LINKING ODONATA DIVERSITY WITH WATER QUALITY: EFFECTS OF FOREST DISTURBANCE IN JOHOR TROPICAL STREAMS, PENINSULAR MALAYSIA

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Abstract. The current Malaysian Water Quality Index (WQI) lacks biological indicators such as Odonata. This study assesses adult and larval Odonata diversity in undisturbed (PD: Sungai Padang, LE: Sungai Lebak) and disturbed forests (BT: Sungai Bantang, PU: Gunung Pulai) in Johor, and examines their relationship with water quality. A total of 659 adult individuals (40 species, 11 families) and 178 larval individuals (10 families) were recorded. PU exhibited the highest adult diversity (H' = 2.540), followed by LE (H' = 2.421), BT (H' = 2.344), and PD (H' = 2.215). Disturbed forests showed lower Zygoptera-Anisoptera Species Richness Ratios (BT = 1.00, PU = 0.29) compared to undisturbed forests (PD = 2.00, LE = 1.43). Significant differences were found in adult species richness, larval family richness, and abundance ($p < 0.05$). Interestingly, the Malaysian WQI values were higher in disturbed forests (BT = 95.90, PU = 94.64; Class I) compared to undisturbed ones (PD = 90.75, LE = 84.16; Class II). Key parameters influencing Odonata communities included temperature, total suspended solids (TSS), ammoniacal nitrogen (AN), ammonia, ammonium, and biochemical oxygen demand (BOD) ($p < 0.05$). Adult communities were significantly correlated with temperature, TSS, and nitrogen compounds, while larval communities with BOD ($p < 0.05$). This study highlights the characteristics of Odonata and river water quality at different forest types and their relationship for better management practices.
Keywords: *biodiversity, bioindicator, dragonfly, physicochemical, relationship*

Introduction

The Malaysian Water Quality Index (WQI) was introduced in 1974 by the Department of Environment (DOE), and has undergone extensive development and study involving 120 physicochemical parameters to set up the standards (Goh and Goh, 1985) until the current Malaysian WQI emerged (DOE, 2024). The Malaysian WQI utilize a total of six main physicochemical parameters, namely dissolved oxygen (DO), pH, biochemical oxygen demand (BOD), chemical oxygen demand (COD), ammoniacal nitrogen (AN), and total suspended solids (TSS). Each parameters, are converted into subindices before substituted into the formula and multiplied with their respective weightage to get a single value of water quality index. The index can be classed into five different classes (I, II, III, IV, and V), where Class I is the best and Class V is the worst and specifically determine their beneficial usage according to the National Water Quality Standards (NWQS) (DOE, 2024).

Comparing the Malaysian WQI with other international water quality, the Malaysian WQI is similar to the Integrated Water Quality Index (IWQI) since both have fixed parameters and assigned weightages, allowing them to be more comparable between

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different areas and studies. In contrast, other indices such as the Canadian Council of Ministers of Environment Water Quality Index (CCME WQI) and National Sanitation Foundation Water Quality Index (NSF WQI), where the parameters are not predetermined and are selected based on different factors such as land use and water usage, provide more flexibility and sensitivity towards newly emerging pollutants (Liang et al., 2023). Some authors recommended to include other components, such as fecal coliform, heavy metals, phosphates (Pak et al., 2021), and biological factors (Liang et al., 2023).

The biological factor could include the macroinvertebrates, such as Odonata, which could act as a bioindicator for assessing the health of the water quality, as they showed a significant relationship with the water quality parameters (Siregar, 2006; Ab Hamid et al., 2016; Mamat, 2018;). These macroinvertebrates could be used as a bioindicator as they are amphibiotic, where their life cycle covers both aquatic and terrestrial habitats (Remsburg and Turner, 2009).

The Odonata is an insect order that consists of two main Suborders, which are Zygoptera (Damselfly) and Anisoptera (Dragonfly), that could act as a bioindicator for water quality due to their specific requirement of the habitats (Ab Hamid et al., 2016). Unfortunately, the studies on the relationship between Odonata diversity and water quality parameters remain limited (Ishak et al., 2021) until now. Furthermore, the main focus of the water quality studies in Malaysia was directed to the industrial, agricultural, and animal waste (Abdullah, 1995; Al-Shami et al., 2011; Akhtar, 2014; Poon et al., 2016; Baharudin et al., 2021) and less attention is given towards the other sector, such as ecotourism, and the water quality characteristics between different forest types. Hence, understanding the dynamics of Odonata diversity and water quality at different forest types could provide important information in developing better management plans, especially for the eco-parks, for a more sustainable ecotourism.

Thus, the objective of this study is to compare Odonata diversity and water quality between ecotourism-impacted (disturbed) forests and protected (undisturbed) forests. Next, to understand the correlation of adult and larval Odonata communities with water quality parameters. The findings highlight a clear relationship between habitat disturbance, aquatic ecosystem health, and insect biodiversity, emphasizing the ecological impact of human activities such as ecotourism.

Methodology

Study sites

Four localities were selected, with two sites representing disturbed forests (Sungai Bantang Forest Eco-Park (BT) within the Labis Forest Reserve and Gunung Pulai Forest Eco-Park (PU) within the Gunung Pulai Forest Reserve) and two sites representing undisturbed forests (Sungai Padang (PD) and Sungai Lebak (LE) within the Gunung Panti Forest Reserve) in Johor (*Figure 1*), with permit numbers PMJS 324/2024, RMJS 805/2024, and PMJS 06/2025. The classification of the disturbed forests and undisturbed forests was according to the Johor State Forestry Department. Each locality was sampled once a month for eight months from June 2024 to February 2025 to cover both dry (four months) and wet seasons (four months). Malaysia experienced tropical climate throughout the year, comprised of two main seasons: dry season (May to September) due to Southeast Monsoon and wet season (November to March) due to Northeast Monsoon (MET Malaysia). The sampling for Odonata and water were done on the same day, and each locality was assigned with three to five sampling points. The specific sampling

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station for each of the localities were provided in *Figure 2* to *Figure 5*. The coordinates and descriptions of each locality have been summarized in *Table 1*.

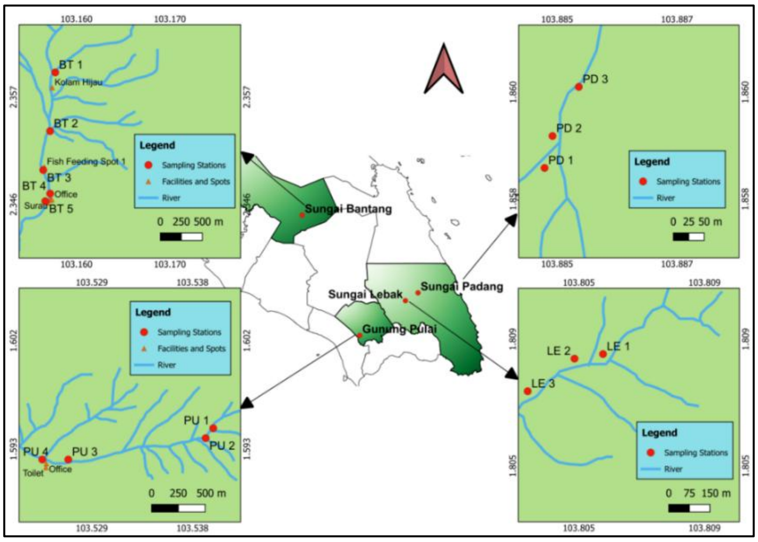

***Figure 1.** Sampling stations for water samples and Odonata larvae. Stations from the upper stream to the lower streams, Sungai Bantang: BT 1, BT 2, BT 3, BT 4, BT 5; Gunung Pulai: PU 1, PU 2, PU 3, PU 4; Sungai Padang: PD 1, PD 2, PD 3; Sungai Lebak: LE 1, LE 2, LE 3*

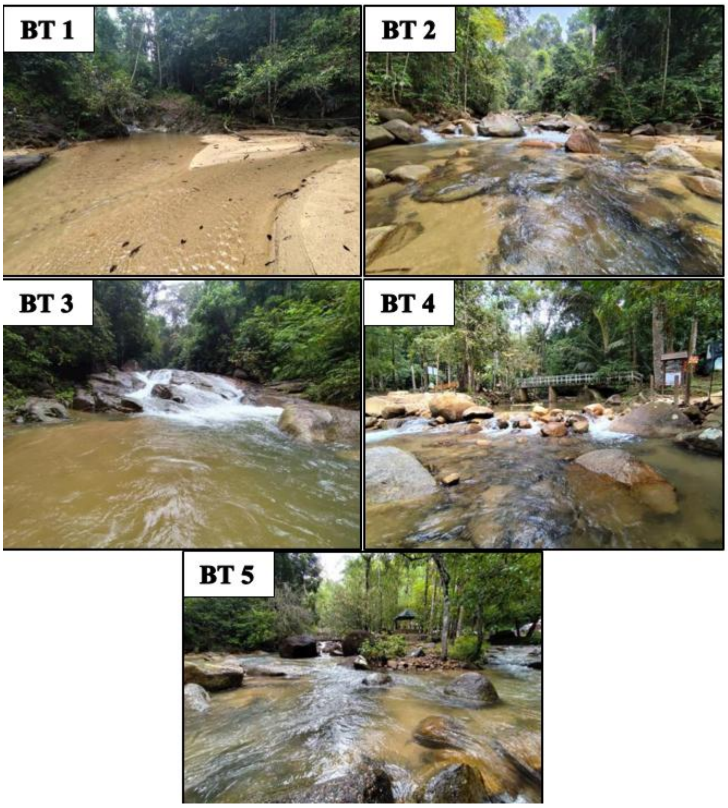

***Figure 2.** Sampling stations at Sungai Bantang from the upper stream to the lower stream: BT 1, BT 2, BT3, BT 4, and BT 5*

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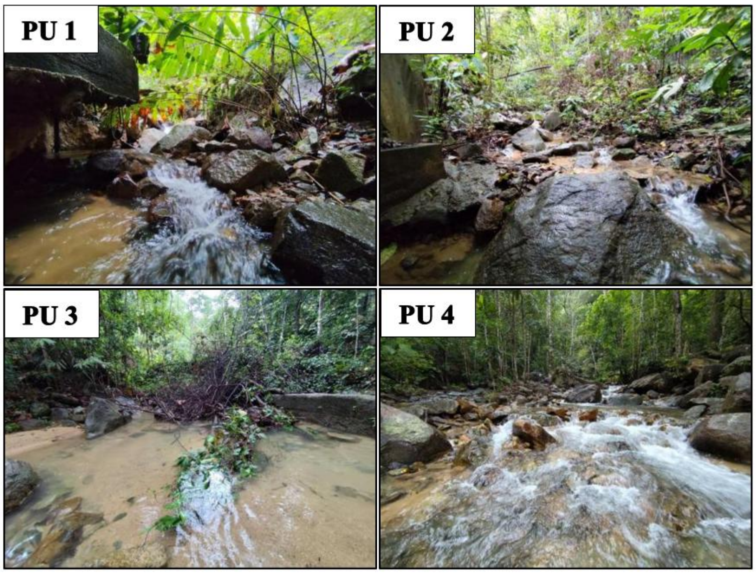

***Figure 3.** Sampling stations at Gunung Pulai from the upper stream to the lower stream: PU 1, PU 2, PU 3 and PU 4*

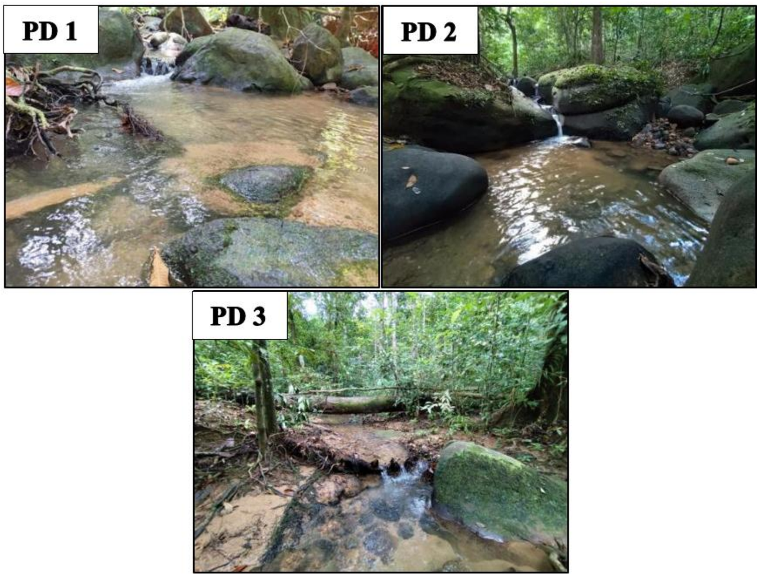

***Figure 4.** Sampling stations at Sungai Padang from the upper stream to the lower stream: PD 1, PD 2, and PD 3*

Odonata sampling

Adult Odonata were sampled using an insect sweep net with a 25 cm diameter (Azmi et al., 2006), and a visual encounter survey (VES) (Prastyanto et al., 2024) through the forest trail along the river within the time frame of 10:00 a.m. to 5:00 p.m.. Then, the samples were pinched at the thorax after being removed from the net and kept in a triangular envelope (Azmi et al., 2006). Spreading and pinning of the samples were conducted before drying in the oven at 45˚C (Orr, 2003), labeled and deposited at the Museum of Zoology, Universiti Malaya.

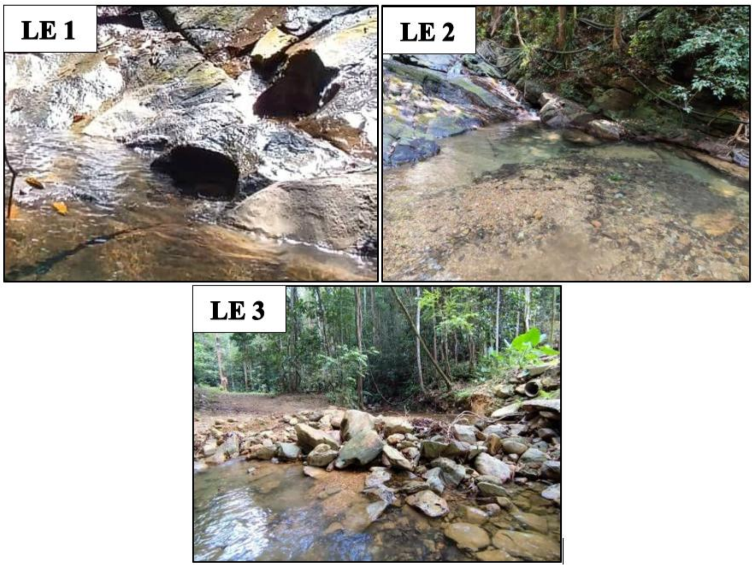

Figure 5. *Sampling stations at Sungai Lebak from the upper stream to the lower stream: LE 1, LE 2 and LE 3*

Table 1. *Coordinates and description for each sampling locality*

No.	Sites and District	Type of Habitats	Management and Status	Recreational Activities
1.	Taman Eko Rimba Sungai Bantang (N 2.3463˚, E 103.1572˚), Bekok	Lowland Dipterocarp Forest	Johor Forestry Department (Eco-Park)	Swimming, camping, trekking, hiking with a permit, picnicking, and research
2.	Taman Eko Rimba Gunung Pulai (N 1.5905˚, E 103.5185˚), Kulai	Hill Dipterocarp Forest	Johor Forestry Department (Eco-Park)	Swimming, cycling, trekking, hiking, with a permit and research
3.	Sungai Padang, Gunung Panti Forest Reserve (N 1.8584˚, E 103.8851˚), Kota Tinggi	Lowland Dipterocarp Forest	Johor Forestry Department (Permanent Forest Reserve)	Hiking and research with a permit
4.	Sungai Lebak, Gunung Panti Forest Reserve (N 1.8089˚, E 103.8058˚), Kota Tinggi	Lowland Dipterocarp Forest	Johor Forestry Department (Permanent Forest Reserve)	Hiking and research with permit

The kick sampling technique was conducted to sample larvae (Siregar, 2006) by placing the long handle-net against the water current and the one square meter area in front of the net was disturbed using legs for two minutes, so that the insects were swept into the net (Ab Hamid et al., 2016). Three collection points were assigned to each sampling station, ensuring equal sampling effort (Zakaria and Mohamed, 2019). Samples were preserved in 95% ethanol according to Farizawati et al. (2014). Samples collected were identified down to the family level according to Orr (2003, 2005) and Yule and Yong (2004).

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Water sampling and water quality assessments

The grab sampling technique was applied to collect the water samples (Matamoros, 2012) during sunny days and standardized sampling time between sampling trips (Suratman et al., 2015). The sampling stations were selected based on the land use, accessibility, and the influent of the river, and were sampled in a consistent sequence for every sampling trip for practicality (Facchi et al., 2007).

Before each sampling trip, water sample containers were cleaned with deionized water (Mohd Zaideen et al., 2017), rinsed at least twice using the river water on-site (Al-Shami et al., 2011; Suratman et al., 2015), and taken at 0.2 m depth from the surface (Mohd Zaideen et al., 2017) using 1000 ml polyethylene bottles (Hashim et al., 2018) and closed under water (Suratman et al., 2015). The samples were stored in an ice box at 4˚C (Suratman et al., 2015; Hashim et al., 2018) and analyzed within 48 hours.

HI98196 HANNA Multiparameter probe was used to measure pH, temperature, and DO in situ. Next, river velocity was measured using the float method by measuring the time taken for a ping pong ball to travel a 1 m distance with triplicate. Then, river width and river depth were measured during every sampling trip. Five-day test was used to measure BOD according to the Standard Method American Public Health Association (APHA) 5210-B (Al-Badaii et al., 2013) through five days of incubation at 20˚C, and calculated through the difference between the initial and final dissolved oxygen (Suratman et al., 2015; Mohd Zaideen et al., 2017; Hashim et al., 2018).

COD was determined using the dichromate method using the HI93754A HANNA COD LR Reagent that utilizes potassium dichromate as an oxidizing agent when the sample being refluxed for 2 hours (Suratman et al., 2015) which was followed by measurement with HI83099 HANNA COD and Multiparameter Photometer. Next, the DR890 HACH Colorimeter was used to measure TSS. Finally, the Nessler method was used to measure AN ammonia and ammonium (Al-Badaii et al., 2013), using HI93700-01 HANNA Ammonia LR Reagent Kit and measured by HI93754 HANNA COD and Multiparameter Photometer.

Malaysian water quality index

The Malaysian WQI utilize a total of six physicochemical parameters: dissolved oxygen (DO), pH, biochemical oxygen demand (BOD), chemical oxygen demand (COD), suspended solids (SS), and ammoniacal nitrogen (AN). The value of these parameters were converted into subindices according to the best fit equation shown in *Figure 6*. Then, the subindices were substituted into the formula from the Malaysian Water Quality Index (WQI) (*Eq. 1*) and used to calculate the water quality index according to DOE (2025). The parameters and index values were classified into different classes (*Table 2*), and categories (*Table 3*). The beneficial uses of each class were according to the National Water Quality Standards (*Table 4*).

$$\begin{aligned} WQI = {} & (0.22 \times SIDO) + (0.19 \times SIBOD) + (0.16 \times SICOD) \\ & + (0.15 \times SIAN) + (0.16 \times SISS) + (0.12 \times SIPH) \end{aligned} \quad \text{(Eq.1)}$$

where,

SIDO : Subindex for Dissolved Oxygen,
SIBOD : Subindex for Biochemical Oxygen Demand,
SICOD : Subindex for Chemical Oxygen Demand,

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SIAN : Subindex for Ammoniacal Nitrogen,
SISS : Subindex for Suspended Solid,s
SIPH : Subindex for pH.

Subindex for DO (in % saturation)
SIDO $= 0$ for $x \leq 8$
SIDO $= 100$ for $x \geq 92$
SIDO $= -0.395 + 0.030x^2 - 0.00020x^3$ for $8 < x < 92$

Subindex for BOD
SIBOD $= 100.4 = 4.23x$ for $x \leq 5$
SIBOD $= 108*\exp(-0.055x) - 0.1x$ for $x > 5$

Subindex for COD
SICOD $= -1.33x + 99.1$ for $x \leq 20$
SICOD $= 103*\exp(-0.0157x) - 0.04x$ for $x > 20$

Subindex for Ammoniacal Nitrogen
SIAN $= 100.5 - 105x$ for $x \leq 0.3$
SIAN $= 94*\exp(-0.573x) - 5*|x - 2|$ for $0.3 < x < 4$
SIAN $= 0$ for $x \geq 4$

Subindex for Suspended Solids
SISS $= 97.5*\exp(-0.00676x) + 0.05x$ for $x \leq 100$
SISS $= 71*\exp(-0.0016x) - 0.015x$ for $100 < x < 1000$
SISS $= 0$ for $x \geq 1000$

Subindex for pH
SIpH $= 17.2 - 17.2x + 5.02x^2$ for $x < 5.5$
SIpH $= -242 + 95.5x - 6.67x^2$ for $5.5 \leq x < 7$
SIpH $= -181 + 82.4x - 6.05x^2$ for $7 \leq x < 8.75$
SIpH $= 536 - 77.0x + 2.76x^2$ for $x \geq 8.75$

Figure 6. *Best fit equation for subindices estimation of each water quality parameters (DOE, 2025)*

Table 2. *River class according to six water quality parameters in Malaysia WQI (DOE, 2025)*

Parameter	Unit	Class				
		I	II	III	IV	V
Ammoniacal Nitrogen	mg/l	<0.1	0.1-0.3	0.3-0.9	0.9-2.7	>2.7
Biochemical Oxygen Demand	mg/l	<1	1-3	3-6	6-12	>12
Chemical Oxygen Demand	mg/l	<10	10-25	25-50	50-100	>100
Dissolved Oxygen	mg/l	>7	5-7	3-5	1-3	<1
pH	-	>7.0	6.0-7.0	5.0-6.0	<5.0	>5.0
Total Suspended Solid	mg/l	<25	25-50	50-150	150-300	>300
Water Quality Index (WQI)		>92.7	76.5-92.7	51.9-76.5	31.0-51.9	<31.0

Table 3. *Classification of water quality according to Malaysia WQI (DOE, 2025)*

Sub Index and Water Quality Index	Index Range		
	Clean	Slightly Polluted	Polluted
Biochemical Oxygen Demand (BOD)	91-100	80-90	0-79
Ammoniacal Nitrogen (NH_3-N)	92-100	71-91	0-70
Suspended Solids (SS)	76-100	70-75	0-69
Water Quality Index (WQI)	81-100	60-80	0-59

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Table 4. *Beneficial use of river water source according to the classes in Malaysia NWQS (DOE, 2025)*

Class	Uses
Class I	Conservation of natural environment. Water Supply I – Practically no treatment necessary. Fishery I – Very sensitive aquatic species.
Class IIA	Water Supply II - Conventional treatment required. Fishery II – Sensitive aquatic species.
Class IIB	Recreational use with body contact.
Class III	Water Supply III – Extensive treatment required. Fishery III – Common of economic value and tolerant species; livestock drinking.
Class IV	Irrigation.
Class V	None of the above.

Statistical analyses

Diversity indices such as Shannon-Weiner Diversity Index (H'), Simpson's Dominance Index (D), Pielou's Evenness Index (J) and Margalef's Richness Index (R) were used to explain Odonata species composition. Graphical methods such as histogram, Q-Q plot, and boxplot, and numerical methods such as normality tests (Kolmogorov-Smirnov and Shapiro-Wilk Test), Z values for skewness and kurtosis, and comparison of the standard deviation value with respect to the mean were used to determine the normality of the data (Kim, 2013; Mishra et al., 2019). The methods indicated that the data distribution was non-normal, thus requiring non-parametric statistical tests. A Kruskal-Wallis Test was conducted on the Odonata diversity and water quality data to determine if there are any significant differences between the four localities. This was followed by Dunn's Post-hoc Test with Bonferroni correction.

Then, to measure the effect of water quality parameters on both adult Odonata (species richness and abundance) and larvae (family richness and abundance), Spearman's Rank Correlation was used. All analyses were conducted in IBM SPSS Statistics Version 29.0.2.0 (20) and R software version 4.5.1.

Results

Overall Odonata composition

The adult Odonata species abundance for each locality, their Common Name, and International Union for Conservation of Nature (IUCN) Status have been summarized in *Appendix 1* while larval family abundance in *Appendix 2*. Adult samples recorded 659 individuals from 40 species and 11 families, while larval samples recorded 178 individuals from 10 families from all localities. Zygoptera represents 75.4% of adult samples and 55.6% of larvae, while Anisoptera represents 24.6% and 44.4% respectively (*Table 5*). Libellulidae was the most abundant adult family (24%) *(Appendix 1)*, while Gomphidae dominated the larval samples (36.5%) *(Appendix 2)*. *Heliocypha biforata* was the most abundant adult species (13.8%).

Odonata diversity between disturbed and undisturbed forests

Adult species richness, abundance, and diversity indices between undisturbed and disturbed forests are summarized in *Table 5*. In both undisturbed forests, Sungai Padang

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(PD) and Sungai Lebak (LE), Zygoptera recorded higher abundance and species richness compared to Anisoptera. In contrast, disturbed forests, specifically Gunung Pulai (PU), recorded higher Anisoptera species richness and abundance, while Sungai Bantang (BT) recorded a higher abundance of Zygoptera, with equal species richness between the two suborders. Thus, the Zygoptera-Anisoptera Species Richness Ratio showed the highest in PD, followed by LE, BT, and PU.

Table 5. *Adult and larval species richness, abundance and diversity indices*

Life Stages	Components	Disturbed Forests		Undisturbed Forests	
		Sungai Bantang	**Gunung Pulai**	**Sungai Padang**	**Sungai Lebak**
Adult	Zygoptera Species Richness	9	4	14	10
	Anisoptera Species Richness	9	14	7	7
	Total Species Richness	18	18	21	17
	Zygoptera Abundance	109	55	215	118
	Anisoptera Abundance	23	93	10	35
	Total Abundance	132	148	225	154
	Simpson's Dominance Index (D)	0.134	0.094	0.155	0.112
	Shannon-Weiner Diversity Index (H')	2.344	2.540	2.215	2.421
	Pielou's Evenness Index (J)	0.811	0.879	0.728	0.854
	Margalef's Richness Index (R)	3.482	3.402	3.693	3.177
	Zygoptera-Anisoptera Species Richness Ratio	1	0.290	2	1.430
Larvae	Zygoptera Family Richness	3	2	4	4
	Anisoptera Family Richness	4	2	2	2
	Total Species Richness	7	4	6	6
	Zygoptera Abundance	14	3	51	31
	Anisoptera Abundance	34	5	31	9
	Total Abundance	48	8	82	40

Both Shannon-Weiner Diversity Index (H’) and Pielou’s Evenness Index (J) showed the same trend, where PU recorded the highest value (H’=2.540, J=0.879) which followed by LE (H’=2.421, J=0.854), BT (H’=2.344, J=0.811), and PD (H’=2.215, J=0.728) (*Table 5*). Conversely, Simpson’s Dominance Index (D) was highest in PD (D=0.155) which followed by BT (D=0.134), LE (D=0.112), and PU (D=0.094). Finally, Margalef’s Richness Index (R) showed almost a similar trend with D, highest in PD (R=3.693) which followed by BT (R=3.482), PU (R=3.402), and LE (R=3.177).

Larval community showed high Zygoptera family richness and abundance in undisturbed forests (PD and LE), while disturbed forests (BT and PU) showed the opposite, except PU displayed equal family richness (*Table 5*). BT recorded the highest family richness, while PD recorded the highest abundance.

Statistical analysis using the Kruskal-Wallis test showed significant differences in adult species richness between localities $H (3, n = 96) = 9.82$, $p < 0.05$, followed by Dunn’s test with Bonferroni correction, which revealed PU was significantly lower than PD ($p < 0.05$) (*Table 6*). For larvae, significant differences were observed in family richness, $H (3, n = 96) = 20.03$, $p < 0.05$, and abundance, $H (3, n = 96) = 22.52$, $p < 0.05$ (*Table 6*). Dunn’s test with Bonferroni correction revealed that family richness, PU was significantly lower than PD ($p < 0.05$) while for abundance, PU was significantly lower than PD ($p < 0.05$) and LE ($p < 0.05$).

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Table 6. *Results of Kruskal-Wallis test and Dunn's Post-hoc test with Bonferroni correction on adult Odonata (species richness and abundance), and Odonata larvae (family richness and abundance) between disturbed and undisturbed forests (BT = Sungai Bantang, PU = Gunung Pulai) and protected forests (PD = Sungai Padang, LE = Sungai Lebak)*

Life Stages	Components	Forests	N	Mean Rank	*p*-value	Significant Pairs (Dunn's Test)
Adult	Species Richness	BT	96	44.02	0.02*	PU-PD
		PU		38.38		
		PD		62.27		
		LE		49.33		
	Abundance	BT	96	43.60	0.102	NS
		PU		42.60		
		PD		60.33		
		LE		47.46		
Larvae	Family Richness	BT	96	49.27	1.67×10^{-4}*	PU-PD
		PU		30.96		
		PD		64.92		
		LE		48.85		
	Abundance	BT	96	49.06	5.07×10^{-5}*	PU-LE PU-PD
		PU		29.17		
		PD		65.50		
		LE		50.27		

*$p < 0.05$, NS = Not Significant

Water quality between disturbed and undisturbed forests

The water quality parameters were categorized into physical (temperature, total suspended solids (TSS), turbidity, river width, river depth, and river velocity) and chemical parameters (dissolved oxygen (DO), dissolved oxygen saturation, pH, ammoniacal nitrogen (AN), ammonia, ammonium, chemical oxygen demand (COD), and biochemical oxygen demand (BOD)). The boxplot and classes across the four localities for physical parameters are summarized in *Figure 7,* while chemical parameters are in *Figure 8*.

The temperature recorded the highest mean in Sungai Padang (PD) (25.31 °C), followed by Sungai Lebak (LE) (25.16 °C), Gunung Pulai (PU) (24.19 °C), and Sungai Bantang (BT) (24.01 °C) (*Figure 7a*). Kruskal-Wallis Test revealed a statistically significant difference in temperature, H (3, n = 96) = 33.91, $p < 0.05$ (*Table 7*). Pairwise comparisons using Dunn's test with Bonferroni correction indicated that the temperature in BT was significantly lower than LE ($p < 0.05$) and PD ($p < 0.05$), while PU was significantly lower than LE ($p < 0.05$) and PD ($p < 0.05$).

TSS recorded the highest mean in PD (16.38 mg/L), followed by PU (4.41 mg/L), BT (3.73 mg/L), and LE (1.17 mg/L) (*Figure 7b*), where all localities were within Class I according to National Water Quality Standards (NWQS). Kruskal-Wallis Test revealed a statistically significant difference in TSS, H (3, n = 96) = 29.85, $p < 0.05$ (*Table 7*). Pairwise comparisons using Dunn's test with Bonferroni correction indicated that the TSS in LE was significantly lower than BT ($p < 0.05$) and PD ($p < 0.05$), while PU was significantly lower than PD ($p < 0.05$).

Turbidity recorded the highest mean in PD (23.01 FAU), followed by PU (11.35 FAU), BT (10.64 FAU), and LE (6.14 FAU) (*Figure 7c*). Kruskal-Wallis Test revealed a statistically significant difference in turbidity, H (3, n = 96) = 29.87, $p < 0.05$ (*Table 7*).

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Pairwise comparisons using Dunn's test with Bonferroni correction indicated that the turbidity in LE was significantly lower than BT ($p < 0.05$), PU ($p < 0.05$), and PD ($p < 0.05$).

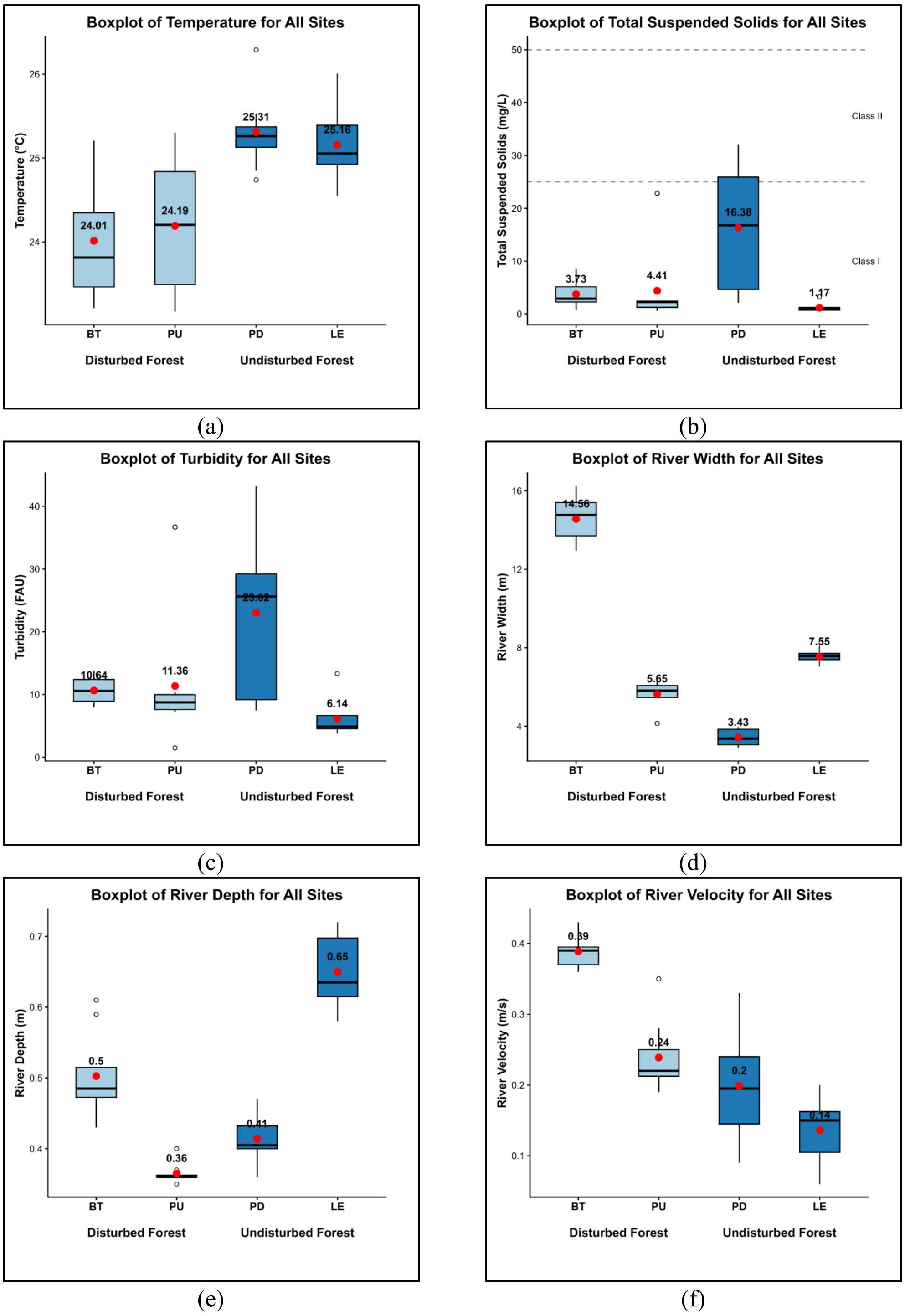

Figure 7. *Boxplot of physical water quality parameters with the mean value shown (red dot): (a) temperature, (b) total suspended solids, (c) turbidity, (d) river width, (e) river depth, and (f) river velocity. (BT: Sungai Bantang, PU: Gunung Pulai, PD: Sungai Padang, LE: Sungai Lebak)*

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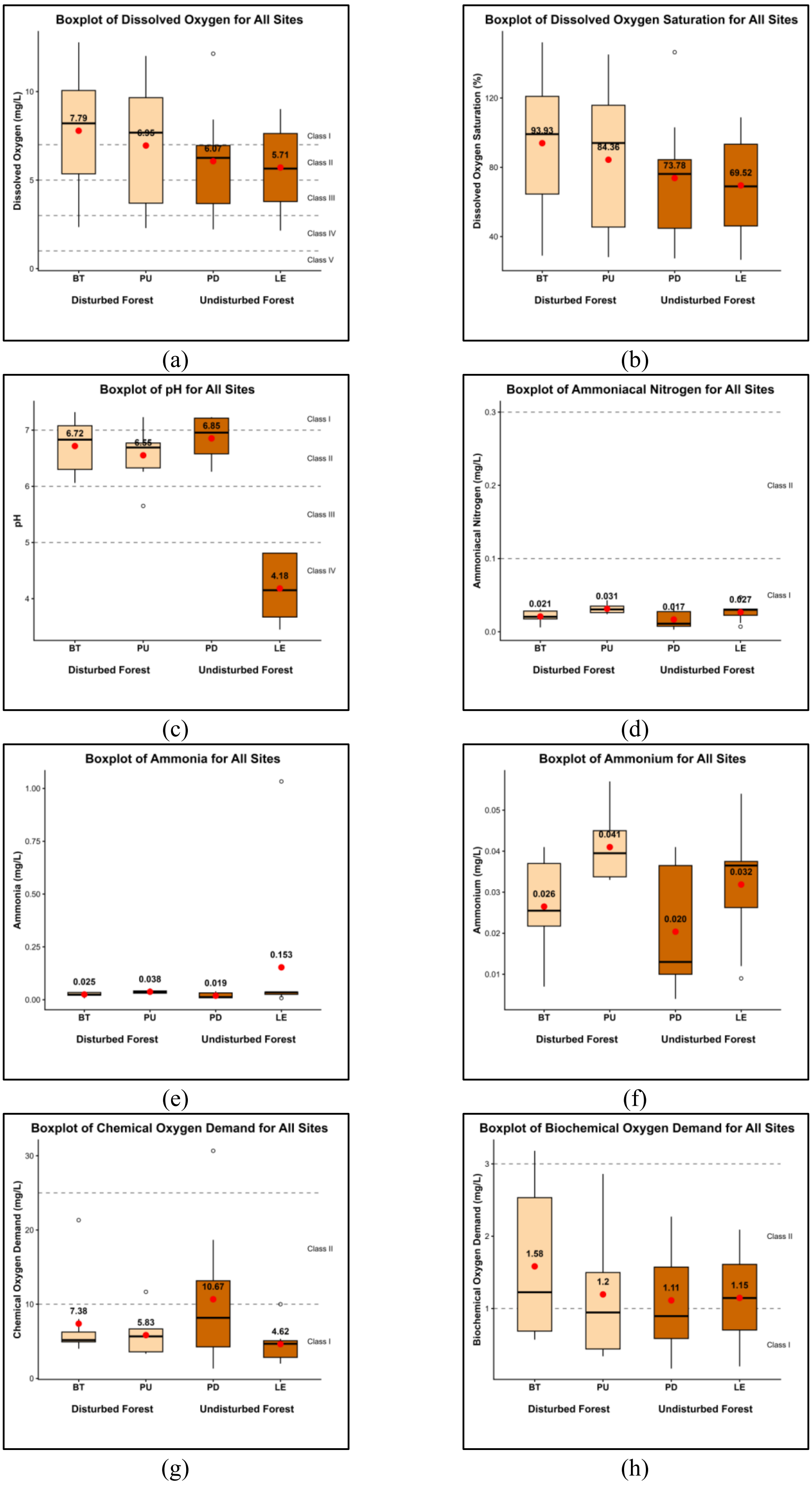

Figure 8. *Boxplot of chemical water quality parameters with the mean value shown (red dot): (a) dissolved oxygen, (b) dissolved oxygen saturation, (c) pH, (d) ammoniacal nitrogen, (e) ammonia, (f) ammonium, (g) chemical oxygen demand, and (h) biochemical oxygen demand. (BT: Sungai Bantang, PU: Gunung Pulai, PD: Sungai Padang, LE: Sungai Lebak)*

Table 7. *Results of Kruskal-Wallis test and Dunn's Post-hoc test with Bonferroni correction on water quality parameters between disturbed and undisturbed forests (BT = Sungai Bantang, PU = Gunung Pulai) and protected forests (PD = Sungai Padang, LE = Sungai Lebak)*

	Parameters	Forests	N	Mean Rank	Test Statistic	*p*-value	Significant Pairs (Dunn's Test)
Physical Parameters	Temperature (°C)	BT PU PD LE	96	27.29 37.02 67.54 61.65	33.91	2.07×10^{-7}*	BT - LE BT - PD PU - LE PU - PD
	Total Suspended Solids (mg/L)	BT PU PD LE	96	54.13 42.98 69.63 27.27	29.85	1.49×10^{-6}*	LE - BT LE - PD PU - PD
	Turbidity (FAU)	BT PU PD LE	96	60.38 45.63 63.69 24.31	29.87	1.47×10^{-7}*	LE - BT LE - PU LE - PD
	River Width (m)	BT PU PD LE	96	82.83 42.90 18.23 50.04	65.84	3.31×10^{-14}*	PD - PU PD - LE PD - BT BT - PU BT - LE
	River Depth (m)	BT PU PD LE	96	57.54 24.67 34.42 77.38	52.13	2.81×10^{-11}*	PU - BT PU - LE PD - BT PD - LE
	River Velocity (m/s)	BT PU PD LE	96	28.50 17.63 13.00 6.88	44.90	9.74×10^{-10}*	LE - PU LE - BT PD - BT
Chemical Parameters	Dissolved Oxygen (mg/L)	BT PU PD LE	96	59.48 51.29 42.00 41.23	6.91	0.075	NS
	Dissolved Oxygen Saturation (%)	BT PU PD LE	96	59.38 51.54 41.96 41.13	6.95	0.074	NS
	pH	BT PU PD LE	96	61.44 53.50 66.56 12.50	56.13	3.95×10^{-12}*	LE - PU LE - BT LE - PD
	Ammoniacal Nitrogen (mg/L)	BT PU PD LE	96	43.88 63.04 33.71 53.38	14.76	0.002*	PD - PU
	Ammonia (mg/L)	BT PU PD	96	44.85 63.54 33.94	14.32	0.003*	PD - PU

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	Parameters	Forests	N	Mean Rank	Test Statistic	*p*-value	Significant Pairs (Dunn's Test)
		LE		51.67			
	Ammonium (mg/L)	BT	96	44.23	14.78	0.002*	PD - PU
		PU		64.31			
		PD		34.31			
		LE		51.15			
	Chemical Oxygen Demand (mg/L)	BT	96	51.65	4.10	0.251	NS
		PU		49.60			
		PD		53.83			
		LE		38.92			
	Biochemical Oxygen Demand (mg/L)	BT	96	58.48	4.29	0.232	NS
		PU		43.79			
		PD		44.63			
		LE		47.10			

*p < 0.05, NS = Not Significant

River width recorded highest mean in BT (14.56 m), followed by LE (7.55 m), PU (5.65 m), and PD (3.43 m) (*Figure 7d*). Kruskal-Wallis Test revealed a statistically significant difference in river width, H (3, n = 96) = 65.84, $p < 0.05$ (*Table 7*). Pairwise comparisons using Dunn's test with Bonferroni correction indicated that the river width in PD was significantly smaller than PU ($p < 0.05$), LE ($p < 0.05$), and BT ($p < 0.05$) while BT was significantly wider than PU ($p < 0.05$) and LE ($p < 0.05$).

River depth recorded the highest mean in LE (0.65 m), followed by BT (0.5 m), PD (0.41 m), and PU (0.36 m) (*Figure 7e*). Kruskal-Wallis Test revealed a statistically significant difference in river depth, H (3, n = 96) = 52.13, $p < 0.05$ (*Table 7*). Pairwise comparisons using Dunn's test with Bonferroni correction indicated that the river depth in PU was significantly shallower than BT ($p < 0.05$) and LE ($p < 0.05$), while PD was significantly shallower than BT ($p < 0.05$) and LE ($p < 0.05$).

River velocity recorded the highest mean in BT (0.39 m/s), followed by PU (0.24 m/s), PD (0.20 m/s), and LE (0.14 m/s) (*Figure 7f*). Kruskal-Wallis Test revealed a statistically significant difference in river velocity, H (3, n = 96) = 44.90, $p < 0.05$ (*Table 7*). Pairwise comparisons using Dunn's test with Bonferroni correction indicated that the river velocity in LE was significantly lower than PU ($p < 0.05$) and BT ($p < 0.05$), while PD was significantly lower than BT ($p < 0.05$).

DO recorded the highest means in BT (7.79 mg/L), followed by PU (6.95 mg/L), PD (6.07 mg/L), and LE (5.71 mg/L) (*Figure 8a*), where BT and PU were within Class I, while PD and LE were within Class II according to NWQS. Kruskal-Wallis Test revealed statistically no significant difference in DO, H (3, n = 96) = 6.91, $p > 0.05$ (*Table 7)*.

DO saturation recorded the highest mean in BT (93.93%), followed by PU (84.35%), PD (73.78%), and LE (69.52%) (*Figure 8b*). Kruskal-Wallis Test revealed statistically no significant difference in DO saturation, H (3, n = 96) = 6.95, $p > 0.05$ (*Table 7*).

pH recorded the highest mean in PD (6.85), followed by BT (6.72), PU (6.55), and LE (4.18) (*Figure 8c*), where all localities were within Class II except for LE in Class IV according to NWQS. Kruskal-Wallis Test discovered a statistically significant difference in river velocity, H (3, n = 96) = 56.13, $p < 0.05$ (*Table 7*). Pairwise comparisons using Dunn's test with Bonferroni correction indicated that the pH in LE was significantly lower than PU ($p < 0.05$), BT ($p < 0.05$), and PD ($p < 0.05$).

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AN recorded the highest mean in PU (0.031 mg/L), followed by LE (0.027 mg/L), BT (0.021 mg/L), and PD (0.017 mg/L) (*Figure 8d*), where all localities were within Class I according to NWQS. Kruskal-Wallis Test revealed a statistically significant difference in AN, H (3, n = 96) = 14.76, $p < 0.05$ (*Table 7*). Pairwise comparisons using Dunn's test with Bonferroni correction indicated that the AN in PD was significantly lower than PU ($p < 0.05$).

Following the same trend, ammonia recorded the highest mean in PU (0.038 mg/L), followed by LE (0.031 mg/L), BT (0.025 mg/L), and PD (0.019 mg/L) (*Figure 8e*). Kruskal-Wallis Test revealed a statistically significant difference in ammonia, H (3, n = 96) = 14.32, $p < 0.05$ (*Table 7*). Pairwise comparisons using Dunn's test with Bonferroni correction indicated that the ammonia in PD was significantly lower than PU ($p < 0.05$).

Similarly, ammonium recorded the highest mean in PU (0.041 mg/L), followed by LE (0.032 mg/L), BT (0.026 mg/L), and PD (0.020 mg/L) (*Figure 8f*). Kruskal-Wallis Test revealed a statistically significant difference in ammonium, H (3, n = 96) = 14.78, $p < 0.05$ (*Table 7*). Pairwise comparisons using Dunn's test with Bonferroni correction indicated that the ammonium in PD was significantly lower than PU ($p < 0.05$).

COD recorded the highest means in PD (10.67 mg/L), followed by BT (7.38 mg/L), PU (5.83 mg/L), and LE (4.63 mg/L) (*Figure 8g*), where all localities were within Class I except for PD in Class II according to NWQS. Kruskal-Wallis Test revealed statistically no significant difference in COD across the four forests, H (3, n = 96) = 4.10, $p > 0.05$ (*Table 7*).

BOD recorded the highest mean in BT (1.58 mg/L), followed by PU (1.20 mg/L), LE (1.15 mg/L), and PD (1.11 mg/L) (*Figure 8h*), where all localities were within Class II according to NWQS. Kruskal-Wallis Test revealed statistically no significant difference in BOD, H (3, n = 96) = 4.29, $p > 0.05$ (*Table 7*).

The Malaysian Water Quality Index (WQI) and the river classes for each locality have been summarized in *Figure 9*. Both disturbed forests, BT (95.90) and PU (94.64) showed higher Malaysian WQI compared to undisturbed forests, PD (90.75) and LE (84.16). Then, both disturbed forests were categorized within Class I while both undisturbed forests were categorized within Class II according to the National Water Quality Standards (NWQS).

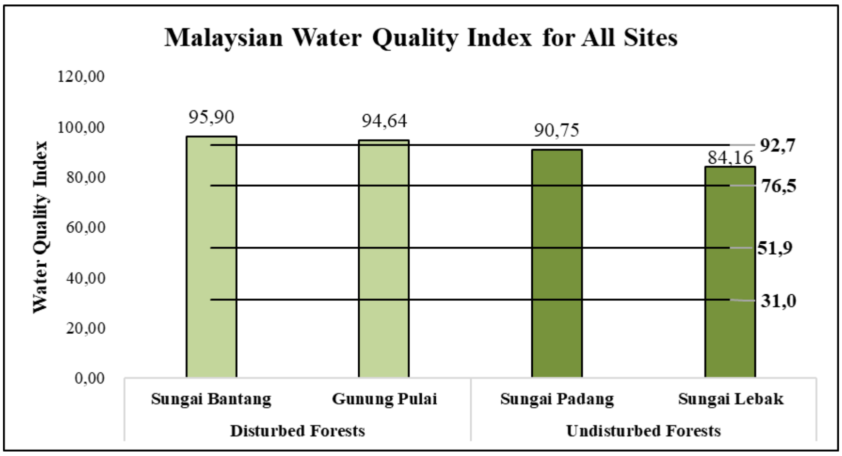

Figure 9. *Malaysia WQI and class between disturbed and undisturbed forests*

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Relationship between Odonata diversity and water quality

The adult Odonata species richness was paired with water quality predictors independently. The Spearman's Rank Correlation revealed that adult species richness has significant positive correlation with temperature (r_s = 0.219, n = 96, p < 0.05) and TSS (r_s = 0.257, n = 96, p < 0.05) while negative correlation with AN (r_s = -0.307, n = 96, p < 0.05), ammonia (r_s = -0.317, n = 96, p < 0.05), and ammonium (r_s = -0.303, n = 96, p < 0.05) (*Figure 10*). Similarly, adult abundance has significant positive correlation with temperature (r_s = 0.204, n = 96, p < 0.05) and TSS (r_s = 0.276, n = 96, p < 0.05) while negative correlation with AN (r_s = -0.326, n = 96, p < 0.05), ammonia (r_s = -0.332, n = 96, p < 0.05), and ammonium (r_s = -0.316, n = 96, p < 0.05) (*Figure 10*).

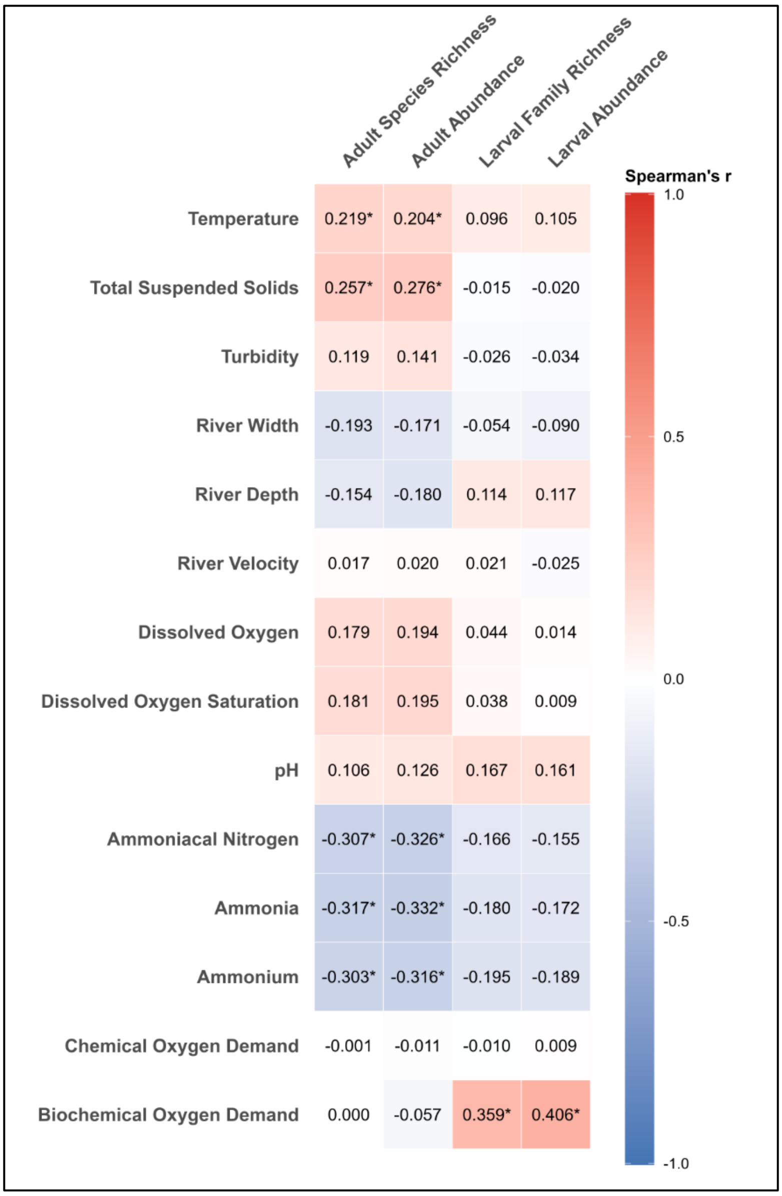

Figure 10. *Spearman Rank Correlation between adult Odonata species richness and abundance, larval Odonata family richness and abundance with water quality parameters (*p < 0.05)*

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The rest parameters were not significant. Next, larval family richness and abundance were positively correlated with BOD (r_s = 0.359, n = 96, $p < 0.05$) and (r_s =0.406, n = 96, $p < 0.05$) respectively while the rest parameters were not significant (*Figure 10*). The Spearman's Rank Correlation scatter plots of adult Odonata community with the significant water quality parameters are shown in *Figure 11a-11e* and *Figure 12a-12e* while for larval community in *Figure 13a-13b*.

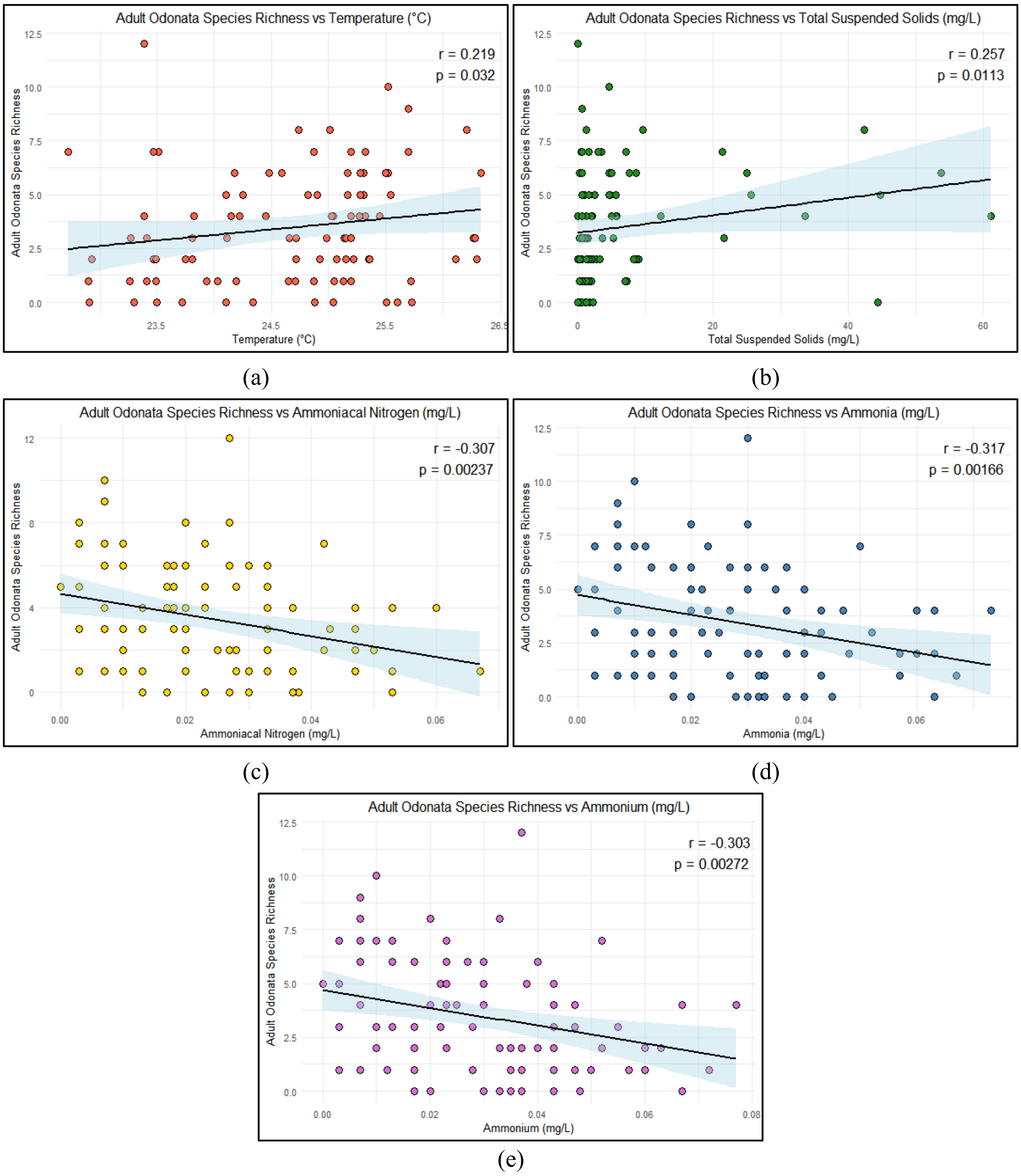

Figure 11. *Scatterplot of Spearman Rank Correlation between adult Odonata species richness and significant water quality parameters with 95% confidence interval (light blue) and correlation line (black): a) temperature, b) total suspended solids, c) ammoniacal nitrogen, d) ammonia, and e) ammonium*

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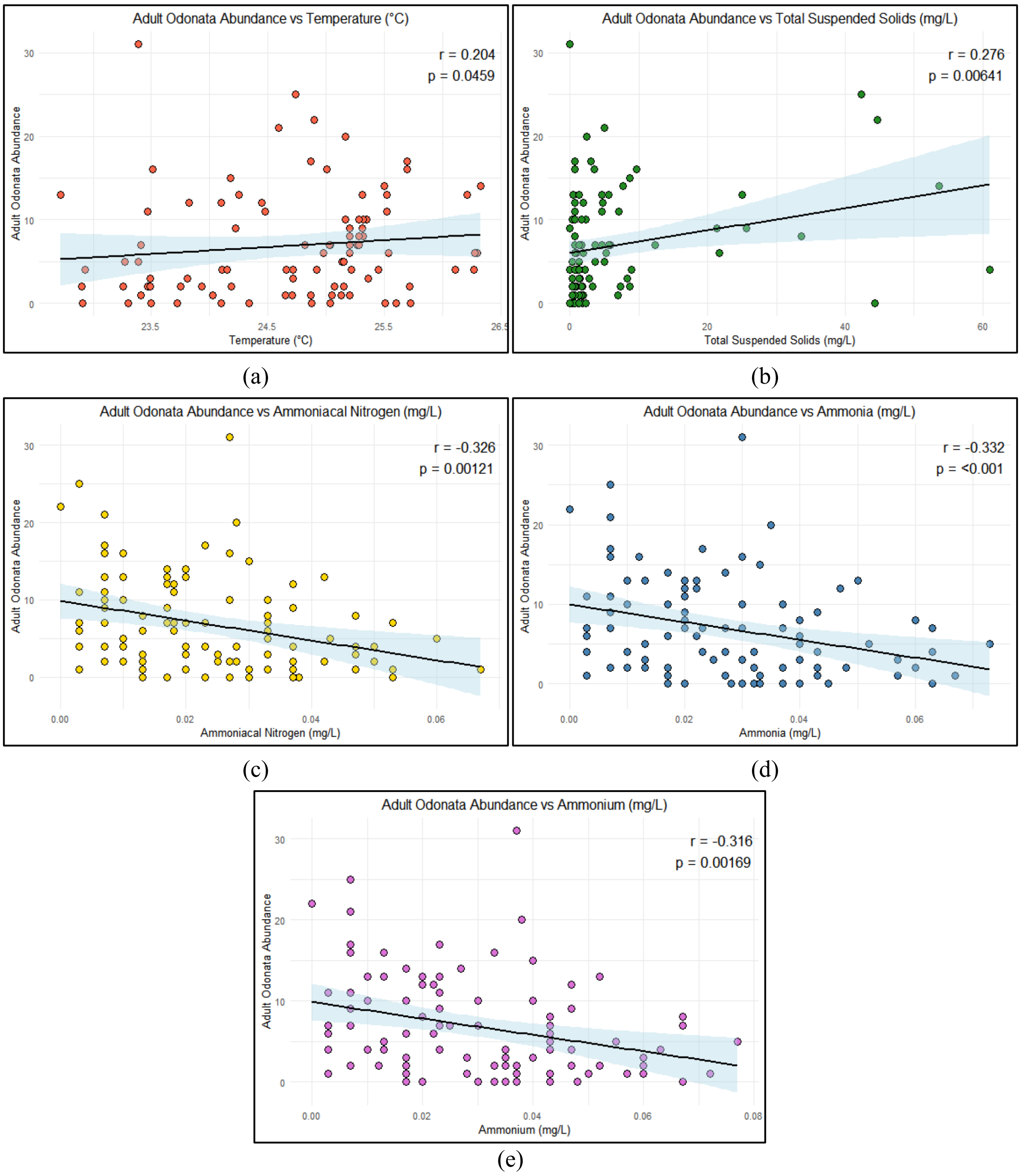
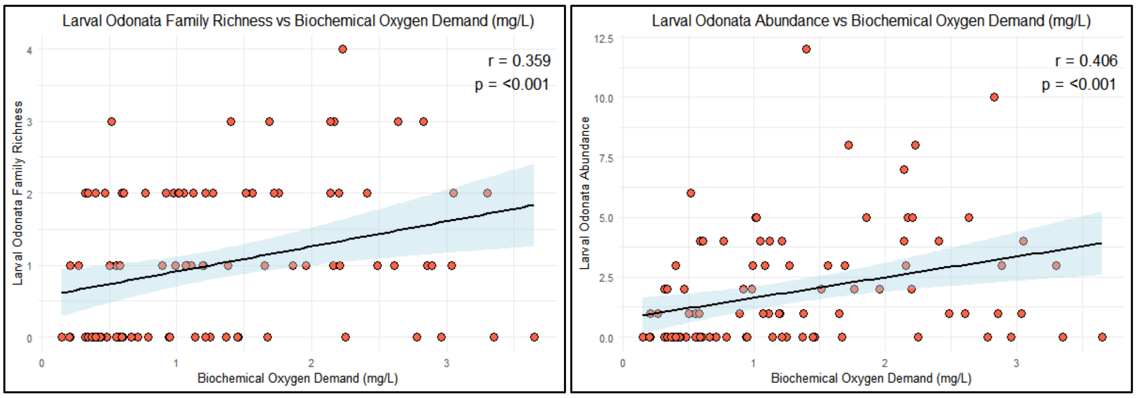


Figure 12. *Scatterplot of Spearman Rank Correlation between adult Odonata abundance and significant water quality parameters with 95% confidence interval (light blue) and correlation line (black): a) temperature, b) total suspended solids, c) ammoniacal nitrogen, d) ammonia, and e) ammonium*



(a) (b)

***Figure 13.** Scatterplot of Spearman Rank Correlation between a) larval Odonata family richness and biochemical oxygen demand and b) larval Odonata abundance and biochemical oxygen demand, with 95% confidence interval (light blue) and correlation line (black)*

Discussions

Overall Odonata composition

Among the adult samples, Zygoptera was more abundant than Anisoptera in most localities, similar to Azmi et al. (2006) except in Gunung Pulai (PU) (*Table 5*). Libellulidae displayed the highest abundance and species richness, consistent with other studies in Peninsular Malaysia (Norma-Rashid et al., 2001; Azmi et al., 2006; Choong, 2009; Farizawati et al., 2014; Aziz et al., 2018; Choong and Alwen, 2018; Muazam et al., 2023). Libellulids have the ability to dominate the open habitat of a water body (Mamat and Mohamed, 2012) such as disturbed forests, such as PU and Sungai Bantang (BT), have open areas which become ideal habitat for them.

Heliocypha biforata was the most abundant species (*Appendix 1*), which aligns with other studies where chlorocyphids become the dominant family within the sample for Zygoptera (Norma-Rashid et al., 2001; Azmi et al., 2006; Mamat, 2018). Chlorocyphids favor flowing-water habitats (Orr, 2005) as all localities selected in this study were fast-flowing streams. Next, *Neurothemis fluctuans* was the only species that was found in all the localities *(Appendix 1)*, as Anisoptera has greater dispersal abilities (Mendes et al., 2015) which align with the previous study (Aziz et al., 2018). Furthermore, this species was known for its cosmopolitan nature that thrives in various habitat types (Prastyanto et al., 2024), high dispersal range, and abundant throughout Peninsular Malaysia (Azmi et al., 2006; Aziz et al., 2018). *Tetracanthagyna plagiata,* which was found in almost all localities except in PU was an iconic species novel to Peninsular Malaysia (Choong and Alwen, 2018), and also one of the largest dragonflies in the world (Orr, 2005).

This study recorded fairly low species richness, where BT (18 species), PU (18 species), Sungai Padang (PD) (21 species), and Sungai Lebak (LE) (17 species) (*Table 5*). Aziz et al. (2018) in a previous study, a total of 32 species in BT and 29 species in PU, before a new updated checklist for BT (Abdul Aziz and Mohamed, 2019), which resulted in a cumulative of 45 species. This study recorded additional new records for the localities, where three new species recorded for BT (*Neurobasis chinensis, Zygonyx ida*, and *T. plagiata*) while six new species were recorded for PU (*H. biforata, Drepanosticta fontinalis, Lyriothemis cleis, Tholymis tillarga, Z. ida*, and *Z. iris*), resulting in a

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cumulative of 48 species and 35 species, respectively. The reduced number of species compared to the previous study could be due to the increase in disturbance over the years.

Then, for Gunung Panti, the first survey within the forest reserve was by Choong (2009) that recorded a total of 52 species from Sungai Pelepah Kiri, PD and Sungai Pak Kinek. This followed by Aziz et al. (2018) with 32 species,which, however focuses at the Gunung Panti Forest Eco Park, which was accessible to the public. Then, Mamat-Noorhidayah et al. (2025) recorded a total of 34 species. Finally, this study added a few new records for Gunung Panti Forest Reserve as overall resulting in a total of 82 species. The new record includes two species from PD (*Anax guttatus* and *Coeliccia octogesima*), one species from LE (*Sundacypha petiolata*), and two species that were present in both localities (*C. albicauda* and *T. plagiata*).

Compared with other studies in Johor, different species richness were recorded such as Taman Negara Johor Gunung Ledang (34 species), Taman Negara Johor Endau-Rompin (29 species), Gunung Arong Forest Eco-Park (27 species), Soga Perdana Forest Eco-Park (35 species), Gunung Belumut Forest Eco-Park (24 species), and Sungai Sayong (24 species) (Aziz et al., 2018), Taman Negara Johor Tanjung Piai (9 species) (Mohamed et al., 2019), Pulau Sibu (5 species) (Azmi et al., 2019), and North Ayer Hitam Forest Reserve (35 species) (Muazam et al., 2023).

In comparison, other studies throughout Peninsular Malaysia include Norma-Rashid et al. (2001) at Tasek Bera in Pahang (78 species), Azmi et al. (2006) at Sekayu Recreational Forest in Terengganu (40 species), Choong and Alwen (2018) at Sungai Dusun Wildlife Reserve (38 species) and, Farizawati et al. (2014) at five islands on the west coast of Peninsular Malaysia (54 species), and finally Mamat (2018) that was surveyed on 22 localities from 11 states in Peninsular Malaysia (70 species).

Overall, among the larval sample, this study recorded a fairly low abundance (178 individuals), but higher family richness (10 families) (*Table 5*), with Gomphidae being the most abundant (*Appendix 2*), compared to other studies in Johor, such as Sungai Kawal, and Taman Negara Johor Endau-Rompin (6 families) (Yap et al., 2021). Previous studies at other localities, Pelepah Kiri and Gunung Muntahak, within Panti Forest Reserve, recorded six families (Chen et al., 2023). In comparison, other studies in Peninsular Malaysia recorded 253 individuals from nine families with Libellulidae as the dominant family in Gunung Jerai Forest Reserve, Kedah (Ab Hamid et al., 2016) and 1212 individuals from eight families with Platycnemididae and Libellulidae as the dominant families in the Kerian River, Kedah (Siregar, 2006).

Odonata diversity between disturbed and undisturbed forests

The high Simpson's Dominance Index (D) in PD was due to dominance of *H. biforata, Prodasineura laidlawii*, and *Euphaea impar,* which represent 60% of the community in PD (*Table 5, Appendix 1*). This aligns with other studies where *H. biforata* was the most abundant species in the genus *Heliocypha* sp. (Abdul Aziz and Mohamed, 2019) and Eupheaeidae as the third largest family (Azmi et al., 2006). In BT, the community was dominated by *Vestalis amoena* and *Aristocypha fenestrella,* representing 42.4% of the community, as both prefer clear and fast-flowing forest streams (Orr, 2005). This aligns with a previous study where *V. amoena* was the most abundant species in BT (Abdul Aziz and Mohamed, 2019). High Shannon-Weiner Diversity Index (H') and Pielou's Evenness Index (J) in PU and LE (*Table 5*), was due to the fairly even species distribution and absence of dominant species as in BT and PD (*Appendix 1*). In comparison, previous studies, all localities in this study showed lower H' while higher J value, where previous

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study recorded for BT (H' = 2.922, J = 0.547), PU (H' = 2.695, J = 0.580), and Gunung Panti (H' = 3.131, J = 0.654) (Aziz et al., 2018). The lower value could be a sign of increased disturbance over the years. The low diversity value could be a result of the dynamics of flowing water (Prastyanto et al., 2024). The highest Margalef's Richness Index in PD was due to high species richness compared to other localities (*Table 5*).

The species richness of Zygoptera (damselfly) and Anisoptera (Dragonfly) are important components in determining disturbed areas, as generalist and heliophilic dragonfly species dominated the habitat altered by human while mature forests have higher specialists and stenotopic damselflies (Seidu et al., 2018). The higher total species richness in disturbed forests, BT (18 species) and PU (18 species), compared to that of the undisturbed forests, LE (17 species), could be explained by the proportion of Zygoptera and Anisoptera species richness (*Table 5*). Although disturbed forests have higher species richness, however, both have lower Zygoptera-Anisoptera Species Richness Ratio, indicating slight disturbance of both localities. The Zygoptera-Anisoptera Species Richness Ratio was an indicator for habitat alteration and degradation (Cruz et al., 2021). Thus, disturbed habitats tend to have low Zygoptera-Anisoptera Species Richness Ratio (Ishak et al., 2021). Zygoptera posses small body size, highly rely on specific environmental requirements, and has low dispersal ability (Mendes et al., 2015; Prastyanto et al., 2024), tend to occupy primary forests with high canopy cover and rely on physical forest structures for various processes such as reproduction, thermoregulation, perching, and emergence (Seidu et al., 2018), while Anisoptera are large, highly mobile and have high dispersal ability (Cruz et al., 2021), possess high tolerance to environmental factor, known to be common and widespread (Prastyanto et al., 2024), and tend to occupy degraded habitat (Ishak et al., 2021).

PD has significantly higher adult species richness and higher larval family richness and abundance compared to PU (*Table 6*). This was contributed by higher species richness and abundance of both adult and larval Odonata in PD, as the undisturbed forests provide refuge from human disturbance compared to PU, which was open and accessible by humans for ecotourism. In contrast, another study found no significant differences in diversity and species richness between the primary forest, disturbed areas such as mining sites, agricultural fields, and human settlements (Seidu et al., 2018). Furthermore, this study found no significant difference in adult abundance between the four forests, which is similar to another study by Azmi et al. (2006).

Water quality between disturbed and undisturbed forests

The temperature means in both undisturbed and disturbed forests were not threatening for the aquatic organisms. Slightly higher temperature in undisturbed forests especially PD probably due to high turbidity resulted from suspended solids (*Figure 7a, 7b,* and *7c, Table 7*), that cause raise in water temperature (Naubi et al., 2016) while lower temperature in BT and PU with less suspended solids.

TSS are the natural pollutants that increase in turbidity when high in concentration (Naubi et al., 2016) due to soil erosion (Naubi et al., 2016) and intensify from anthropogenic activities such as mining, deforestation and plantation (Al-Badaii et al., 2013) lead to sedimentation (Hashim et al., 2018). High TSS concentration in PD (*Figure 7b, Table 7*) likely resulted from riverbank soil erosion and runoff, while low concentration in other localities was due to the presence of stones and riparian vegetation that help in trapping the suspended solids (Mohd Zaideen et al., 2017). However, all the localities were within Class I according to NWQS (*Figure 7b*).

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Turbidity could result from sources such as organic matter, suspended solids, silt, plankton, clay, decomposing microorganisms (Al-Badaii et al., 2013), effluent and surface runoff reduce light penetration towards aquatic plants, decreasing DO and threaten aquatic organisms (Naubi et al., 2016). High turbidity in PD could be due to the riverbank's erosion brought in organic matter and suspended solids (*Figure 7c, Table 7*). Furthermore, soft and clay-like soil was spotted during sampling, which increased turbidity. In contrast, low turbidity in other localities could result from the trapping of suspended solids and organic matter by the stones and plant root mass along the streams.

River width, depth and velocity were important components in river discharge which is the volume of river water flowing through the stream at a specific point per second. BT has the widest river among the localities, however, with moderate depth and high velocity, while in comparison, LE has with average width, however, deepest among the localities and with the lowest velocity (*Figure 7d, 7e,* and *7f, Table 7*). These components have an effect on the survival and preferences of the living aquatic organisms.

DO is an important indicator for a healthy ecosystem, where high concentrations indicate good water quality (Naubi et al., 2016). DO in the water is the result of diffusion of the atmospheric oxygen and photosynthesis of the aquatic plants, where it is consumed when organic matter is being decomposed (Al-Badaii et al., 2013). High DO in BT was due to the high river velocity that facilitates aeration in replenishing DO (Mohd Zaideen et al., 2017), and low temperature enhances solubility of DO (*Figure 8a*) (Alisawi, 2020). Lower DO within Class II in undisturbed forests could result from the decomposition process of leaf litter and bacteria growth in decomposing organic matter, reducing DO (Suratman et al., 2015; Naubi et al., 2016; Mohd Zaideen et al., 2017), compared to DO in disturbed forests that fall within Class I for BT and Class II for PU which almost reach Class I according to NWQS (*Figure 8a*). These were the same for DO saturation as it follows the same trend as DO (*Figure 8b*).

Low pH could be caused by high organic content (Suratman et al., 2015) where decomposition will increase the carbon dioxide in water causing drop in pH level (Mohd Zaideen et al., 2017). In contrast, pH could increase due to activity by photosynthetic algae that reduce the carbon dioxide (Al-Badaii et al., 2013). Low pH in LE (*Figure 8c, Table 7*), could result from the runoff water that brought the organic matter and fertilizers from the nearby agricultural site called "Taman Kekal Pengeluaran Makanan (TKPM) Sungai Lebak" that raised organic content and nutrients in water, carbon dioxide increased when DO was consumed during the decomposition process, leading to a drop in pH level (Suratman et al., 2015; Mohd Zaideen et al., 2017) as LE pH falls within Class IV, compared to the other localities, which were within Class II according to NWQS (*Figure 8c*).

AN is the combination of concentration between ammonia and ammonium, sourced from fertilizers of agricultural sites and effluent from industry (Naubi et al., 2016; Mohd Zaideen et al., 2017), and sewage from humans and animals which are toxic to living organisms in aquatic habitats (Hashim et al., 2018). The AN concentration can be considered very low within the Class I (*Figure 8d*). Both disturbed forests showed higher AN concentration than one of the undisturbed forests PD, which could be attributed to the nutrients from human food waste that accidentally entered the river stream and the presence of fish sanctuary of *Tor tambroides* which is locally known as "Kelah" in BT. The fishes were fed every day. The waste from the fish and nutrients from feed could elevate the AN in the water (Suratman et al., 2015). Slightly higher AN in LE was probably due to the fertilizer from runoff water of the nearby agricultural site. However,

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the AN in all the localities was within Class I according to NWQS (*Figure 8d*). This is also the same for ammonia and ammonium concentration as both follow the same trend as AN where all three parameters are interrelated (*Figure 8e* and *8f, Table 7*).

COD measures the amount of dissolved oxygen required in decomposing organic matter by chemicals (Suratman et al., 2015) and oxidizing the compounds (Hashim et al., 2018), where high COD concentration could cause the stream to be unsuitable to be occupied by living aquatic organisms (Naubi et al., 2016). High COD could result from the municipal waste and industrial waste that are being discharge into the river water (Suratman et al., 2015), fertilizers and sewage (Al-Badaii et al., 2013). COD within Class I in all localities except for PD in Class II according to NWQS (*Figure 8g*), due to the presence of many organic matters such as leaf litter.

BOD measure the amount of DO required in decomposing organic matter by microorganisms (Suratman et al., 2015; Ab Hamid et al., 2016). Similar with COD, high BOD could be caused by nutrient pollution such as organic matter (Suratman et al., 2015), fertilizers, septic tank and animal farm (Al-Badaii et al., 2013). High BOD in both disturbed forests (*Figure 8h*) probably resulted by the fish feed and fish waste from the fish sanctuary in BT while in PU, due to runoff water that brought in organic matter from the surroundings, as PU is a Hill Dipterocarp Forest that easily collects organic matter, especially when rain occurs. All localities were within the Class II according to NWQS (*Figure 8h*), indicating slightly high organic matter content within the waterway.

Comparing the Malaysian WQI with the previous record by DOE, BT water quality index has been improved since 2019 with value 91 (Class II) in Clean category and last year, in 2023, with value 97 (Class I) in Environmental Quality Report (EQR) 2023 (DOE, 2024), which is not far from this study which is 95.9 (Class I) within the Clean category (*Figure 9*). Next, the river in PU that flows into Sungai Ayer Hitam Besar has no record of water quality assessment by DOE. Similarly, with PD and LE in EQR 2023 (DOE, 2024). Thus, this study is the baseline data for water quality in those localities. PU with water quality index of 94.64 (Class I) while PD at 90.75 (Class II) and LE at 84.16 (Class II). Moreover, both localities of disturbed forests have the water quality suitable for recreational activity with body contact as the water quality need to be at least at Class II to ensure the safety of the visitors (DOE, 2024) (*Table 4*). The better water quality at disturbed forests were possibly due to the high TSS and COD, and low DO in PD (*Figure 7b, 8a* and *8g, Table 7*), while low DO and pH in LE (*Figure 8a* and *8c, Table 7*). DO was given the highest weightage in the Malaysian WQI formula *(Eq.1)*, which contribute to this result. Additionally, despite slightly lower weightage given towards pH (*Eq.1*), due to the extremely low pH in LE also lead to worse WQI index.

Relationship between Odonata diversity and water quality

The river water quality parameters could influence the adult community as they prefer different requirements for egg deposition. Both adult species richness and abundance have significant weak positive correlation with temperature and suspended solids (*Figure 11a and 11b, Figure 12a and 12b*). Similarly, previous study found that adult species richness increased with temperature, as this positive relationship helps the Odonata to thermoregulate on warm water surface (Ishak et al., 2021), and enhance foraging activity at higher temperature (Ab Hamid et al., 2016). Then, this is also due to the Odonata preference to deposit their egg into warm and shallow water (Ishak et al., 2021). Other than that, weak positive correlation between adult species richness with DO

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(*Figure 10*), align with study by Ishak et al. (2021), as DO also important in egg deposition and predation.

Next, weak negative correlation of adult species richness with river depth (*Figure 10*), coincide with study by Ishak et al. (2021) that reported richness decreased with river depth. Then, weak negative correlation with nutrients such as AN, ammonia and ammonium might be due to the adult Odonata preference to the habitats with less pollution as chemicals from runoff water such as fertilizers and pesticides, cause drop in larval growth, development and survival (Ishak et al., 2021) (*Figure 11c-11e, Figure 12c-12e*). Similar with this study, Mamat (2018) reported that species such as *H. biforata, A. fenestrella, Z. iris, Dysphaea dimidiata,* and *Euphaea ochracea* which all present in this study were negatively affected by the increase in pollutants such as sulphate, ammonia, iron and nitrite.

Additionally, the presence of *N. chinensis* showed clean water in BT (Farizawati et al., 2014). Furthermore, BT is the only locality where all three calopterygids species in this study were present in high abundance, indicating clean water, as these species tend to be found in forest streams with clear water (Orr, 2005). This reflects the Malaysian WQI in *Figure 9,* as BT has the best water quality. Then, the high abundance of *H. biforata* and other chlorocyphids, and *P. laidlawii* from Protoneuridae in PD, indicates clean water (Orr, 2005; Farizawati et al., 2014). Additionally, Mamat (2018) reported that *P. laidlawii* was negatively correlated with pollutants such as nitrate.

Both larval family richness and abundance have weak significant positive correlation with BOD (*Figure 13a and 13b*). Similarly, study by Ab Hamid et al. (2016) reported that the abundance of *Zygonyx* sp. and *Euphaea* sp. has significant positive correlation with BOD. Interestingly, this study showed a positive correlation towards BOD (*Figure 13a and 13b*), although it was weak, as high BOD will cause limited dissolved oxygen available for the larvae, as they could not survive in an anoxic environment (Oertli, 2008). Next, although not significant, larval richness and abundance showed weak positive correlation with temperature (*Figure 10*). This is supported by studies that found positive correlation between larval generic diversity and abundance of *Euphaea* sp. larvae with temperature (Siregar, 2006; Ab Hamid et al., 2016). The weak positive correlation of both larval richness and abundance with river depth (*Figure 10*), align with previous studies (Siregar, 2006; Ab Hamid et al., 2016). The submerged logs at the deeper water offer site for egg deposition and suitable habitat for the larvae (Ab Hamid et al., 2016).

The weak negative correlation of larval abundance with river velocity (*Figure 10*), align with the previous study that found significant negative correlation of general larval abundance and *Zygonyx* sp. abundance with river velocity (Ab Hamid et al., 2016). Other than that, the weak positive correlation of larval richness with DO coincide with the previous study (Siregar, 2006). Finally, this study also found weak positive correlation between both larval richness and abundance with pH (*Figure 10*). This was also supported by previous studies that generic richness and abundance of *Euphaea* sp. increased with pH (Siregar, 2006; Ab Hamid et al., 2016). This is due to the low pH condition could harm the development and success of eggs hatching rates (Ishak et al., 2021).

Sensitive families commonly showed significant correlation with certain water quality parameters, however, tolerant families, especially libellulids (Siregar, 2006; Farizawati et al., 2014), tend to be less influenced by any parameters such as *Neurothemis tullia* (Che Salmah et al., 1998) or tolerate polluted water, such as *Platycnemis annulata* and *Brachythemis contaminata* that survived in slightly acidic water (Siregar, 2006). The high

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abundance of gomphids in this study could be due to their morphology that mimics dead leaves (Yule and Yong, 2004) which helps them to camouflage among the dead leafs. Furthermore, the presence of this family also indicates clean water in the localities, especially in BT and PD, as this family is one of the most sensitive families (Ab Hamid et al., 2016). Other than that, the presence of other families such as Chlorocyphidae and Calopterygidae also indicates the clean water as these families have a preference for clear forest streams (Siregar, 2006; Farizawati et al., 2014; Ab Hamid et al., 2016). The weak correlation showed in this study was possibly due to the fact that all sampling sites were flowing-water bodies with almost similar environmental characteristics. In the absent of extreme conditions, there are no factor that could increase the slope of the correlation to raise the coefficient.

Conclusion

In conclusion, disturbed forests tend to have a low Zygoptera-Anisoptera Species Richness Ratio, indicating slight disturbance due to the open habitat that allows Anisoptera to thrive compared to undisturbed forests that offer refuge from humans, allowing Zygoptera to flourish. Adult species richness, larval family richness, and abundance were significantly different between undisturbed and disturbed forests. Then, disturbed forests showed slightly better Malaysian Water Quality Index (WQI), which was within Class I, indicating their suitability for recreational activity involving body contact, while undisturbed forests were within Class II according to National Water Quality Standards (NWQS). However, all localities were within the Clean category. Parameters such as temperature, TSS, turbidity, river width, river depth, river velocity, pH, AN, ammonia, and ammonium were significant. Finally, the adult Odonata community was significantly correlated with temperature, total suspended solids, AN, ammonia, and ammonium, while the larval community was correlated with BOD. We recommend future studies to focus on specific potential species as bioindicators and determine their relationship towards particular water quality parameters for a more accurate relationship, which could be considered as a biological component in our Malaysian WQI.

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APPENDIX

Appendix 1. *Adult Odonata species abundance for each locality, common name, and IUCN status*

	Families	Species	Sungai Bantang	Gunung Pulai	Sungai Padang	Sungai Lebak	Common Name	IUCN Status
Zygoptera	Argiolestidae	Podolestes orientalis (Selys, 1862)	0	0	0	2	Blue-spotted Flatwing	LC
	Calopterygidae	Neurobasis chinensis (Linnaeus, 1758)	5	0	0	0	Common Green Metalwing	LC
		Vestalis amethystina (Lieftinck, 1965)	19	0	4	13	Common Flashwing	LC
		Vestalis amoena (Selys, 1853)	34	0	24	0	Charming Flashwing	LC
	Chlorocyphidae	Aristocypha fenestrella (Rambur, 1842)	22	0	0	0	Peacock Jewel	LC
		Heliocypha biforata (Selys, 1859)	0	15	64	12	Magenta-backed Jewel	LC
		Heliocypha perforata (Percheron, 1835)	9	0	0	0	Common Blue Jewel	LC
		Libellago stigmatizans (Selys, 1859)	0	0	1	0	Orange-faced Gem	LC
		Sundacypha petiolata (Selys, 1859)	0	0	0	6	Sunda Jewel	LC
	Devadattidae	Devadatta argyoides (Selys, 1859)	1	12	16	6	Malayan Grisette	LC
	Euphaeidae	Dysphaea dimidiata (Selys, 1853)	0	0	4	0	Black Velvetwing	LC
		Euphaea impar (Selys, 1859)	5	7	31	35	Blue-sided Satinwing	LC
		Euphaea ochracea (Selys, 1859)	10	0	0	0	Ochraceous Darkie	LC
	Philosinidae	Rhinagrion macrocephalum (Selys, 1862)	0	0	14	6	Western Signaltail	LC
	Platycnemididae	Coeliccia albicauda (Förster, 1907)	0	0	4	11	White-tailed Sylvan	LC
		Coeliccia octogesima (Selys, 1863)	0	0	1	0	Telephone Sylvan	LC
		Indocnemis orang (Förster, 1907)	4	0	0	0	Greater Sylvan	LC
		Prodasineura collaris (Selys, 1860)	0	0	2	0	Collared Threadtail	LC
		Prodasineura laidlawii (Förster, 1907)	0	0	40	0	Laidlaw's Threadtail	LC
		Prodasineura notostigma (Selys, 1860)	0	0	9	19	Crescent Threadtail	LC
	Platystictidae	Drepanosticta fontinalis (Lieftinck, 1937)	0	21	1	8	N/A	LC
Anisoptera	Aeshnidae	*Anax guttatus* (Burmeister, 1839)	0	0	1	0	Lesser Green Emperor	LC
		Tetracanthagyna plagiata (Waterhouse, 1877)	1	0	1	1	Giant Hawker	LC
	Libellulidae	*Brachydiplax chalybea* (Brauer, 1868)	0	7	0	0	Yellow Patched Lieutenant	LC
		Cratilla metallica (Brauer, 1878)	6	0	1	0	Dark-tipped Forest Skimmer	LC

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	Families	Species	Sungai Bantang	Gunung Pulai	Sungai Padang	Sungai Lebak	Common Name	IUCN Status
		Hydrobasileus croceus (Brauer, 1867)	0	18	0	0	Amber-winged Glider	LC
		Lyriothemis cleis (Brauer, 1868)	0	4	0	0	Crimson Bombardier	LC
		Neurothemis fluctuans (Fabricius, 1793)	3	19	2	2	Coppertone Velvetwing	LC
		Orthetrum chrysis (Selys, 1891)	2	3	0	16	Spine-tuffed Skimmer	LC
		Orthetrum glaucum (Brauer, 1865)	0	17	0	1	Common Blue Skimmer	LC
		Orthetrum testaceum (Burmeister, 1839)	1	2	0	0	Orange Skimmer	LC
		Orchithemis pulcherrima (Brauer, 1878)	1	0	1	0	Forest Skimmer	LC
		Rhyothemis obsolescens (Kirby, 1889)	0	1	0	0	Bronze Flutterer	LC
		Rhyothemis phyllis (Sulzer, 1776)	0	5	1	0	Yellow -striped Flutterer	LC
		Tholymis tillarga (Fabricius, 1798)	0	1	0	0	Coral-tailed Cloud Wing	LC
		Trithemis aurora (Burmeister, 1839)	0	2	0	0	Crimson Marsh Glider	LC
		Trithemis festiva (Rambur, 1842)	1	3	0	1	Indigo Dropwing	LC
		Tyriobapta torrida (Kirby, 1889)	0	0	3	14	Tree Hugger	LC
		Zygonyx ida (Selys, 1869)	5	10	0	0	Ida's Cascader	LC
		Zygonyx iris (Selys, 1869)	3	1	0	1	Iridescent Stream Glider	LC

LC: Least Concern; N/A: Not Available

Appendix 2. *Larval Odonata family abundance for each locality*

Suborder	Families	Sungai Bantang	Gunung Pulai	Sungai Padang	Sungai Lebak
Zygoptera	Calopterygidae	1	0	2	0
	Chlorocyphidae	12	2	8	1
	Euphaeidae	0	0	0	1
	Philosinidae	1	1	3	28
	Platystictidae	0	0	0	1
	Protoneuridae	0	0	38	0
Anisoptera	Chlorogomphidae	1	1	0	0
	Corduliidae	1	0	0	0
	Libellulidae	4	0	4	3
	Gomphidae	28	4	27	6

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