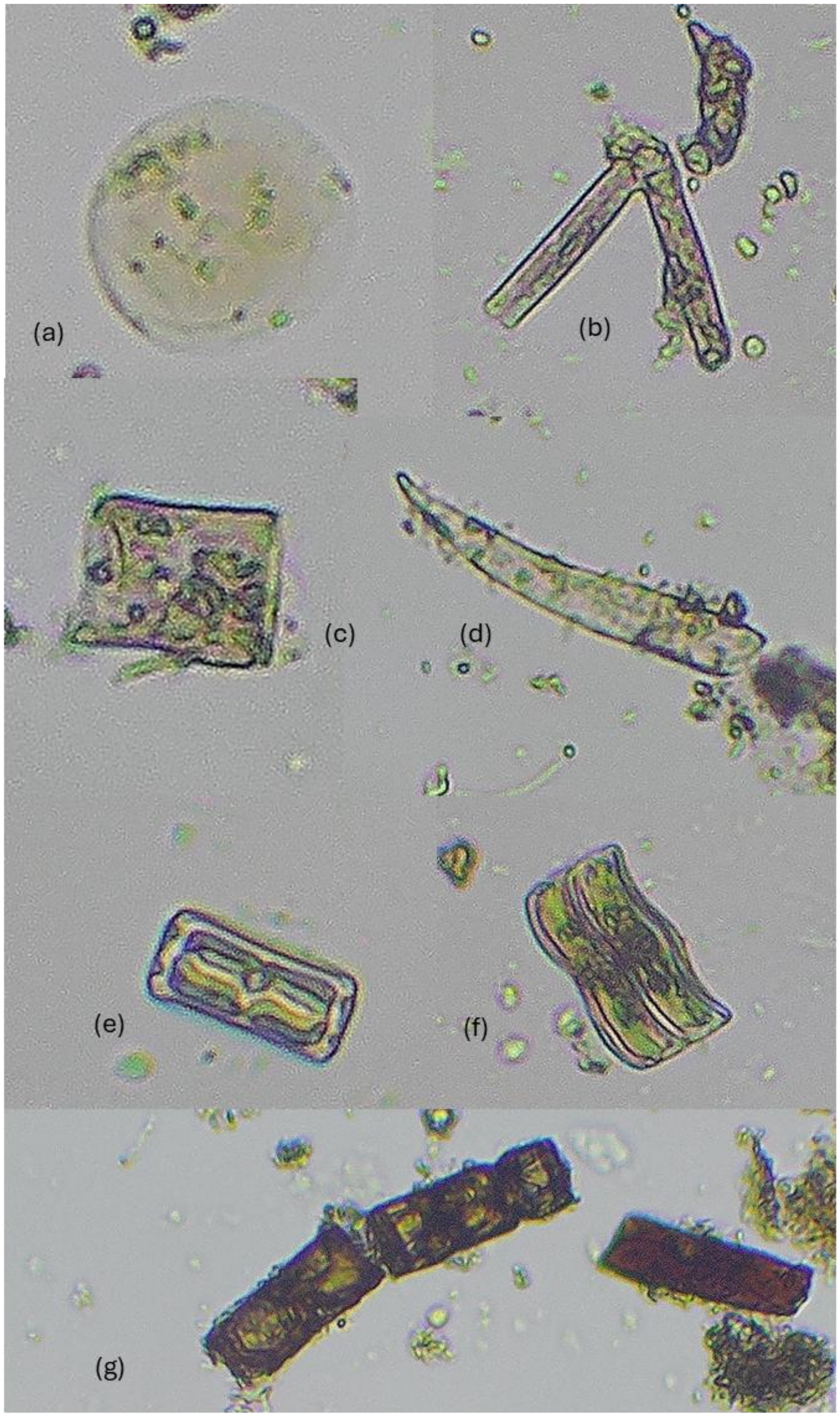

Figure 6. (a) *Stephanodiscus sp.*, (b) *Diatoma sp.*, (c) *Thalassiosira*, (d) *Pyrocystis,* (e) *Grammatophora sp.*, (f) *Entomoneis*, (g) *Pleurosira sp.*

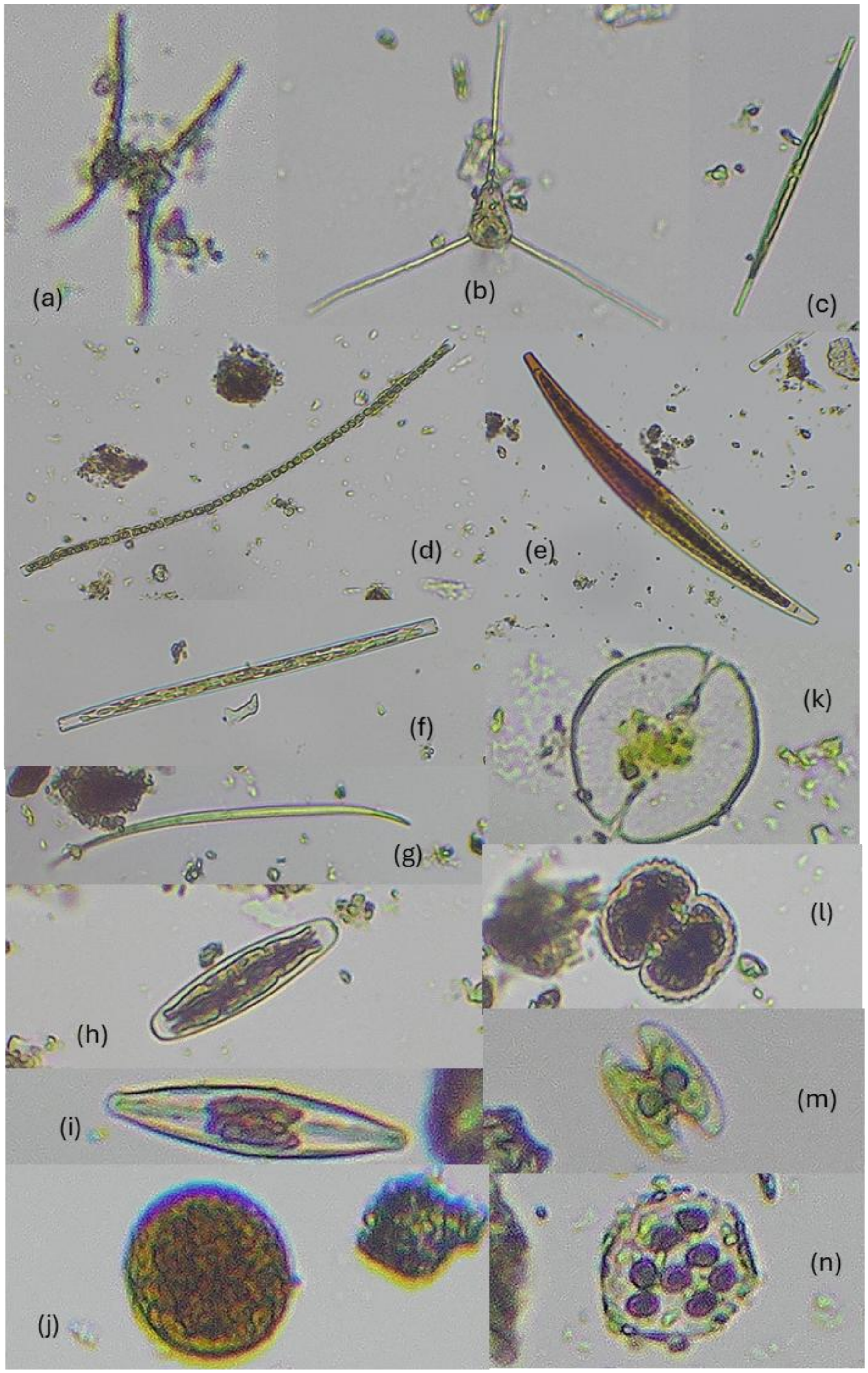

Figure 7. (a) *Staurastrum sp.1*, (b) *Staurastrum sp2*, (c) Roya sp., (d) *Ulotrichales,* (e) *Closterium sp.*, (f) *Gonatozygon sp.*, (g) *Closterium sp.1,* (h) Netrium sp.1, (i) *Closterium sp.2,* (j) *Haematococcus* sp., (k) *Cosmarium* sp.1, (l) *Cosmarium* sp.2, (m) *Cosmarium* sp.3, (n) *Pleodorina*

Table 6. Relative abundance (%) according to stations, mean relative abundance (RA), frequency and important species index of plant microflora

No	Kingdom	Phylum	Species	ST A	ST B	ST C	ST D	RA	F	ISI
1	Plantae	Chlorophyta	*Staurastrum sp.1*	15.04	25.40	70.30	29.63	35.09	1.00	35.09
2	Plantae	Chlorophyta	*Netrium sp.1*	5.31	0.00	0.00	9.26	3.64	0.50	1.82
3	Plantae	Chlorophyta	*Roya sp.*	2.65	1.59	0.00	0.00	1.06	0.50	0.53
4	Plantae	Chlorophyta	*Cosmarium sp.3*	0.00	1.59	0.00	1.85	0.86	0.50	0.43
5	Plantae	Chlorophyta	*Gonatozygon sp.*	0.00	0.00	0.00	1.85	0.46	0.25	0.12
6	Plantae	Chlorophyta	*Cosmarium sp.2*	1.77	0.00	0.00	0.00	0.44	0.25	0.11
7	Plantae	Chlorophyta	*Haematococcus sp.*	0.00	0.00	0.00	0.93	0.23	0.25	0.06
8	Plantae	Chlorophyta	*Closterium sp.*	0.00	0.00	0.00	0.93	0.23	0.25	0.06
9	Plantae	Chlorophyta	*Closterium sp.2*	0.00	0.00	0.00	0.93	0.23	0.25	0.06
10	Plantae	Chlorophyta	*Staurastrum sp.2*	0.00	0.00	0.00	0.93	0.23	0.25	0.06
11	Plantae	Chlorophyta	*Pleodorina*	0.88	0.00	0.00	0.00	0.22	0.25	0.06
12	Plantae	Chlorophyta	*Ulotrichales*	0.88	0.00	0.00	0.00	0.22	0.25	0.06
13	Plantae	Chlorophyta	*Closterium sp.1*	0.88	0.00	0.00	0.00	0.22	0.25	0.06
14	Plantae	Chlorophyta	*Cosmarium sp.1*	0.88	0.00	0.00	0.00	0.22	0.25	0.06
	Total number of species			**8**	**3**	**1**	**8**	**14**		

Important Species

Table 7 summarizes the 11 most important species (ISI > 1.00) identified in the Belaga riverine system. These species represented all four kingdoms: Plantae (2 species), Animalia (2 species), Chromista (5 species), and Protozoa (2 species). The green alga *Staurastrum* sp.1 was the most important species overall, with an ISI value of 35.09, followed by the rotifer *Brachionus* sp.1 (ISI = 8.43) and the diatom *Licomorpha* sp. (ISI = 4.84). These important species showed varying distribution patterns across the four stations. Some, like *Staurastrum* sp.1, *Brachionus* sp.1, and *Licomorpha* sp., were present at all stations (F = 1.00), indicating their adaptability to different environmental conditions within the riverine system. Others, such as *Peridinium* sp. and *Netrium* sp.1, were more restricted in their distribution (F = 0.50), suggesting more specific habitat requirements.

Table 7: Relative abundance (%) according to stations, mean relative abundance (RA), frequency and important species index of most important microflora and fauna (ISI > 1.00)

No	Kingdom	Phylum	Species	ST A	ST B	ST C	ST D	RA	F	ISI
1	Plantae	Chlorophyta	*Staurastrum*	15.04	25.40	70.30	29.63	35.09	1.00	35.09
2	Animalia	Rotifera	*Brachionus sp1.*	7.96	15.87	0.61	9.26	8.43	1.00	8.43
3	Chromista	Bacillariophyta	*Licomorpha sp.*	0.88	9.52	0.61	8.33	4.84	1.00	4.84
4	Animalia	Rotifera	*Brachionus sp2.*	4.42	0.00	8.48	2.78	3.92	0.75	2.94
5	Chromista	Bacillariophyta	*Navicula sp.*	8.85	0.00	2.42	2.78	3.51	0.75	2.63
6	Chromista	Bacillariophyta	*Lauderia sp.*	4.42	3.17	1.21	0.93	2.43	1.00	2.43
7	Protozoa	Amoebozoa	*Difflugidae sp1*	0.00	1.59	6.67	2.78	2.76	0.75	2.07
8	Chromista	Dinoflagellata	*Peridinium sp.*	5.31	9.52	0.00	0.00	3.71	0.50	1.85
9	Plantae	Chlorophyta	*Netrium sp.1*	5.31	0.00	0.00	9.26	3.64	0.50	1.82
10	Protozoa	Ciliophora	*Vorticella*	0.00	3.17	1.21	3.70	2.02	0.75	1.52
11	Chromista	Bacillariophyta	*Fragillaria sp.*	2.65	6.35	0.00	0.00	2.25	0.50	1.13

Ecological Indices

The ecological indices calculated for each station are presented in Table 8. The Shannon-Wiener Diversity Index (H') ranged from 1.296 at Station C to 3.152 at Station A, indicating substantial variation in species diversity across the riverine system. Similarly, the Evenness Index (E) varied from 0.448 at Station C to 0.894 at Station A, reflecting differences in the equitability of species abundance distributions.

Station A exhibited the highest diversity (H' = 3.152), evenness (E = 0.894), and species richness (34 species), suggesting relatively favourable and stable environmental conditions at this location. In contrast, Station C showed the lowest diversity (H' = 1.296) and evenness (E = 0.448), despite having 18 species. This pattern at Station C is largely attributable to the overwhelming dominance of *Staurastrum* sp.1, which constituted 70.30% of the total abundance at this station. Stations B and D showed intermediate levels of diversity (H' = 2.450 and 2.691, respectively) and evenness (E = 0.832 and 0.808, respectively), with 19 and 28 species, respectively. These results indicate a gradient of ecological conditions across the four stations, potentially reflecting varying degrees of environmental stress or resource availability.

Table 8. Diversity Index, Evenness Index and Number of Species According to Stations

Station	Diversity Index	Evenness Index	Num.Spec.
ST A	3.152	0.894	34
ST B	2.450	0.832	19
ST C	1.296	0.448	18
ST D	2.691	0.808	28

DISCUSSION

The assessment of aquatic microflora and microfauna in the Belaga riverine system revealed a diverse community comprising 60 species across four kingdoms, with varying patterns of abundance, distribution, and ecological significance. These findings provide valuable insights into the current ecological status of the riverine system and the potential impacts of environmental changes in the region.

Community Structure and Dominant Taxa

The predominance of green algae (Plantae), particularly *Staurastrum* sp.1, in the Belaga riverine system is noteworthy. *Staurastrum* species are common in freshwater environments and are often associated with mesotrophic to eutrophic conditions (Bellinger & Sigee, 2015). The exceptionally high abundance of *Staurastrum* sp.1, especially at Station C (70.30%), suggests potential nutrient enrichment at this location, possibly due to agricultural runoff from the surrounding oil palm plantation (Smith et al., 1999). Similar dominance patterns of green algae have been reported in other tropical riverine systems affected by agricultural activities (Bere & Tundisi, 2010).

The significant presence of rotifers, particularly *Brachionus* species, is also ecologically relevant. *Brachionus* is known to thrive in environments with elevated organic matter and nutrients, and its abundance can indicate moderate levels of organic pollution (Sládeček, 1983). The co-dominance of *Brachionus* sp.1 and *Staurastrum* sp.1 at most stations suggests a trophic relationship, where rotifers may be grazing on the abundant algal resources (Wallace & Snell, 2010).

Diatoms (Bacillariophyta) represented the most diverse group within Chromista, with 15 species identified. Diatoms are excellent bioindicators of water quality due to their specific environmental requirements and sensitivity to changes in physical and chemical parameters (Kelly et al., 2008). The presence of diverse diatom communities, particularly at Station A (14 species), indicates relatively good water quality conditions at this location. However, the lower diatom diversity at other stations might reflect less favourable environmental conditions, possibly due to increased sedimentation or altered water chemistry associated with land-use changes in the catchment area (Stevenson et al., 2010).

Spatial Variations in Community Structure

The substantial variations in species diversity, evenness, and composition across the four sampling stations reflect spatial heterogeneity in environmental conditions within the Belaga riverine system. Station A, with the highest diversity (H' = 3.152) and species richness (34 species), likely represents a relatively less disturbed section of the riverine system with more stable ecological conditions. In contrast, Station C, with the lowest diversity (H' = 1.296) and evenness (E = 0.448), appears to be experiencing more significant environmental stress, possibly related to agricultural inputs or habitat modifications that favour the dominance of *Staurastrum* sp.1 at the expense of other species (Dudgeon et al., 2006).

These spatial patterns align with findings from other studies in tropical regions, where riverine sections adjacent to agricultural lands often show reduced biodiversity and increased dominance of tolerant species compared to less disturbed areas (Mercer et al., 2014). The gradient of ecological conditions observed across the four stations in the Belaga riverine system likely reflects the varying intensity of anthropogenic influences, including potential impacts from the surrounding oil palm plantation.

The composition and structure of aquatic microflora and microfauna communities in the Belaga riverine system provide valuable insights into the ecological health of this ecosystem. The presence of diverse taxonomic groups, including sensitive organisms like certain diatom species, suggests that the riverine system still maintains some level of ecological integrity despite the environmental pressures in the region (Bellinger & Sigee, 2015). However, the dominance patterns observed, particularly the overwhelming abundance of *Staurastrum* sp.1 at Station C, indicate potential ecological imbalances that may be linked to anthropogenic disturbances.

Conservation and Management Implications

The findings of this study have important implications for the conservation and management of the Belaga riverine system and similar ecosystems in Sarawak. The spatial variations in microflora and microfauna community structure highlight the need for targeted management approaches that address specific ecological conditions and challenges at different sections of the riverine system. The relatively high diversity at Station A suggests that this area may serve as an important ecological reference or potential refuge for aquatic biodiversity. Conservation efforts could prioritize the protection of such relatively intact sections of the riverine system to maintain ecological resilience and support the recovery of more disturbed areas (Dudgeon et al., 2006). For sections showing signs of ecological stress, such as Station C, management interventions could focus on reducing nutrient inputs and sedimentation from surrounding agricultural lands. Implementing riparian buffer zones, improving agricultural practices to minimize runoff, and enhancing sediment control measures could help mitigate these impacts and support the recovery of more balanced and diverse microflora and microfauna communities (Smith et al., 1999).

CONCLUSION

This comprehensive assessment of aquatic microflora and microfauna in the Belaga riverine system has revealed a diverse community comprising 60 species across four kingdoms, with varying patterns of abundance, distribution, and ecological significance. The green alga *Staurastrum* sp.1 emerged as the most dominant species, particularly at Station C, while other important taxa included the rotifer *Brachionus* sp.1 and various diatom species. Significant spatial variations in community structure were observed across the four sampling stations, with Station A exhibiting the highest diversity and species richness, and Station C showing the lowest diversity and evenness due to the overwhelming dominance of *Staurastrum* sp.1. These patterns reflect a gradient of ecological conditions within the riverine system, likely influenced by varying degrees of anthropogenic disturbances, including potential impacts from the surrounding oil palm plantation.The findings of this study provide valuable baseline data on the aquatic microflora and microfauna community structure in the Belaga riverine system, which can serve as an important reference for future ecological monitoring and conservation efforts in the region.

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FISH COMPOSITION

INTRODUCTION

Freshwater ecosystems are among the most threatened globally due to increasing human activities such as deforestation, land conversion, and agricultural development (Carpenter et al., 2011). In Southeast Asia, these threats are particularly severe, with the rapid expansion of oil palm plantations posing significant risks to aquatic biodiversity (Giam et al., 2015). In Sarawak, Malaysian Borneo, land-use change driven by oil palm development has altered freshwater habitats, yet the impacts on ichthyofaunal communities remain understudied especially in remote regions like Belaga. Freshwater fish are vital to both ecosystem functioning and rural livelihoods, providing food, income, and ecological services (McIntyre et al., 2016). However, habitat degradation, sedimentation, and increased fishing pressure associated with plantation development can lead to shifts in species composition and declines in fish populations (Ferreira et al., 2018). Despite this, baseline data on freshwater fish diversity in plantation landscapes across Sarawak is limited.

This study aims to document the freshwater fish inventory in streams within oil palm plantation areas in Belaga, Sarawak. By providing foundational data on species presence and diversity, this work contributes to understanding how land-use change affects aquatic ecosystems and supports future conservation and management efforts in tropical plantation-dominated landscapes.

MATERIALS AND METHODS

Study site

Study were conducted at the Belaga palm oil Estates (Figure 1). A river that flows in the estate was selected for the fish inventory study.

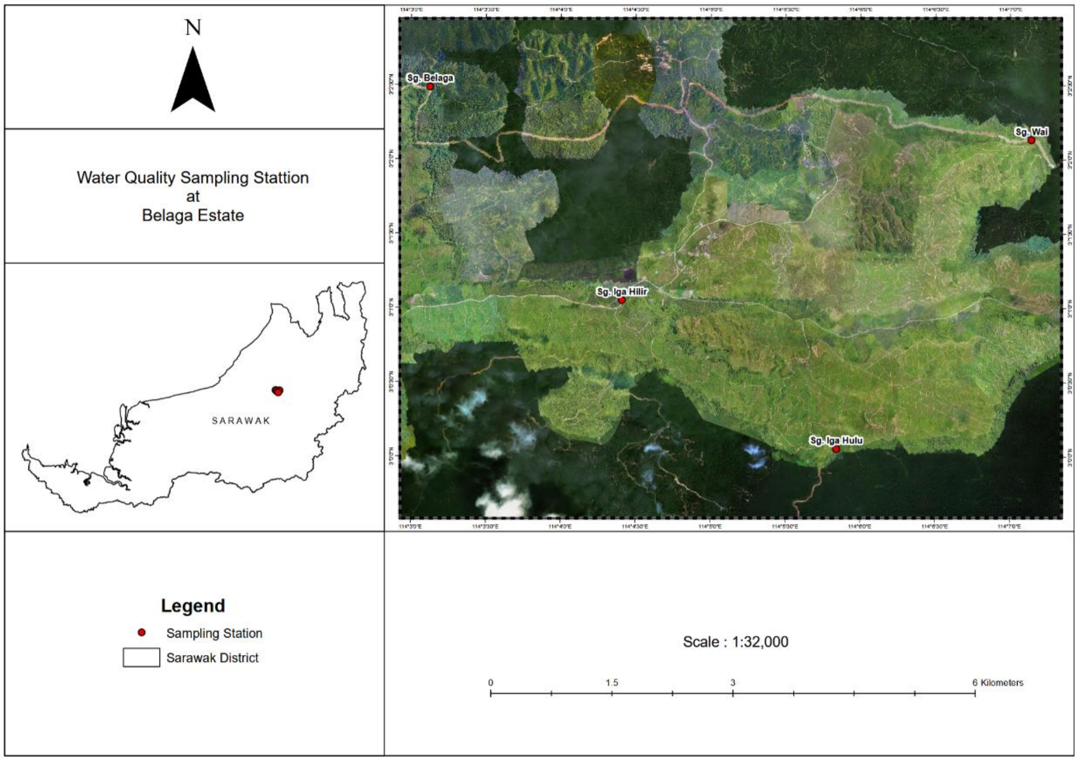

Figure 1: Study location at Belaga oil palm estates

Sampling Procedure and Analysis

A total of 1 sampling station which river that located in the Belaga Estate were used as fish sampling site. Sampling was carried once in Mac 2025. Fish sample was collected using fishing gear (gill net) with length 50 m and 2 m wide which consisting of mesh size of 2 inch. The nets were placed using stack across the river for three hours. After the located time, trapped fish in the net were collected for observation, measurement and photographed. Fish samples were identified to the species and family levels through morphological examination, referencing standard taxonomic keys and field guides based on (Froese & Pauly, 2025; Parenti & Lim, 2005; Sholihah et al., 2020; Sulaiman & Mayden, 2012) works. The number of species and their respective families were recorded manually. Species identification was based on distinguishing features such as fin structure, body shape, scale pattern, and coloration. Each of the identified fish were compare with the International Union for Conservation of Nature (IUCN) list.

RESULTS AND DISCUSSION

A total of seven (7) freshwater fish species were recorded from the sampling efforts conducted at Glenealy Belaga Estate (Table 1, Figure 2). These species were classified into six (6) genera and grouped under two (2) families, with Cyprinidae being the dominant family with 71% from the total species recorded.

Table 1: Species of freshwater fishes recorded from Glenealy Belaga Estate

No.	Family	Scientific name	Common name	IUCN list
1	Cyprinidae	*Barbonymus balleroides*	Wader merah	LC
2	Cyprinidae	*Barbonymus collingwoodii*	Kepiat	LC
3	Cyprinidae	*Hampala macrolepidota*	Adong/Seberau	LC
4	Cyprinidae	*Lobocheilos kajanensis*	Kulong	LC
6	Cyprinidae	*Tor douronensis*	Semah	NE
5	Danionidae	*Rasbora hosii*	Seluang	LC
7	Danionidae	*Luciosoma setigerum*	punjut	LC

The genus *Barbonymus* emerged as the most frequently encountered (29%), indicating its prevalence in the aquatic ecosystem of the study area (Figure 3). Other genera consists of 14% respectively from the total recorded genera. Among the identified species, all were listed as Least Concern (LC) on the IUCN Red List, except for *Tor douronensis*, which is currently Not Evaluated (NE) (IUCN, 2025). The presence of *T. douronensis*, a species culturally valued and often associated with pristine habitats, highlights the need for future monitoring and conservation attention (Colvin et al., 2019). The dominance of Cyprinidae is consistent with patterns observed in other freshwater ecosystems in Southeast Asia, where the family is recognized for its ecological adaptability and species richness (van der Sleen & Albert, 2022). The genus *Barbonymus* in particular is commonly reported in lowland rivers and disturbed habitats, making it a useful bioindicator of ecological resilience (Chow et al., 2016). The findings represent a new inventory record for Glenealy Belaga Estate, providing baseline biodiversity data for future ecological assessments and plantation landscape planning. While species richness is relatively low, the absence of invasive or exotic species suggests a relatively undisturbed freshwater habitat. This is notable, considering the increasing anthropogenic pressures on Sarawak's inland water bodies (Wilkinson et al., 2018). This study contributes to the growing body of knowledge on freshwater fish diversity in Sarawak, where ichthyofaunal surveys remain limited, especially in estate and plantation environments (Wilkinson et al., 2018) Such inventories are critical for identifying biodiversity hotspots and informing conservation and land-use policy.

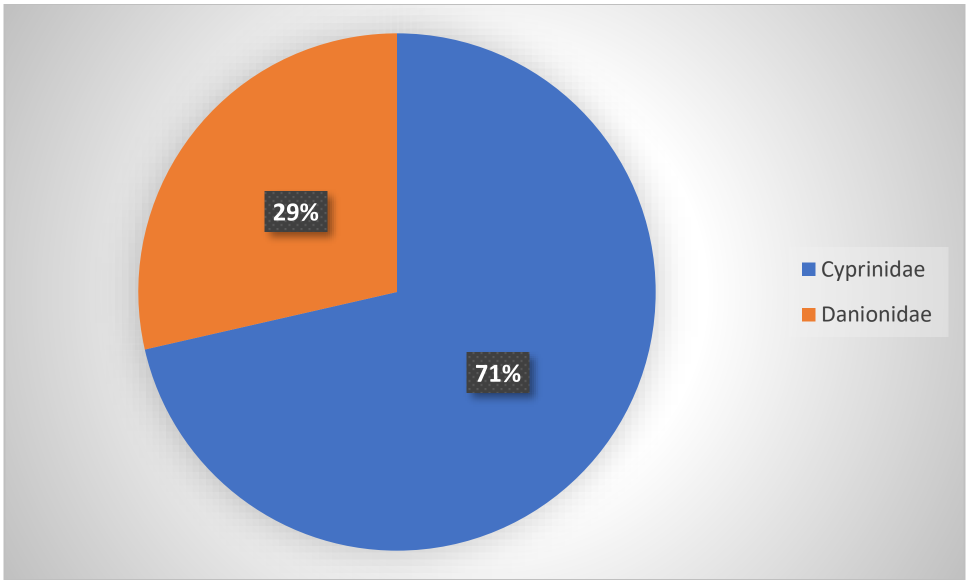

Figure 2: Percentage of fish family from the Belaga oil palm estate

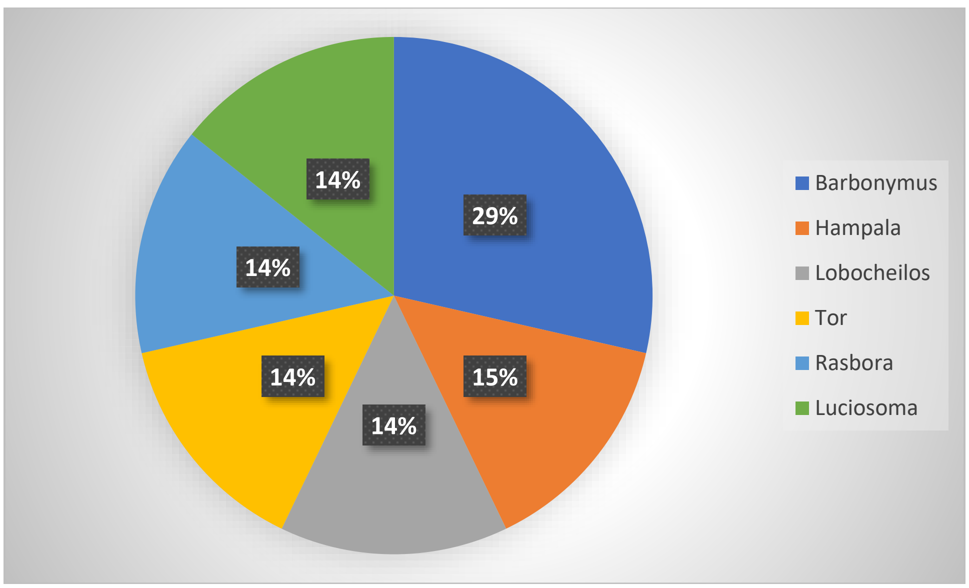

Figure 3: Percentage of fish genus from the Belaga oil palm estate

CONCLUSION

This study provides a new inventory of freshwater fish species in the Glenealy Belaga Estate, Sarawak, documenting seven species across six genera and two families, with Cyprinidae as the dominant family. The presence of native genera such as *Barbonymus* and the absence of invasive species indicate a relatively intact aquatic ecosystem. Although most identified species are currently listed as Least Concern on the IUCN Red List, the detection of *Tor douronensis* which remains Not Evaluated suggests the need for ongoing monitoring and potential conservation attention. As one of the first faunal surveys conducted in this estate, the findings establish a baseline for future biodiversity assessments, contributing valuable data to regional conservation efforts and plantation landscape management planning.

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APPENDICES

Plate 1: *Hampala macrolepidota*

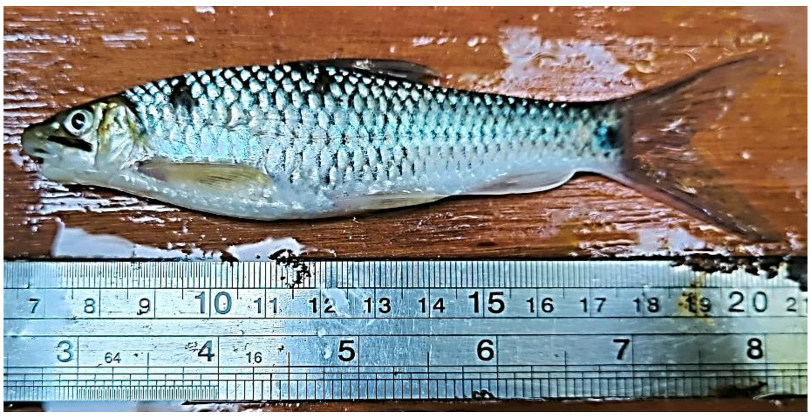

Plate 2: *Lobocheilos kajanensis*

Plate 3: *Barbonymus collingwoodii*


Plate 4: *Barbonymus schwanenfeldii*


Plate 5: *Tor douronensis*

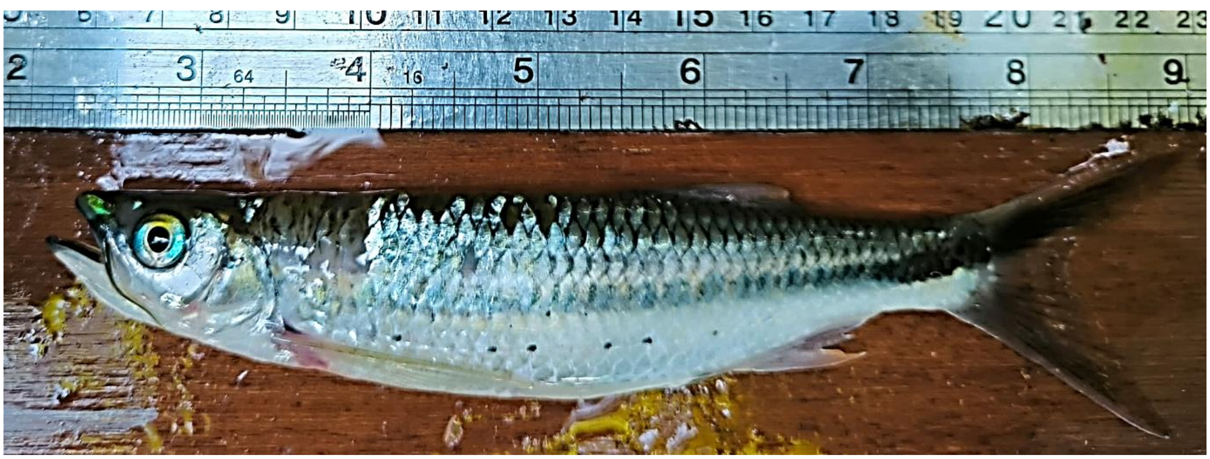
Plate 6: *Luciosoma setigerum*

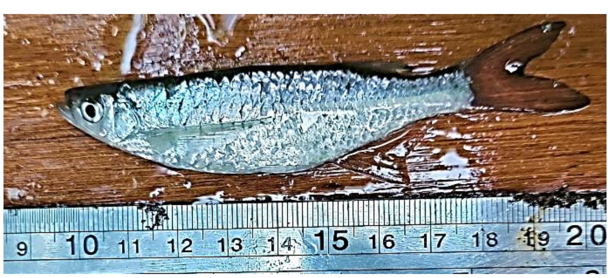
Plate 7: *Rasbora hosii*

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The collective efforts and collaboration demonstrated by all parties have significantly advanced the same goal of promoting responsible stewardship of riverine ecosystems within the Belaga oil palm estates. The authors look forward to continued partnership in future conservation initiatives with Glenealy Plantations Sdn Bhd.

-UPMKB team-