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Research Article

Biodiversity and Seasonal Abundance of Dragonflies (Order: Odonata) in the Urban Areas of Makassar City and Gowa Regency, South Sulawesi, Indonesia

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ABSTRACT
Dragonflies are insects belonging to the order Odonata; at the nymph stage, they act as bioindicators of water quality, and at the adult stage, they act as predators of small insects. Seasonal changes and environmental issues in urban areas can affect the existence of dragonfly populations. This study aims to identify species diversity, abundance, similarity, and the relationship between biotic vegetation characteristics and abiotic seasonal elements. The study was conducted in freshwater habitats, including running water and stagnant water habitats, in Makassar City and Gowa Regency during the dry and rainy seasons. Data collection was conducted using the Visual Encounter Survey (VES) method and specimen collection using insect nets. The results showed 12 species from 2 families, 11 species from Makassar City, and 6 species from Gowa Regency. The Shannon-Wiener diversity index showed that the dry season's diversity value is H' = 1.39 and the rainy season's value is H' = 1.72. The abundance of dragonflies showed that the species *Agriocnemis pygmaea* and *Brachythemis contaminata* were the most frequently observed species. Additionally, one particular research site shared the same species across six different aquatic environments. There was a correlation between the abundance of dragonflies in each research location and the variation of abiotic variables. Differences in vegetation composition also affected the structure of the dragonfly community.

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INTRODUCTION

Biodiversity, according to Mokodompit et al. (2022), is the diversity of living organisms, including types of flora and fauna. Biodiversity includes genetic variation, species, and ecosystems found in an area. Suwarso et al. (2019) and Siboro (2019) explain that biodiversity has variations in each region that show unique characteristics, both flora and fauna, because living things naturally have limitations in distribution so that biodiversity differs in a region, which indicates variations in colour, size, and shape. Biodiversity is influenced by both environmental and genetic factors, which shape the distinct characteristics of living organisms.

Dragonflies, belonging to the order Odonata, are an important component of insect biodiversity across Indonesia (Virgiawan et al. 2015). Dragonflies were among the first flying insects in the world, having existed since the Carboniferous period approximately 360-290 million years ago and are still alive today. In the egg and nymph stages, dragonflies spend most of their lives in freshwater habitats such as lakes, fish ponds, reservoirs, rice fields, rivers, and canals. The sensitivity of dragonfly nymphs to the aquatic environment causes dragonflies to act as bioindicators because dragonfly nymphs can only survive in clean water conditions (Choong et al. 2020). In addition to acting as bioindicators, adult dragonflies act as predators for small insects such as flies and mosquitoes (Dalia & Leksono 2014).

The number of dragonfly species spread throughout the world is around 5680 species, the Anisoptera suborder 2941 species belonging to 12 families and the Zygoptera suborder 2,739 species belonging to 19 families (Kalkman et al. 2008). Sigit et al. (2013) reported that approximately 700 dragonfly species have been recorded in Indonesia, representing 15 % of the world's total dragonfly diversity. Dow et al. (2024) reported that the total number of dragonflies in Indonesia is 743 species. Western Indonesia, known as Sundaland, includes the islands of Sumatra, Java, Kalimantan, and Bali, with 549 species. Eastern Indonesia, known as Wallacea, includes the islands of Sulawesi and Maluku, and the small islands, with 270 recorded species; 76 species were found in the two regions. Mehmood et al. (2021) and Aranda et al. (2021) reported that seasonal variations (dry season and rainy season) related to precipitation and temperature affect the abundance of insects in urban areas.

Urban areas are characterised by city life, such as high population density, advanced infrastructure, and centres of economic activity. Urban areas usually have high-rise buildings, highways, public transportation, and various public facilities such as schools, hospitals, and shopping centres. Urban areas are generally centres of trade, industry, and services and have a dynamic and diverse social and cultural life (Amaya et al. 2024). According to Harahap (2013), urbanisation is a phenomenon that occurs due to an increase in the human population in urban areas, and it can affect the growth and expansion of urban areas.

Urbanisation has an important influence on environmental conservation techniques, which can continuously result in environmental damage and ecosystem imbalance, this includes transforming natural environments into artificial ones, such as housing, infrastructure, and industrial areas, leading to habitat fragmentation Knapp et al. (2021) explained that urbanization and biodiversity have significant interest based on several interspecific and intraspecific levels, namely phylogenetic levels (Sol et al. 2017; Ricotta et al. 2009), genetic diversity levels (Miles et al. 2019), taxonomic levels (Beninde et al. 2015), inter-species community levels (Williams et al. 2015), and functional levels (Lasosová et al. 2016; La Sorte et al. 2018).

Makassar City is one of the largest cities in Indonesia, located in the eastern region of the country, with an area of 175.77 km^2 and a population of 1,465,000, according to the Makassar City Central Statistics Agency (2024). This reflects a population increase of almost 3 % in four years. Gowa Regency is one of the regencies located 10 km south of Makassar City. Although Gowa Regency is a small city, its development is quite rapid. Makassar City and Gowa Regency both contain freshwater ecosystems; however, due to dense population growth and increasing human activities, these habitats have undergone significant changes, impacting water quality. For example, household and industrial waste, changes in the use of rice fields in residential areas, and invasive water hyacinth plants whose populations are abundant cause the water bodies in irrigation channels to be blocked. This results in the aquatic ecosystem, which should be a natural habitat for organisms living in freshwater, being damaged and its population being disrupted, which ultimately affects the survival of organisms in freshwater ecosystems in urban areas, including dragonflies.

Changes in habitat and seasons also affect the lives of organisms. Seasons play a crucial role in the life cycle of an organism, especially insects, so changes in seasons and air temperature in an area can affect insect activity. Sánchez-Reyes et al. (2019) explain that seasonal changes can affect the existence of the number of species as changes occur in the composition of the environment. Therefore, seasonal characteristics such as rain and drought, as well as environmental factors such as temperature, sunlight, humidity, vegetation, food availability, and interactions with other organisms, can affect the morphology, physiology, behaviour, interactions between species, and insect activity (Rizal & Hadi 2015; Trong et al. 2021).

Dragonflies are insects that can indicate changes in a habitat that affect freshwater biodiversity, climate change, conservation efforts in the area, and monitoring the quality of the area (Buchori et al. 2019). Cadena et al. (2023) reported that in the last two decades, extensive global data has been published globally on the impact of increasing climate change on distribution patterns and fauna composition. McCauley et al. (2015) explained that diversity can change, due to changes in temperature and different geographic distribution patterns. Dragonfly species change due to temperature changes, showing that dragonflies have different geographic distributions, development levels, size, and colour, and phenology changes with increasing temperature so that dragonflies can also act as bioindicators of climate change. Perez and Bautista (2020) explained that anthropogenic impacts in urban areas could cause species diversity and abundance of dragonflies to decrease, which influences the destruction and fragmentation of habitat, thus causing a decline in dragonfly populations.

Research on dragonflies in South Sulawesi, especially in the areas of Makassar City and Gowa Regency, remains limited. Initial observations that have been carried out in several areas of Makassar City and Gowa Regency show that the presence of dragonfly species can still be found in several types of freshwater habitats, including running water and stagnant water habitats. However, until now the comparative data between species diversity and abundance of dragonflies found in the dry season and the rainy season remain uncertain. In response to these issues, this study aimed to assess the presence and status of dragonflies in the Makassar City and Gowa Regency areas and the influence of seasons on the diversity and abundance of dragonflies.

METHODS

Research Location

The research location and dragonfly specimen collection were conducted in six locations, divided into two habitat categories. The research location map is shown in Figure 1.: 1. Stagnant water habitat: (a) Unhas Lake (5.137364°S, 119.489816°E) and Kera-Kera Pier (5.12361° S, 119.47972° E) Tamalanrea, Makassar City; (b) Tamarunang fish pond, Gowa Regency (5.214190°S, 119.511265°E); (c) Somba Opu rice field area, Gowa Regency (5.197240°S, 119.481525°E). 2. Running water habitat: (a) Sinrijala Panakkukang River, Makassar City (5.140134°S, 119.444553°E); (b) River in Bumi Tamalanrea Permai Housing Complex Tamalanrea, Makassar City (5.147369°S, 119.513114°E); (c) River along the Canal Borong Manggala, Makassar City (5.153208°S, 119.476829°E).

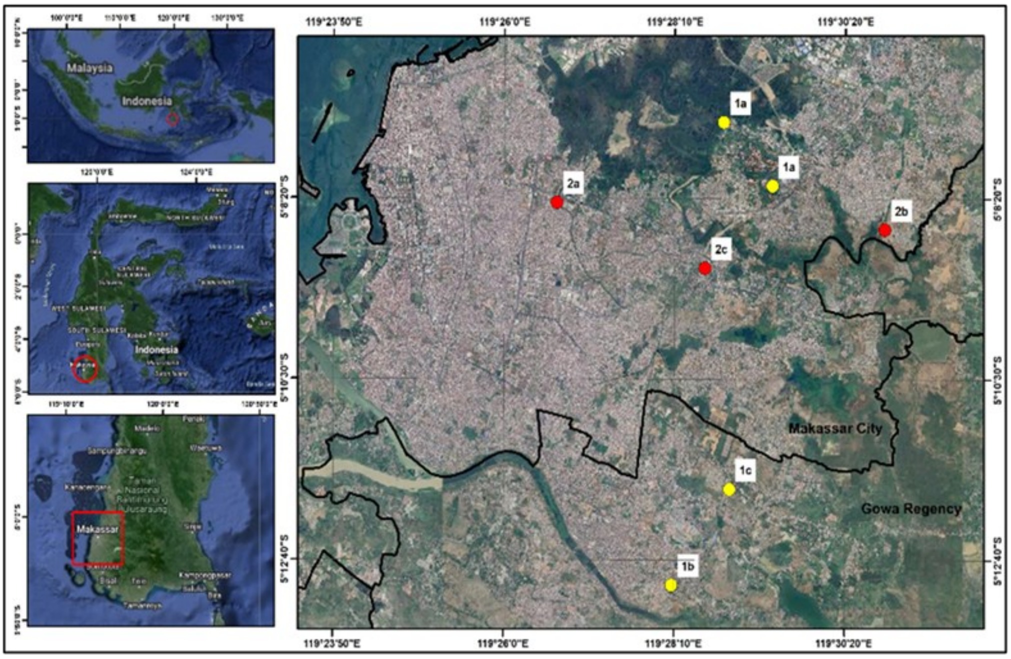

Figure 1. Dragonfly sampling locations in the urban areas of Makassar City and Gowa Regency.

Observation and collection of specimens in the field

Dragonfly observations were conducted using the Visual Encounter Survey (VES) method (Scott et al. 1994). Observations were made by catching adult dragonflies of each species using insect nets. Flying dragonflies observed were counted by the number of individuals per species. To minimise observation bias, captured dragonflies were temporarily stored and released after observations were completed. Dragonflies sighted were documented using a digital camera. Each representative species was collected for further identification in the laboratory (Susanto et al. 2024). Dragonfly specimens were collected using insect nets, and the dragonfly specimens that had been obtained were put into and stored on papillote paper (Susanto et al. 2024). Observations were conducted in the morning at 07:00-11:00 WITA and in the afternoon at 14:00-17:00 WITA. The area of observation at each location was 500 m^2. The observations are done three times a month: 12 times during the dry season, and 15 times during the rainy season. The dry season lasted from August to November 2023, while in the rainy season spanned December 2023 to April 2024.

Identification of specimens in the laboratory

Dragonfly identification was conducted at the Environmental and Marine Sciences Laboratory, Entomology Section, Faculty of Mathematics and Natural Sciences, Hasanuddin University. Dragonfly species were identified by observing morphological characteristics such as body size, colour, pattern, and wing venation (Susanto et al. 2024). Species identification refers to identification books (Kalkman & Orr 2013; Sigit et al. 2013; Orr & Kalkman 2015; Irawan & Rahadi 2018). Confirmation of species naming was carried out by Vincent J. Kalkman from the Naturalis Biodiversity Center.

Abiotic and Biotic Factors

The parameters observed in this study include two main factors, namely abiotic factors and biotic factors. Abiotic factors include precipitation and air temperature obtained from the Meteorology, Climatology, and Geophysics Agency, Region IV, South Sulawesi. Water quality data parameters at each observation location include biochemical oxygen demand (BOD) and chemical oxygen demand (COD). Water samples from each research location were taken at a depth of 10 cm from the water surface using a 300 ml sterile sample bottle. The COD and BOD analyses were conducted at the Makassar Health Laboratory Center. Vegetation at each research site was assessed through direct observation of the plants surrounding the site, recording vegetation types and plant species, including trees, herbs, grasses, shrubs, and aquatic plants.

Data analysis

The data analysis used included the following: diversity was calculated using the Shannon-Wiener index equation (H'), and species similarity at each research location was calculated using the Bray-Curtis similarity index (Magurran 1988). The abundance of individuals using the relative abundance index (RA), the relationship between dragonfly abundance and seasonal abiotic factors using Canonical Correspondence Analysis (CCA) (Ter Braak 1986). Dragonfly species tolerance to high pollution was assessed using the Dragonfly Biotic Index (DBI) (Samways & Simaika 2016). Data analysis was performed using the Paleontological Statistics Software Package (PAST) version 4.13 and Microsoft Excel 2021.

Shannon-Wiener Index Formula (H') (Magurran 1988):

$$H' = \sum \left(\frac{ni}{N} ln \frac{ni}{N}\right)$$

Information:
H' = Shannon-Wiener diversity index
ni = Number of individuals of species
N = Number of individuals of all species
Relative abundance (RA) formula:

$$RA = \frac{ni}{N} x100\ \%$$

Information:
RA = Relative abundance
ni = Number of individuals of species
N = Number of individuals of all species
The DBI value of each dragonfly species is determined based on three subindices: distribution in research locations, International Union for Conservation of Nature (IUCN) criteria checked at https://www.iucnredlist.org/, and dragonfly sensitivity to habitat water conditions. The DBI sub-indices score ranges from 0-3 (Table 1).

Table 1. DBI Sub-indices

Score	Distribution	IUCN	Sensitivity level
0	Distribution of almost all research locations	LC	not sensitive found living in excellent water quality based on COD and BOD analysis
1	Often seen in several research locations	NT	low sensitivity was found to live in good water quality.
2	Limited distribution in specific locations	VU	medium sensitivity was alive in polluted water quality.
3	Only found in one research location	EN	extreme sensitivity was found to live in highly polluted water quality.

RESULTS AND DISCUSSION

The results of the study conducted in the urban areas of Makassar City and Gowa Regency in stagnant and running water habitats in the dry season and rainy season, obtained 12 species belonging to two families: Libellulidae and Coenagrionidae. The species found were: *Acisoma panorpoides*, *Brachydiplax chalybea*, *Brachythemis contaminata*, *Crocothemis servilia*, *Diplacodes trivialis*, *Macrodiplax cora*, *Orthetrum serapia*, *Rhyothemis Phyllis*, *Agriocnemis femina*, *Agriocnemis pygmaea*, *Ischnura senegalensis*, and *Pseudagrion microcephalum*. The composition of dragonfly species in Makassar City and Gowa Regency is presented in Table 2.

Dragonflies found in Makassar City numbered 640 individuals from 11 species, while in Gowa Regency there were 242 individuals from six species. The highest percentage value of dragonfly species in Makassar City and Gowa Regency is *Brachythemis contaminata* from the Libellulidae family with a relative abundance value of 0.52 % in Makassar City and 0.43 % in Gowa Regency, indicating that *Brachythemis contaminata* is the most abundant in both urban areas. while for the Coenagrionidae family, the species with the highest percentage value in Makassar City is *Ischnura senegalensis* with a value of 0.14 %, and in Gowa Regency is *Agriocnemis pygmaea* with a value of 0.26 %.

The families of dragonflies in this research are similar to the research of Pandey and Mohapatra (2017), which reported that the most dominant and abundant widespread dragonfly in the urban areas belong to the Libellulidae from Anisoptera suborder and Coenagrionidae from the Zygoptera suborder. Anisoptera was the most dominant suborder across all research locations, likely due to its greater roaming ability compared to the Zygoptera suborder (Albab et al. 2019). According to Narender et al. (2016), the Libellulidae family from the Anisoptera suborder and Coenagrionidae from the Zygoptera suborder are the families most often found in various types of habitats in freshwater ecosystems such as lakes, ponds, reservoirs, rice fields, and rivers because they have a wide distribution. This demonstrates their adaptability to diverse freshwater environmental conditions.

Dragonfly species of the suborder Anisoptera from the family Libellulidae can be seen in Figure 2, while species of the suborder Zygoptera from the

Table 2. The composition and relative abundance of dragonfly species in Makassar City and Gowa Regency.

Species	Makassar City						Gowa Regency			
	1a	2a	2b	2c	N	RA (%)	1b	1c	N	RA (%)
Anisoptera										
Libellulidae										
Acisoma panorpoides	1				1	0.00				
Brachydiplax chalybea	47				47	0.07				
Brachythemis contaminata	263	32	36		331	0.52	47	56	103	0.43
Crocothemis servilia	10		8		18	0.03	22		22	0.09
Diplacodes trivialis	3	4	21		28	0.04		34	34	0.14
Macrodiplax cora	24		7		31	0.05				
Orthetrum serapia	5	7	3		15	0.02	2		2	0.01
Rhyothemis phyllis		1			1	0.00				
Zygoptera										
Coenagrionidae										
Agriocnemis femina							18		18	0.07
Agriocnemis pygmaea	49		25		74	0.12		63	63	0.26
Ischnura senegalensis	79	5	6		90	0.14				
Pseudagrion microcephalum		4			4	0.01				
Total Individual	481	53	106	0	640		89	153	242	
Total Species	9	6	7	0	11		4	3	6	

Note: N = Number of total individuals; RA = Relative Abundance family Coenagrionidae can be seen in Figure 3.

Based on Table 3, dragonflies found in dry seasons numbered 230 individuals from nine species, while in rainy seasons there were 714 individuals from ten species. Relative abundance results show that in the dry season, *Brachythemis contaminata* had a percentage value of 0.60 %, indicating that this species dominated the dragonfly population during this period. The significant percentage values are the species *Ischnura senegalensis* with a value of 0.13 % while the species with the smallest percentage value is *Acisoma panorpoides* with a value of 0.00 % indicating that this species rarely appears in the dry season. During the rainy season, *Brachythemis contaminata* remained the dominant species, though its percentage value decreased to 0.41 %. *Ischnura senegalensis* continued to appear prominently, similar to the dry season, while *Rhyothemis phyllis* had the lowest percentage at 0.00 %, indicating its rarity during this period.

Figure 2. Dragonflies species of the suborder Anisoptera from the family Libellulidae: (A) *Diplacodes trivialis*; (B) *Acisoma panorpoides*; (C) *Crocothemis servilia*; (D) *Brachythemis contaminata*.

Figure 3. *Ischnura senegalensis* from the family Coenagrionidae.

Table 3. The composition and relative abundance of dragonfly obtained during the dry season and rainy season in Makassar City and Gowa Regency.

Species	Dry Season								Rainy Season							
	Individual						N	RA (%)	Individual						N	RA (%)
	1a	1b	1c	2a	2b	2c			1a	1b	1c	2a	2b	2c		
Anisoptera																
Libellulidae																
Acisoma panorpoides	1						1	0.00								
Brachydiplax chalybea									47						47	0.07
Brachythemis contaminata	105	11			22		138	0.60	158	36	56	32	14		296	0.41
Crocothemis servilia		6					6	0.03	10	16			8		34	0.05
Diplacodes trivialis				4	17		21	0.09	3		34		4		41	0.06
Macrodiplax cora					7		7	0.03	24						24	0.03
Orthetrum serapia	1			7	3		11	0.05	4	2					6	0.01
Rhyothemis phyllis												1			1	0.00
Zygoptera																
Coenagrionidae																
Agriocnemis femina										18					18	0.03
Agriocnemis pygmaea	12						12	0.05	37		63		25		125	0.18
Ischnura senegalensis	24				6		30	0.13	55		62	5			122	0.17
Pseudagrion microcephalum				4			4	0.02								
Total Individual	143	17	0	15	55	0	230		338	72	215	38	51	0	714	
Total Species	5	2	0	3	5	0	9		8	4	4	3	4	0	10	

Note: N = Number of individuals of all species; RA = Relative Abundance

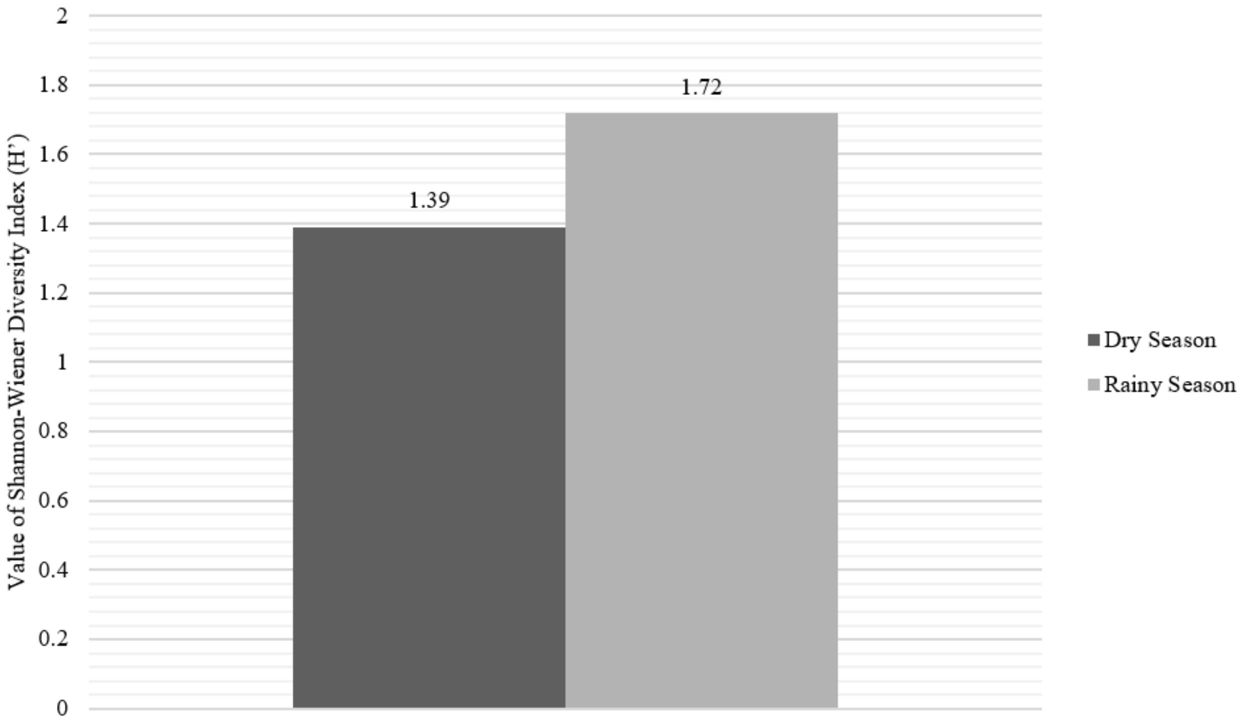

Figure 4. The value of the Shannon-Wiener index (H') of dragonflies was obtained during the dry and rainy seasons in Makassar City and Gowa Regency.

The results of the Shannon-Wiener diversity index (H') calculations show that the dragonfly diversity value in the dry season is H' = 1.39 and in the rainy season is H' = 1.72, presented in Figure 4.

The diversity value of dragonflies in both seasons shows a moderate diversity category. Variations in dragonfly diversity are influenced by seasonal changes and species' habitat. According to Sintayehu (2018), seasonal changes are a threat to biodiversity and can have an impact on increasing and decreasing species diversity. Dwita et al. (2022) state that environmental conditions affect the body temperature of dragonflies and result in diversity in distribution patterns, phenology, physiology, and abundance of dragonflies. Seasonal changes can affect dragonfly activity so that ecological mechanisms such as competition, interactions between organisms, changes in morphology, physiology, phenology, and behaviour that form community composition are disrupted (Jaworski & Hilszczański 2013). In addition to climate factors, dragonfly diversity can occur due to the location of the study being in an urban area, as reported by Menke et al. (2011). The influence of urbanisation in urban areas causes fragmentation and loss of natural habitat, resulting in a decrease in community structure.

The results of relative abundance of dragonfly species in the dry and rainy seasons presented in Table 3 and Figure 5.

Brachythemis contaminata shows a relatively high abundance in both seasons. This indicates that *Brachythemis contaminata* is highly adaptive and capable of surviving in various seasonal conditions, despite experiencing a population decline from the dry season to the rainy season. Rohmare et al. (2016) reported that the dragonfly populations are lower in the dry season compared to the rainy season. Due to the dry water conditions in the natural habitat of dragonflies during the dry season, the dragonfly life cycle became difficult so adult female dragonflies could not lay their eggs in the water. During the dry season, dragonflies tend to be difficult to find because the presence of dragonflies depends on the availability of water in their habitat. When water becomes scarce in their habitat, adult female dragonflies are unable to lay their eggs, prompting them to migrate to areas with more abundant water sources.

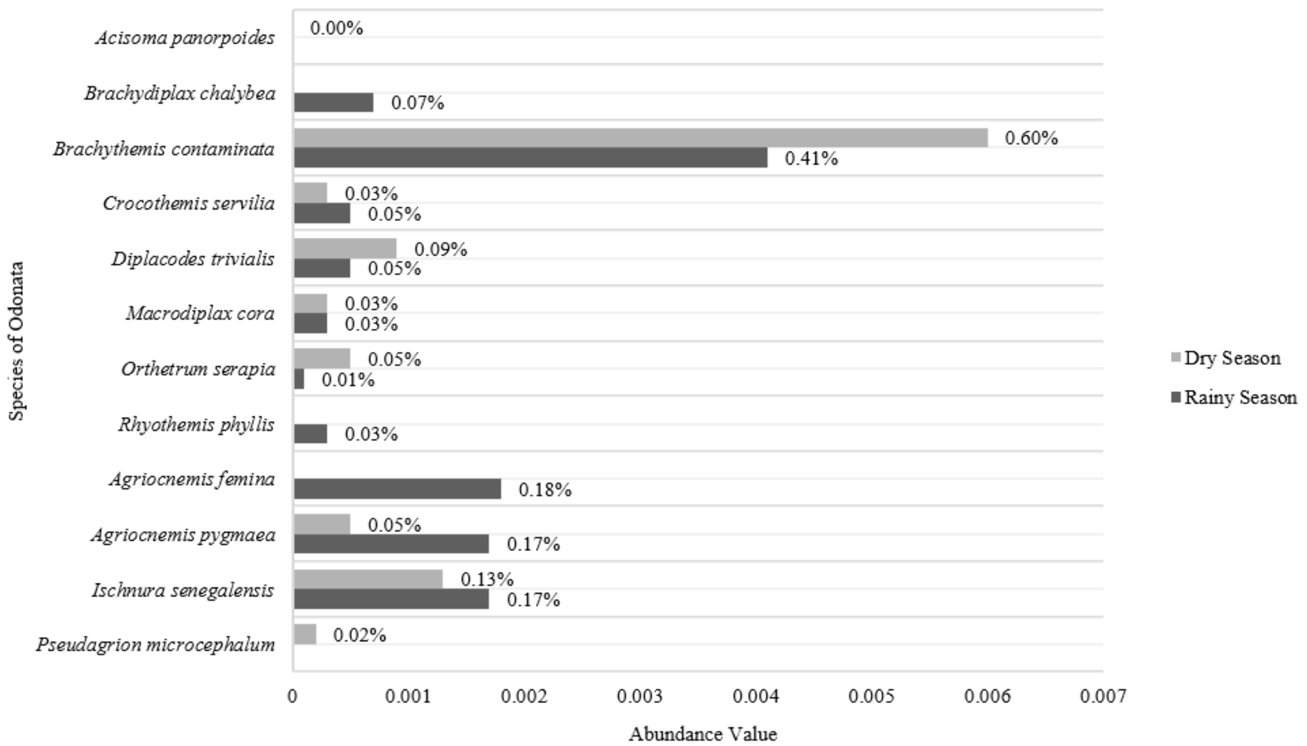

Figure 5. The relative abundance of dragonfly species during the dry and rainy seasons in Makassar City and Gowa Regency.

Table 4. The relative abundance of dragonfly species in stagnant water habitats and running water habitats during the dry and rainy seasons in Makassar City and Gowa Regency.

Species	Stagnant Water					Running Water				
	1a	1b	1c	N	RA (%)	2a	2b	2c	N	RA (%)
Anisoptera										
Libellulidae										
Acisoma panorpoides	1			1	0.00					
Brachydiplax chalybea	47			47	0.07					
Brachythemis contaminata	263	47	56	366	0.51	32	36		68	0.44
Crocothemis servilia	10	22		32	0.04		8		8	0.05
Diplacodes trivialis	3		34	37	0.05	4	21		25	0.16
Macrodiplax cora	24			24	0.03		7		7	0.05
Orthetrum serapia	5	2		7	0.01	7	3		10	0.06
Rhyothemis phyllis						1			1	0.01
Zygoptera										
Coenagrionidae										
Agriocnemis femina		18		18	0.02					
Agriocnemis pygmaea	49		63	112	0.15		25		25	0.16
Ischnura senegalensis	79			79	0.11	5	6		11	0.07
Pseudagrion microcephalum						4			4	0.03
Total Individual	481	89	153	723		49	106	0	159	
Total Species	9	4	3	10		6	7	0	9	

Note: N = Number of individuals of all species; RA = Relative Abundance

The number of dragonfly individuals per species found in stagnant water habitats and running water habitats is presented in Table 4.

In stagnant water habitats, 723 individuals from 10 species were obtained, while in running water habitats 155 individuals from 9 species were obtained. The most abundant in both stagnant and running water habitats is *Brachythemis contaminata*, with a relative abundance of 0.51 % in stagnant water habitats. In running water habitats, *Brachythemis contaminata* has a relative abundance of 0.44 %. Meanwhile, *Agriocnemis pygmaea* shows a relative abundance of 0.15 % in stagnant water habitats and 0.16 % in running water habitats. Irawan and Rahadi (2018) reported that *Brachythemis contaminata* and *Agriocnemis pygmaea* are spread across various freshwaters. *Brachythemis contaminata* and *Agriocnemis pygmaea* can be found in stagnant water habitats such as rice fields, grass near ponds or lakes, swamps, and in running water habitats such as rivers and canals with calm currents. Kulkarni and Subramanian (2013) reported that *Brachythemis contaminata* has low sensitivity to disturbed areas, as it is highly tolerant and often thrives in contaminated waters. The species that are least often in stagnant water habitats are *Acisoma panorpoides* with a relative abundance value of 0.00 % and *Agriocnemis femina* with a percentage value of 0.02 %. In running water habitats are *Rhyothemis phillis* with a percentage value of 0.01 % and *Pseudagrion microcephalum* with a percentage value of 0.03 %. According to Renner et al. (2022), several factors that cause dragonfly species to be rarely found are the habitat of the research location and the existence of competition between species that can reduce the population of other species.

Conditions of aquatic habitat in running water and stagnant water of dragonflies in the Makassar City and Gowa Regency are presented in Figure 6.

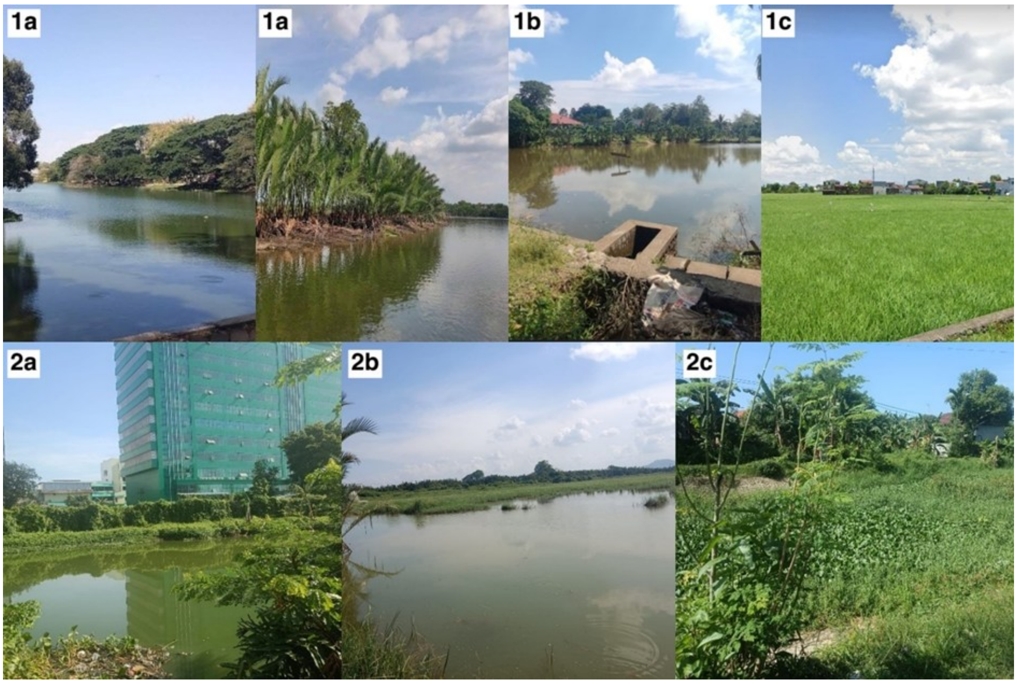

Figure 6. Habitat Conditions at the Research Site. (1a) Unhas Lake and Kera – Kera Pier; (1b) Tamarunang Fish Pond; (1c) Somba Opu Rice Fields; (2a) Sinrijala River; (2b) BTP River; (2c) Borong Canal.

The results of the Shannon-Wiener diversity index (H’) show that the dragonfly diversity value in stagnant water is H’ = 1.60 and in running water is H’ = 1.72, as presented in Figure 7.

The diversity value of dragonflies in both stagnant water and running water shows a moderate diversity category. Susanto (2022) explained that the moderate diversity of dragonfly species in urban areas suggests that these areas still maintain a relatively good environment, supporting the presence of dragonflies commonly found in various water habitats. The results showed that the location with the highest diversity value was in running water habitats, while the lowest diversity value was in stagnant water habitats. This is caused by factors such as water quality at the research location where running water habitats have better water quality compared to stagnant water based on the results of COD and BOD analysis (Table 6.), the composition of vegetation types in running water habitats is also more supportive compared to stagnant water (Table 7) so that it supports the availability of resources for dragonflies. Padilla-Morales et al. (2021), reported that freshwater environments, namely stagnant and running water, are important for dragonfly nymphs. Clausnitzer et al. (2009) reported that adult dragonflies are highly dependent on aquatic habitats for their life cycle, including egg-laying and nymphal development.

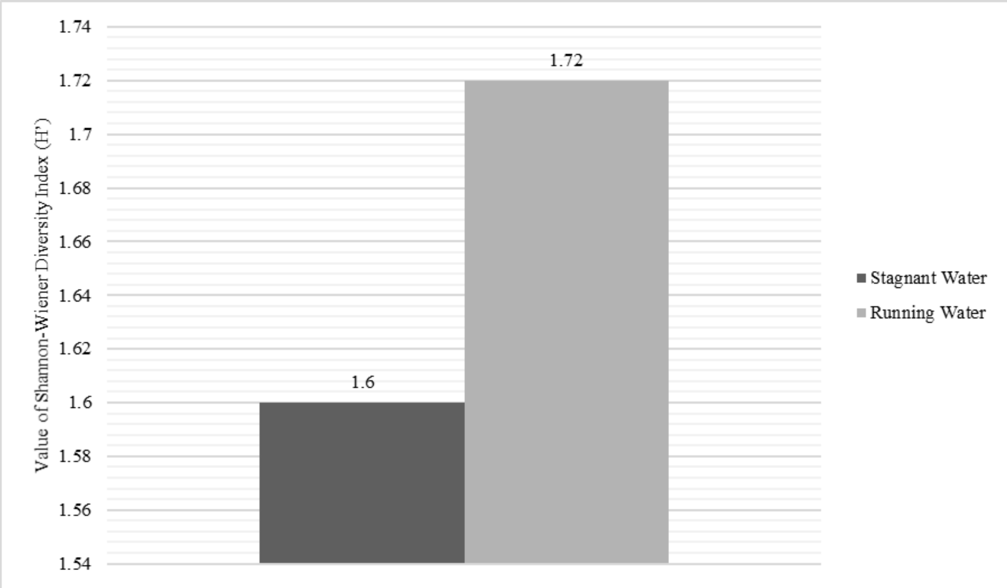

Figure 7. Value of Shannon-Wiener Diversity Index (H') of dragonflies in the Stagnant Water and Running Water.

Dragonflies are widely distributed across various freshwater habitats and can adapt to diverse environmental conditions. Therefore, species similarity analysis was conducted to examine the distribution of dragonfly species in stagnant and running water habitats. The Bray-Curtis similarity index dendrogram is presented in Figure 8.

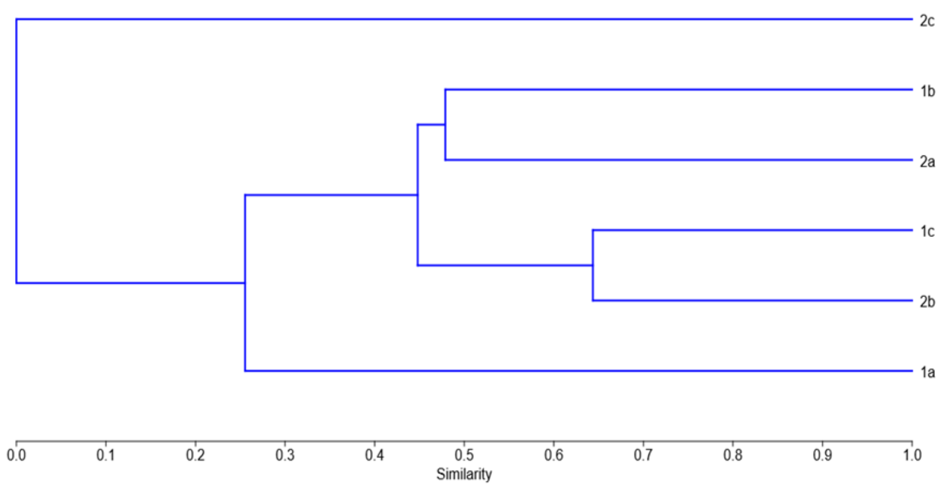

Figure 8. Dendrogram analysis of clustering using the Bray-Curtis similarity index in the city of Makassar and Gowa Regency.

The similarity value of dragonfly species at each research location shows that the species found in the rice fields (1c) have the highest similarity value with the species found in the BTP river (2b) of 0.63 having similar species, namely *Brachythemis contaminata*, *Diplacodes trivialis*, and *Agriocnemis pyg-*

maea. The dragonfly species found in the Sinrijala River (2a) have a similarity value with the BTP River species (2b) of 0.55 having similar species, namely *Brachythemis contaminata*, *Diplacodes trivialis*, *Orthetrum serapia*, and *Ischnura senegalensis*. The species at the Tamarunang fish pond location (1b) have a similar value with the species at the Sinrijala River location (2a) of 0.48 having similar species, namely *Brachythemis contaminata* and *Orthetrum serapia*. The *Brachythemis contaminata* species appears in three stagnant water habitats and two running water habitats. The species at the canal location (2c) show no similarity with any other location, as no dragonfly species were observed there during both seasons. This was likely due to the presence of abundant water hyacinths, which completely covered the water body.

Dragonflies are insects that require a clean water environment. However, some species can survive in polluted water environments due to their tolerance to low oxygen conditions or other forms of water pollution. To determine species that are tolerant to high pollution, the Dragonfly Biotic Index (DBI) is used. The DBI value of each dragonfly species is determined based on three subindices: distribution in research locations, International Union for Conservation of Nature (IUCN) criteria, and dragonfly sensitivity to habitat water conditions, as presented in Table 5.

Table 5. Dragonfly Biotic Index values of dragonfly species in Makassar City and Gowa Regency.

Species	Dragonfly Biotic Index			
	Distribution	IUCN	Sensitivity	Total
Anisoptera				
Libellulidae				
Acisoma panorpoides	3	0	3	6
Brachydiplax chalybea	3	0	3	6
Brachythemis contaminata	0	0	1	1
Crocothemis servilia	1	0	1	2
Diplacodes trivialis	1	0	1	2
Macrodiplax cora	2	0	2	4
Orthetrum serapia	1	0	1	2
Rhyothemis phyllis	3	0	3	6
Zygoptera				
Coenagrionidae				
Agriocnemis femina	3	0	0	3
Agriocnemis pygmaea	1	0	2	3
Ischnura senegalensis	1	0	1	2
Pseudagrion microcephalum	3	0	1	4

Based on Table 5, the DBI values in Makassar City and Gowa Regency range from 1 to 6. Species with a DBI value of 1 include *Brachythemis contaminata*. Species with a DBI value of 2 include *Crocothemis servilia*, *Diplacodes trivialis*, *Orthetrum serapia*, and *Ischnura senegalensis*. Species with a DBI value of 3 are *Agriocnemis femina* and *Agriocnemis pygmaea*, while species with a DBI value of 4 include *Macrodiplax cora* and *Pseudagrion microcephalum*. Finally, species with a DBI value of 6 are *Acisoma panorpoides*, *Brachydiplax chalybea*, and *Rhyothemis phyllis*. This shows that the species with the highest value DBI 6, shows high sensitivity to clean aquatic habitat conditions. In contrast, species with the lowest DBI value of 1 indicate high tolerance to polluted aquatic habitats.

Golfieri et al. (2016) explained that dragonfly species with high DBI values are sensitive to clean water habitat conditions or have low tolerance compared to other species; this indicates that the species can only live in specific habitats. Ilhamdi et al. (2020) explained that species with a low DBI value of 1 indicate that the species has a wide distribution, so it is commonly found in every research location. This also suggests that species with low DBI values are highly adaptive and have low sensitivity, making them tolerant to disturbances in various conditions of polluted water habitats.

Makassar City and Gowa Regency are characterised by a tropical climate with two distinct seasons: the dry season and the rainy season. The average precipitation and temperature values in Makassar City and Gowa Regency are presented in Figure 9.

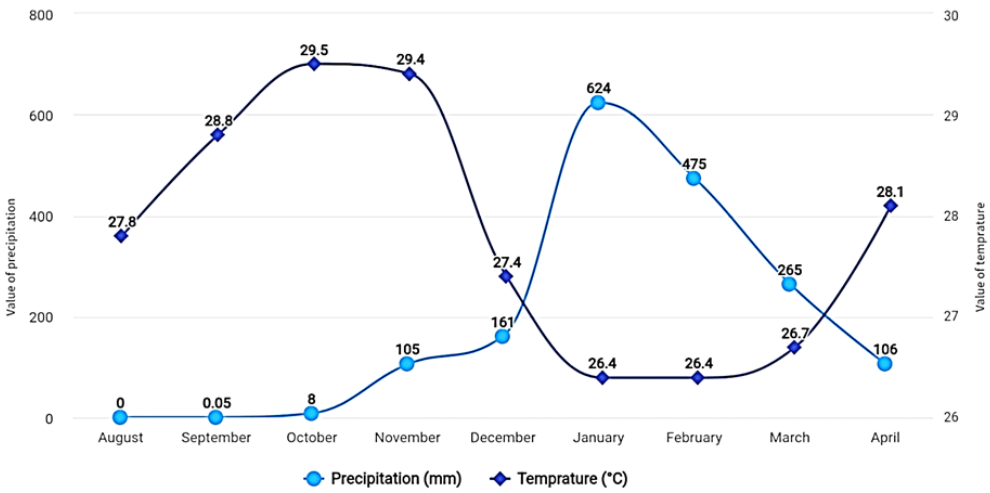

Figure 9. Average precipitation (mm) and temperature (°C) in Makassar City and Gowa Regency from August 2023 to April 2024 (Source: Internal document of Meteorology, Climatology and Geophysics Agency of South Sulawesi, 2024).

The dry season occurs from August to October 2023 with low precipitation levels and high temperatures. This can lead to a decline of the dragonfly population and hinder the nymph development process. The rainy season is marked by an increase in precipitation and a decrease in air temperature, occurring from January to March 2024. The availability of water in dragonfly habitats allows the nymph to develop well.

The results of the Canonical Correspondence Analysis (CCA) to examine the relationship between dragonfly species abundance and environmental factors, as presented in Figure 10.

The precipitation coefficient shows a positive correlation between the abundance of dragonfly species and precipitation; when precipitation is high, dragonfly species tend to be more abundant or more active. This is because dragonflies require a humid or aquatic habitat. Luke et al. (2020) reported that a higher abundance of dragonflies was observed in the rainy season because it can provide a habitat with suitable water conditions for dragonfly nymphs. Water habitats in the rainy season can have a positive impact on dragonfly nymphs, rainfall such as stable water temperatures which are ideal for nymphs, rainfall can dissolve pollution in water. When the dry season arrives, breeding is not optimal due to the drying habitat conditions. The temperature coefficient shows a negative correlation between the abundance of dragonfly species and temperature, indicating that low-temperature conditions make dragonfly species more active or more abundant. High temperatures create less-than-ideal environmental conditions for dragonflies, thus affecting their existence and activity. This is because of high humidity provides a suitable habitat for dragonflies, such as aquatic areas and vegetation. Dragonfly species are more abundant or more active in high humidity conditions because the humidity coefficient shows a positive correlation between humidity and the abundance of dragonfly species. Trong et al. (2021) explained that temperature and humidity in the habitat affect the life cycle of dragonflies, which affects their development time. Each stage of development

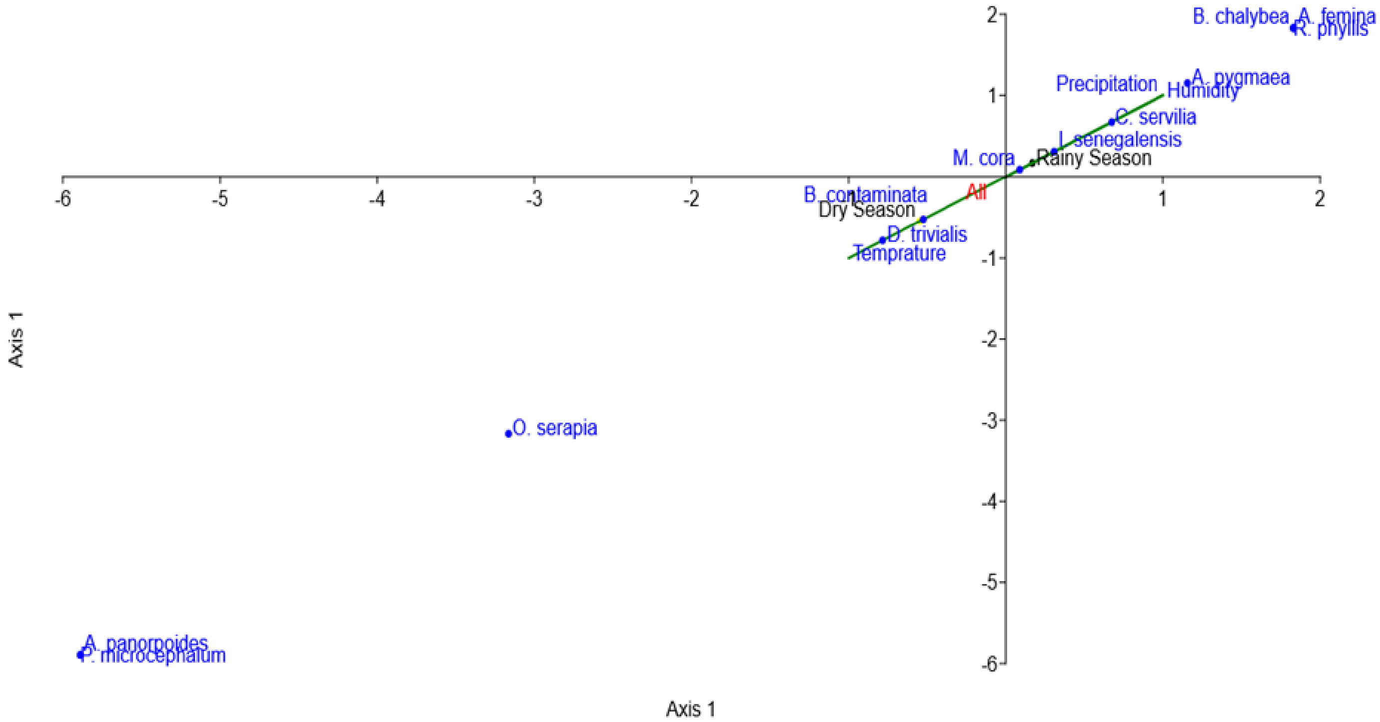

Figure 10. Canonical Correspondence Analysis (CCA) of the relationship between the abundance of dragonfly species and abiotic factors.

can take place quickly or slowly. The nymph stage in warm conditions can last about a month; however, if the water temperature is cold, it will last longer. Therefore, temperature is one of the components that greatly affects the growth and development of dragonflies.

The Indonesian government has established freshwater quality standards (rivers, lakes, reservoirs, water sources) in Government Regulation (PP) of the Republic of Indonesia No. 82 of 2001 concerning Water Quality Management and Water Pollution Control. This regulation contains freshwater quality standards categorized into four classes: maximum COD for Class I is 10 mg L^{-1}; Class II is 25 mg L^{-1}; Class III is 50 mg L^{-1}; Class IV is 100 mg L^{-1}; and maximum BOD for Class I is 2 mg L^{-1}; Class II is 3 mg L^{-1}; Class III is 6 mg L^{-1}; and Class IV is 12 mg L^{-1}. The water quality analysed for Chemical Oxygen Demand (COD) and Biological Oxygen Demand (BOD) at each research location is presented in Table 6.

The water quality test results for the canal (2c) show a COD value of 205.41 mg L^{-1} and a BOD value of 78.25 mg L^{-1}, indicating that the canal water is highly polluted and does not support the life of dragonflies. The high levels of COD and BOD at this location are likely influenced by pollutants from household waste and water bodies covered with water hyacinths. The results of the water quality test from the rice field (1c) show a COD value of 62 mg L^{-1} and a BOD value of 163.07 mg L^{-1}, indicating that the location is highly polluted; however, dragonflies can still be seen flying around the field. The high levels of COD and BOD in this area are likely influenced by pollutants from the use of pesticides by farmers. The results of the water quality tests indicate that the water in Lake Unhas (1a) has a COD value of 42.22 mg L^{-1} and a BOD value of 17.36 mg L^{-1}. This signifies that the water quality in the lake is polluted, although dragonflies can still be seen flying in the area. Despite the high COD and BOD values of the lake water (1a), there are still areas around the lake with slightly better conditions, such as the edges of the lake where there is more vegetation. The water quality test results for the river (2a) show a COD value of 31.56 mg L^{-1}, which falls into Category III, and a BOD value of 11.6 mg L^{-1}, approaching category IV, indicating that the

Table 6. Results of the Biochemical Oxygen Demand (BOD) and Chemical Oxygen Demand (COD) analysis in various habitats where dragonflies are found in Makassar City and Gowa Regency.

Location code	Sampling Location	Water quality values (mg L^{-1})		Government Regulation (PP) of the Republic of Indonesia No. 82 of 2001		Category of water quality		Classification Water quality
		COD	BOD			COD	BOD	
1a	Unhas Lake	42.22	17.36	Class I = 10 mg L^{-1}	Class I = 2 mg L^{-1}	Class III	Above Class IV	Poor quality (polluted)
1a	Kera – Kera Pier	22.05	8.39	Class II = 25 mg L^{-1}	Class II = 3 mg L^{-1}	Class II	Class IV	Moderate quality (good condition)
1b	Tamarunang Fish Pond	17.34	6.38	Class III = 50 mg L^{-1} Class IV = 100 mg L^{-1}	Class III = 6 mg L^{-1} Class IV = 12 mg L^{-1}	Class II	Class III	Good quality (good condition)
1c	Rice Field	62	163.07			Above Class III	Above Class IV	Poor quality (polluted)
2a	Sinrijala River	31.56	11.6			Class III	Class IV	Moderate quality (good condition)
2b	BTP River	14.44	6			Class II	Class III	Very good quality (very good condition)
2c	Borong canal	205.41	78.25			Above Class IV	Above Class IV	Very bad quality (very polluted)

river water is already polluted and less supportive of dragonfly life. The water quality test results for the fish pond (1a) show a COD value of 22.05 mg L^{-1}, which corresponds to Category II, and a BOD value of 8.39 mg L^{-1}, which falls into Category III, indicating that the water is polluted but still capable of supporting dragonfly life. The water quality test results for the fish pond (1b) show good water quality, with a COD value of 17.34 mg L^{-1} and a BOD value of 6.38 mg L^{-1}, corresponding to category III, thus supporting dragonfly habitat. The water quality test results for the river (2b) show a COD value of 14.44 mg L^{-1} and a BOD value of 6 mg L^{-1}, which also falls into Category III, indicating that the water quality is relatively good and supports dragonfly life.

Sharma and Gupta (2014) explain that the quality of water in a body of water will affect the quality of life of the organisms living within it, such as their growth and development. The levels of COD and BOD in a body of water are very important for understanding the degree of pollution. Supriyantini et al. (2017) reported that if excessive COD levels occur in a body of water, it will lead to a decrease in dissolved oxygen (DO) and pH, resulting in a decline in water quality. In addition, the productivity of resources, such as aquatic biota is also declining. Vigiak et al. (2019) reported that high BOD concentrations can disrupt water utilization, damage aquatic habitats and biodiversity, and reduce oxygen availability. Human activities such as industrial waste, domestic waste, and agricultural waste are the main causes of the increase in COD and BOD levels in freshwater habitats.

Dragonflies are a group of insects that require clean aquatic environments and sufficient oxygen levels for the survival of their nymphs. Virgiawan et al. (2015) explain that the sensitivity of dragonfly nymphs to aquatic environments causes dragonflies to serve as bioindicators, as dragonfly nymphs can only survive in good water conditions. As adults, dragonflies will hunt small insects around their aquatic habitat. Polluted water conditions can reduce the population of small insects that will serve as prey for dragonflies.

The abundance of dragonflies in an area is influenced by vegetation (Susanto et al. 2022). The types of vegetation found in this location are grass,

Table 7. Types of vegetation at each research location in Makassar City and Gowa Regency

No	Type of Vegetation	Species	Locations					
			1a	**1b**	**1c**	**2a**	**2b**	**2c**
1	Tree	*Samanea saman*	+					
2		*Tectona grandis*	+					
3		*Pterocarpus indicus*	+					
4		*Nypa fruticans*	+				+	
5		*Sonneratia caseloris*	+			+		
6		*Muntingia calabura*		+		+	+	
7		*Terminalia catappa*				+	+	
8		*Acasia sp.*					+	
9		*Hibiscus tiliaceus*					+	
10		*Mangifera indica*		+				
11		*Moringa oleifera*		+				
12		*Rhizophora mucronata*	+					
13	Herbs	*Musa paradisiaca*	+					+
14		*Typha angustifolia*		+		+	+	
15		*Eclipta prostrata*			+			
16	Grass	*Cyperus rotundus*	+		+	+	+	+
17		*Cenchrus purpureus*						+
18		*Eleusine indica*		+	+		+	+
19		*Cymbopogon citratus*		+				
20		*Oryza sativa*			+			
21	Bush	*Lantana camara*				+	+	
22		*Chromolaena odorata*					+	+
23		*Manihot utilisima*		+				
24		*Ricinus communis*					+	
25	Water plant	*Eichornia crassipes*		+				+
26		*Monochoria vaginalis*		+				+
Total			8	9	4	6	11	8

shrubs, trees, and aquatic plants found on the banks of rivers, lakes, fish ponds, and canals. The types of vegetation at each research location are presented in Table 7.

The location with the most vegetation is in the running water habitat at the BTP river location (2b), which has 11 types of vegetation, while the fish pond location (1b) in the stagnant water habitat has 9 types of vegetation. Based on research conducted by Maldonado-Benítez et al. (2022), the factors that influence the dragonfly community in urban areas are aquatic habitats and riparian vegetation. Riparian vegetation, according to Siahaan and Ai (2014), is a plant located on the edge of aquatic habitats such as rivers and lakes that has an ecological function as a buffer for terrestrial and aquatic ecosystems.

Tree vegetation such as *Samanea saman*, *Pterocarpus indicus*, *Nypa fruticans*, and *Terminalia catappa* provide resting places, perches, and places to monitor territorial areas (Paulson 2009). Shrubs such as *Lantana camara* and *Chromolaena odorata* provide hiding places for adult dragonflies from their predators (Lubis et al. 2021). Aquatic plants such as *Monochoria vaginalis* and *Eichhornia crassipes* help oxygenate the water for nymphs, provide perches for female dragonflies to lay their eggs, and offer hiding places for dragonfly nymphs from predators (Syarifah et al. 2018). Grasses such as *Typha angustifolia* and *Cyperus rotundus* attract many small insects that serve as a food source for dragonflies and provide perching spots (Wijayanto et al. 2016).

CONCLUSIONS

The results of this study identified the composition of dragonflies in Makassar City and Gowa Regency in the dry and rainy seasons in running water and stagnant water habitats, namely 12 species from 2 families. The Shannon Wienner diversity index in both shows a moderate category, the season, namely in the rainy season of H '= 1.72 is higher than in the dry season of H' 1.39. *Brachythemis contaminata* and *Agriocnemis pygmaea* are the most abundant and dominant dragonfly species across all research habitats both in Makassar City and Gowa Regency, including both running and stagnant water habitats. Seasonal abiotic factors and the natural habitat of dragonflies in urban areas are the main causes of dragonfly diversity and abundance, with sufficient rainfall, stable air temperature, and good humidity levels in the rainy season providing ideal conditions for the their life cycle. Urbanisation has led to water pollution in several habitats, such as the Borong Canal and Unhas Lake, with high COD and BOD levels that threaten dragonflies populations. However, in some habitats such as rice fields and rivers, dragonflies are still found. Improved waste management in Makassar City and Gowa Regency is highly recommended to reduce COD and BOD pollution levels and ensure the sustainability of freshwater habitat fauna in urban areas.

AUTHOR CONTRIBUTION

I.M. collected and analysed the data and wrote the manuscript, while S. designed the research and supervised all the processes.

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CONFLICT OF INTEREST

The authors declare that there is no conflict of interest in any part of this research.

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