



















## Water Quality Influences on *Macrobrachium* spp. Shrimp Abundance in the Rongkong Sub Watershed, Indonesia

Jurniati<sup>1</sup>, Asmanik<sup>2</sup>, Aditya P. Iswara<sup>3,4\*</sup>, Anita R. P. Raharjeng<sup>5</sup>, Sonny Kristianto<sup>5</sup>,  
Daniar Kusumawati<sup>2</sup>, Mohammad A. Adam<sup>2</sup>, Reagan Septory<sup>2</sup>, Hasriani A. Lestari<sup>2</sup>, Apri I. Suprii<sup>2</sup>,  
Riza Zulkarnain<sup>5</sup>, Suhardi A. B. Susilo<sup>6</sup>, Dendy Mahabor<sup>6</sup>, Shahbaz Abbas<sup>7</sup>, Acbellita A. Zevhiana<sup>3</sup>,  
Yudi Prastiyono<sup>8</sup>

<sup>1</sup> Aquaculture Study Program, Faculty of Fisheries, Andi Djemma University (UNANDA), Palopo 91922, Indonesia

<sup>2</sup> Mariculture Research Center, National Research and Innovation Agency, Lombok 83352, Indonesia

<sup>3</sup> Department of Disaster Management, Postgraduate School, Airlangga University, Surabaya 60115, Indonesia

<sup>4</sup> Department of Forensic Science, Postgraduate School, Airlangga University, Surabaya 60115, Indonesia

<sup>5</sup> State Islamic University Raden Fatah, Palembang 30267, Indonesia

<sup>6</sup> Environmental Technology and Clean Technology Research Center, National Research and Innovation Agency, Kawasan Sains, Teknologi BJ Habibie, Tangerang Selatan 15314, Indonesia

<sup>7</sup> Systems Analysis Lab, McCormick School of Engineering, Northwestern University, Evanston 60201, USA

<sup>8</sup> Directorate of Scientific Collection Management, Gedung Kehati, Kawasan Sains dan Teknologi (KST) Soekarno, Bogor 16911, Indonesia

Corresponding Author Email: [aditya.prana@pasca.unair.ac.id](mailto:aditya.prana@pasca.unair.ac.id)

Copyright: ©2026 The authors. This article is published by IETA and is licensed under the CC BY 4.0 license (<http://creativecommons.org/licenses/by/4.0/>).

<https://doi.org/10.18280/ijdne.210508>

### ABSTRACT

**Received:** 16 March 2026

**Revised:** 21 May 2026

**Accepted:** 28 May 2026

**Available online:** 31 May 2026

#### Keywords:

Canonical Correspondence Analysis, ecological relationships, *Macrobrachium* spp., Principal Component Analysis, water quality parameters

This study examined the relationship between water quality parameters and the abundance of *Macrobrachium* spp. in three rivers—Waelawi, Salujambu, and Pombakka—within the Rongkong Sub-Watershed, South Sulawesi, Indonesia. Monthly sampling was conducted for one year using mini traps (Kopa'). Shrimp species were identified using morphological characteristics and DNA barcoding. Water quality parameters measured included temperature, Secchi disk transparency, depth, current velocity, dissolved oxygen (DO), pH, nitrite (NO<sub>2</sub>), nitrate (NO<sub>3</sub>), phosphate (PO<sub>4</sub>), calcium (Ca), magnesium (Mg), sodium (Na), potassium (K), hardness, alkalinity, and ammonia (NH<sub>3</sub>). Data were analyzed using two-way analysis of variance (ANOVA), cluster analysis, non-metric multidimensional scaling (nMDS), Pearson correlation, Principal Component Analysis (PCA), and Canonical Correspondence Analysis (CCA). Four *Macrobrachium* species were identified: *Macrobrachium mammillodactylus* (MM), *Macrobrachium idae* (MI), *Macrobrachium latidactylus* (ML), and *Macrobrachium esculentum* (ME). MM dominated all sampling sites, accounting for 64.58–67.99% of total abundance, and exhibited broad ecological adaptability under DO concentrations of 4.39–5.75 mg/L and pH values of 6.09–7.02. ME abundance was positively correlated with water transparency ( $r = 0.606$ ) and peaked during the second transitional season (TS2), whereas ML showed a negative correlation with water transparency ( $r = -0.595$ ) and was more abundant during the eastern monsoon (EM). MI abundance increased during the western monsoon (WM) and was associated with higher potassium concentrations. The CCA model revealed a significant relationship between environmental variables and shrimp distribution ( $F = 4.9111$ ,  $p = 0.003$ ). The most influential environmental parameters were K, temperature, DO, pH, transparency, and NH<sub>3</sub>. These findings highlight the importance of hydrological seasonality and water quality in shaping freshwater shrimp distribution and provide ecological insights for freshwater biodiversity conservation and sustainable watershed management.

## 1. INTRODUCTION

The Rongkong Watershed (DAS Rongkong), located in Luwu and North Luwu Regencies, South Sulawesi Province, Indonesia, covers an area of approximately 190,748 hectares. The Rongkong River is classified as class 3–4 (intermediate), with a gradient of 12–15 m/km, indicating a moderately fast and irregular water flow. Several rivers within the Rongkong

Sub-Watershed, including the Waelawi River, Salujambu River, and Pombakka River, serve as natural habitats for *Macrobrachium* spp. freshwater shrimp.

In recent years, shrimp catches have declined due to a high reliance on fishing in nature, putting great pressure on the natural population of shrimp. In particular, the shrimp population in the Waelawi River is dominated by small-sized individuals, which is characterized by high mortality and

exploitation rates, as well as a low proportion of marketable-sized shrimp. The decline in river water quality is one of the main factors in reducing the diversity of fauna in the ecosystem. The underlying factors of water quality are closely related to the value of physicochemical parameters, as concrete evidence of quantitative analysis. Physicochemical levels are considered more effective and become a strong predictor for environmental assessments, especially when used to analyze multiple tributaries in a watershed [1].

The physicochemical characteristics of the Rongkong Sub-Watershed are strongly influenced by upstream topography, land-use changes, sedimentation, and seasonal hydrological fluctuations [2-4]. Previous research has reported an increase in sediment load, erosion, and nutrient runoff associated with agricultural expansion and deforestation in watersheds, especially during the rainy season, which can alter the quality of aquatic habitats and freshwater biodiversity [2-4]. These environmental changes can affect water transparency, dissolved oxygen (DO), nutrient concentration, and substrate composition, thus impacting the stability of freshwater ecosystems [5-7].

DO reflects the availability of oxygen in aquatic systems, and low levels of DO can reduce water quality and increase shrimp mortality [8-10]. Similarly, a drop in pH due to anthropogenic pollution can inhibit the larval development of *M. rosenbergii*, prolong the larval phase, and decrease the rate of metamorphosis [11]. Temperature also plays an important role because it affects oxygen solubility, chemical reaction rate, toxicity, and microbial activity, thus affecting the distribution, growth, and reproduction of aquatic organisms [12, 13]. Foreign pollutants such as microplastics are also a serious problem for aquatic ecosystems, especially for the organisms within them. Microplastics can increase the level of total suspended solids (TSS) in waters and continue to accumulate in water and aquatic organisms [14, 15]. Rapid industrial development, population growth, intensive land use, aquaculture, and agriculture have increased the pressure on the natural aquatic environment globally [16], thus resulting in waste disposal that disturbs the balance of the ecosystem [17].

Evaluation of physicochemical parameters is especially important for *Macrobrachium* spp. because these freshwater shrimps have a catadromous life cycle and high sensitivity to environmental changes [18-20]. Adult shrimp live in freshwater river systems, whereas larval development requires an estuarine or brackish environment before the postlarval stage migrates upstream [19, 20]. Therefore, fluctuations in DO, pH, temperature, transparency, nutrient concentration, and flow velocity can directly affect migration, larval survival, moulting processes, reproduction, and population distribution [8-13, 21].

Accurate species identification is also of interest in the ecological study of freshwater shrimp because *Macrobrachium* species that have morphological similarities can exhibit overlapping diagnostic characters as well as different ecological responses to environmental conditions. Therefore, DNA barcoding using mitochondrial genes cytochrome c oxidase subunit I (COI) becomes an important complementary tool for species confirmation and biodiversity assessment in freshwater crustaceans.

This study aims to evaluate the physicochemical characteristics of water in the Rongkong Sub-Watershed (Waelawi River, Salujambu, and Pombakka River) and their relationship to the population dynamics of *Macrobrachium* spp. The resulting data may serve as a foundation for more

effective fisheries resource management, conservation strategies, and the application of risk management in aquaculture.

## 2. MATERIALS AND METHOD

### 2.1 Sampling sites

The Waelawi, Salujambu, and Pombakka Rivers were selected because they represent important freshwater shrimp habitats within the downstream area of the Rongkong Sub-Watershed and exhibit differences in hydrological characteristics, land-use influence, and water quality conditions. These rivers are also frequently utilized by local communities for shrimp harvesting activities, making them ecologically and socioeconomically relevant for evaluating freshwater shrimp distribution patterns.

The study was conducted from September 2018 to August 2019 at three river locations: Salujambu, Waelawi, and Pombakka, situated in Luwu and North Luwu Regencies in the downstream area of the Rongkong Sub-Watershed (Figure 1). Three sampling stations were established along each river. Sampling stations for the Waelawi River were located at: Station I: 2°51'05.03"S, 120°18'21.54"E; Station II: 2°51'11.37"S, 120°18'30.41"E; Station III: 2°51'19.05"S, 120°18'43.62"E. Sampling stations for the Salujambu River (SJ): Station I: 2°49'19.51"S, 120°15'18.22"E; Station II: 2°49'24.07"S, 120°15'38.26"E; Station III: 2°50'18.57"S, 120°15'21.18"E. Sampling stations for the Pombakka River (P): Station I: 2°51'34.40"S, 120°16'14.08"E; Station II: 2°52'12.30"S, 120°16'29.23"E; Station III: 2°52'51.29"S, 120°16'24.08"E.

Rainfall data during the study period showed fluctuations, with the highest precipitation recorded in June 2019 (542.2 mm) and the lowest in October 2018 (100.7 mm). The number of rainy days ranged from 9 to 27 days. The Luwu and North Luwu regions fall under climate type A, with an average annual rainfall of 3,500–4,000 mm. The year is divided into four seasons: second transitional season (TS2, September–November), western monsoon (WM, December–February), first transitional season (TS1, March–May), and eastern monsoon (EM, June–August) [1].

### 2.2 Water quality parameters

Water quality measurements and sampling were conducted monthly over 12 months. Water temperature (°C) was measured using a mercury thermometer; water transparency (cm) was assessed with a Secchi disk; and water depth (cm) was measured using a calibrated sounding line. Current velocity (m/s) was measured using a current meter, and DO (mg/L) was measured with a DO meter. Water pH was measured using a pH meter. These six parameters were measured in situ.

Laboratory analysis of nitrite (NO<sub>2</sub>), nitrate (NO<sub>3</sub>), phosphate (PO<sub>4</sub>), and ammonia (NH<sub>3</sub>) concentrations was carried out using a spectrophotometer and expressed in mg/L. Calcium (Ca), magnesium (Mg), sodium (Na), and potassium (K) concentrations were measured using an atomic absorption spectrophotometer, also in mg/L, following the method described by Hagage et al. [22]. Total hardness (mg/L CaCO<sub>3</sub>) was assessed using the Hanna hardness test kit, and alkalinity (mg/L CaCO<sub>3</sub>) was measured using the HANNA Instrument

HI755; both parameters were measured in situ.

Water samples were collected from a depth of 30 cm below the surface at each station using dark-colored bottles or Winkler bottles. The samples were then stored in a cool box [23] and transported to the Water Quality Laboratory, Faculty of Marine and Fisheries Science, Hasanuddin University, for further analysis.

Before field measurements, the DO meter and pH meter were calibrated according to the manufacturer's instructions using standard calibration solutions. The spectrophotometer was calibrated using analytical blanks and standard reference solutions before laboratory analysis. To improve analytical reliability, triplicate water samples were collected at each sampling station during each sampling event.

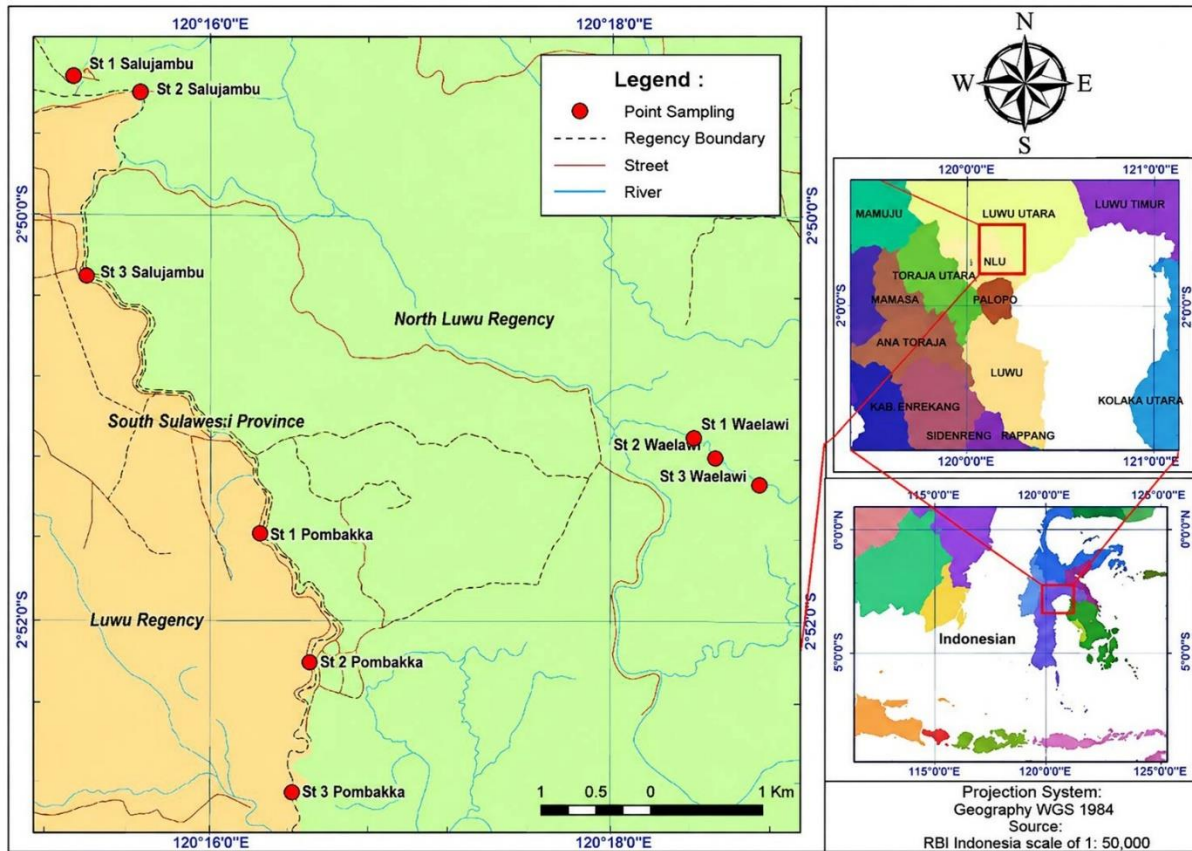


Figure 1. Map of the study area and sampling locations

### 2.3 Shrimp sampling and identification

Sampling of *Macrobrachium* spp. was conducted monthly with the assistance of local fishermen in the early morning using mini bamboo traps (Kopa') baited with coconut or coconut tubers and submerged in the water. A purposive sampling method was applied, with samples collected from three predetermined river locations in the Rongkong Sub-Watershed: W, Salujambu, and P, each with several designated stations.

Collected samples were sorted by species and counted on-site. Specimens that were difficult to identify were placed in cool boxes and transported to the laboratory for further analysis. During the study period, 1,628 individuals were collected from W, 1,657 from Salujambu, and 1,568 from P. Morphological identification of *Macrobrachium* spp. was conducted at the Biology Laboratory of the Indonesian Institute of Sciences (LIPI), Cibinong, Bogor. DNA-based identification was conducted at the Indonesia Biodiversity Laboratory, South Denpasar, Bali, and Genetics Science, Jakarta.

Morphometric measurements followed manuals from previous studies [24, 25], including nine morphometric characters (total length, abdominal length, telson length, carapace length, carapace width, diagonal carapace length, first abdominal segment length, rostrum length, and second

abdominal segment length) and two meristic characters (number of dorsal and ventral rostral teeth). Measurements were based on the protocol of the study [26], using a digital caliper with 0.01 mm accuracy. Sex determination was based on visual morphological differences, as documented in previous studies [27].

Morphologically identified freshwater shrimp samples were further confirmed using DNA barcoding methods. Abdominal muscle tissue was used for DNA extraction, conducted with the Qiagen DNeasy Blood and Tissue Kit (Germany), following the manufacturer's protocol. Genomic DNA was amplified using PCR targeting the COI gene region, with primers jgLCO1490 and jgHCO2198 [28]. Each PCR reaction contained: 4 µL of 10× PCR buffer (Applied Biosystems), 2.5 µL of 10 mM dNTPs, 1.2 µL of 10 mM of each primer, 2 µL of 25 mM MgCl<sub>2</sub>, 0.125 µL of AmpliTaq Gold™ DNA polymerase (Applied Biosystems), and 14.5 µL of ddH<sub>2</sub>O. The same primers were used for *Macrobrachium mamilodactylus* (MM), *Macrobrachium idea* (MI), *Macrobrachium latidactylus* (ML), and *Macrobrachium esculentum* (ME) in this study, as COI gene-based DNA barcoding studies often utilize the same primer set for multiple species within the same genus, provided the species are phylogenetically closely related [29].

The total reaction volume was 25 µL, including 1 µL of DNA template. PCR conditions were as follows: initial

denaturation at 94 °C for 14 seconds, followed by 38 cycles of denaturation at 94 °C for 30 seconds, annealing at 50 °C for 30 seconds, and extension at 72 °C for 45 seconds, with a final extension at 72 °C for 5 minutes. PCR products were visualized on 1% agarose gel stained with Biotium DNA dye. Successful PCR products were sequenced at PT. Genetika Science Indonesia, Jakarta. The forward and reverse sequences were edited using Chromas (<http://technelysium.com.au/wp/chromas/>) and further processed using MEGA 7 software [30]. The resulting sequences were compared to reference sequences of the same genus in the NCBI GenBank database to determine identity (% identity and % query coverage).

## 2.4 Data analysis

Mean values, standard deviations, and species abundance graphs were calculated using Microsoft Excel 2010. Two-way analysis of variance (ANOVA) was used to evaluate differences in water quality parameters across seasons and stations. Cluster analysis was conducted to assess similarities among stations based on shrimp species abundance. A two-dimensional non-metric multidimensional scaling (nMDS) plot was used to visualize and verify the relationship between species abundance and water quality parameters. Pearson correlation coefficients (*r*) were calculated to assess relationships between water quality and shrimp abundance. These analyses were performed using IBM SPSS Statistics 27.

Principal Component Analysis (PCA) was employed to reduce environmental variables and identify relationships among sampling stations and seasons. Before PCA and CCA analyses, Pearson correlation analysis was conducted to identify highly correlated environmental variables. Variables with correlation coefficients  $\geq 0.70$  were considered potentially collinear and evaluated for exclusion to reduce

redundancy among predictors [31]. Environmental variables with PCA loading scores greater than 0.60 were considered ecologically relevant and retained for subsequent CCA analysis [32]. Variables excluded from the final model were those contributing redundant information or showing limited ecological interpretability relative to shrimp distribution patterns.

Kaiser–Meyer–Olkin (KMO) and Bartlett’s tests of sphericity were performed to evaluate sampling adequacy and dataset suitability for multivariate analysis. Bartlett’s test was significant ( $\chi^2 = 79.548$ ;  $p = 0.001$ ), indicating that the correlation matrix was appropriate for PCA. However, the KMO value was relatively low (0.275), likely due to the limited sample size and high dimensionality of environmental variables.

Canonical Correspondence Analysis (CCA) was used to examine the influence of environmental parameters on shrimp abundance. Because the number of environmental variables should not exceed the number of samples, and the dependent variables included four shrimp species, only a maximum of seven environmental variables were retained to maintain model validity. Multicollinearity among retained variables was assessed using the Variance Inflation Factor (VIF), where values exceeding 5 indicated moderate multicollinearity and values above 10 indicated high multicollinearity [33]. PCA and CCA analyses were performed using RStudio.

## 3. RESULTS

### 3.1 Water quality parameters

Mean values of water quality parameters at each sampling station and during each season are presented in Table 1. The results of the two-way ANOVA are shown in Table 2.

**Table 1.** Mean values of water quality parameters across sampling locations

Parameter	N	Sampling Location	TS2	WM	TS1	EM
Temperature (°C)	9	SJ	25.11 ± 1.05	25.22 ± 0.44	25.11 ± 0.93	25.00 ± 1.23
	9	W	25.11 ± 0.60	24.55 ± 0.52	24.77 ± 0.67	24.89 ± 0.93
	9	P	26.66 ± 0.70	25.22 ± 0.66	25.66 ± 0.87	25.56 ± 1.01
Water transparency (cm)	9	SJ	42.22 ± 7.94	38.88 ± 11.11	42.22 ± 10.92	30.56 ± 5.27
	9	W	42.22 ± 7.12	36.66 ± 4.33	30.55 ± 5.27	28.89 ± 5.47
	9	P	38.33 ± 6.12	33.88 ± 9.93	32.77 ± 5.65	36.11 ± 9.61
Water depth (cm)	9	SJ	137.44 ± 18.06	137.88 ± 11.07	137.22 ± 7.95	133.89 ± 11.40
	9	W	139.66 ± 22.82	151.11 ± 9.61	148.22 ± 5.36	147.78 ± 3.63
	9	P	122.22 ± 28.18	132.77 ± 13.71	140.55 ± 11.02	140.78 ± 9.44
Current velocity (m/s)	9	SJ	0.25 ± 0.01	0.26 ± 0.01	0.26 ± 0.02	0.27 ± 0.02
	9	W	0.27 ± 0.01	0.29 ± 0.01	0.28 ± 0.02	0.29 ± 0.02
	9	P	0.27 ± 0.03	0.30 ± 0.02	0.32 ± 0.03	0.30 ± 0.03
DO (mg/L)	9	SJ	4.51 ± 0.46	5.44 ± 1.68	5.29 ± 0.71	5.44 ± 0.95
	9	W	4.68 ± 1.10	5.30 ± 1.76	5.14 ± 0.50	5.49 ± 0.47
	9	P	4.39 ± 0.48	5.75 ± 1.65	5.32 ± 1.18	5.45 ± 1.03
pH	9	SJ	7.02 ± 0.69	6.55 ± 0.64	6.62 ± 0.59	6.77 ± 0.77
	9	W	6.72 ± 0.54	6.61 ± 0.52	6.68 ± 0.36	6.86 ± 0.46
	9	P	6.91 ± 0.54	6.09 ± 0.66	6.52 ± 0.64	6.74 ± 0.74
NO <sub>2</sub> (mg/L)	9	SJ	0.04 ± 0.03	0.05 ± 0.01	0.05 ± 0.02	0.06 ± 0.01
	9	W	0.05 ± 0.03	0.05 ± 0.01	0.04 ± 0.02	0.06 ± 0.01
	9	P	0.04 ± 0.03	0.17 ± 0.29	0.06 ± 0.07	0.06 ± 0.01
NO <sub>3</sub> (mg/L)	9	SJ	0.02 ± 0.01	0.08 ± 0.03	0.05 ± 0.02	0.06 ± 0.02
	9	W	0.02 ± 0.01	0.06 ± 0.03	0.07 ± 0.03	0.04 ± 0.02
	9	P	0.08 ± 0.10	0.09 ± 0.03	0.08 ± 0.03	0.07 ± 0.02
PO <sub>4</sub> (mg/L)	9	SJ	0.74 ± 0.16	0.42 ± 0.31	0.69 ± 0.18	0.89 ± 0.08
	9	W	0.70 ± 0.14	0.55 ± 0.29	0.74 ± 0.17	0.82 ± 0.19
	9	P	0.87 ± 0.10	0.49 ± 0.32	0.91 ± 0.12	1.03 ± 0.11
Ca (mg/L)	9	SJ	1.63 ± 0.57	2.32 ± 0.46	3.05 ± 0.54	3.34 ± 0.27
	9	W	2.27 ± 0.86	3.06 ± 0.66	2.95 ± 0.77	2.97 ± 0.56

Mg (mg/L)	9	P	3.06 ± 1.22	3.63 ± 0.79	3.89 ± 0.27	4.18 ± 0.67
	9	SJ	3.45 ± 0.60	3.8 ± 0.43	3.65 ± 0.24	3.31 ± 0.49
	9	W	3.76 ± 0.58	3.86 ± 0.40	3.51 ± 0.64	3.28 ± 0.64
	9	P	4.18 ± 0.51	3.98 ± 0.50	4.11 ± 0.49	4.04 ± 0.37
Na (mg/L)	9	SJ	6.98 ± 1.63	5.42 ± 0.52	5.93 ± 1.47	5.99 ± 0.75
	9	W	8.47 ± 2.27	6.59 ± 0.78	6.93 ± 0.61	7.12 ± 0.93
	9	P	7.18 ± 0.90	6.28 ± 0.41	6.71 ± 0.65	7.32 ± 0.77
K (mg/L)	9	SJ	2.38 ± 1.15	3.08 ± 1.11	2.16 ± 0.77	2.48 ± 0.33
	9	W	2.60 ± 0.86	2.51 ± 0.29	2.36 ± 0.21	2.46 ± 0.37
	9	P	3.28 ± 0.86	3.63 ± 1.05	2.67 ± 0.43	3.57 ± 0.50
Hardness (mg/L CaCO <sub>3</sub> )	9	SJ	33.66 ± 10.67	50.44 ± 18.18	32.44 ± 5.68	34.56 ± 8.44
	9	W	27.44 ± 5.85	44.22 ± 16.85	33.56 ± 6.69	30.11 ± 7.85
	9	P	33.11 ± 9.33	57.44 ± 24.59	34.11 ± 5.71	31.33 ± 6.54
Alkalinity (mg/L CaCO <sub>3</sub> )	9	SJ	35.88 ± 8.31	46.66 ± 17.85	40.44 ± 6.52	36.00 ± 7.73
	9	W	41.00 ± 6.74	41.66 ± 9.13	38.44 ± 6.84	31.78 ± 4.97
	9	P	58.11 ± 9.79	50.77 ± 15.73	62.00 ± 8.79	54.56 ± 8.32
NH <sub>3</sub> (mg/L)	9	SJ	0.0003 ± 0.0001	0.0004 ± 0.0003	0.0003 ± 0.0001	0.0003 ± 0.0001
	9	W	0.0002 ± 0.00009	0.0003 ± 0.00014	0.0002 ± 0.00007	0.0002 ± 0.00009
	9	P	0.0003 ± 0.00012	0.0003 ± 0.00008	0.0003 ± 0.00007	0.0002 ± 0.0001

Notes: N = number of samples; W = Waelawi River; SJ = Salujambu River; P = Pombakka River; TS2 = Transition Season 2; WM = West Monsoon; TS1 = Transition Season 1; EM = East Monsoon.

**Table 2.** Two-way analysis of variance (ANOVA) results for water quality parameters

Parameter	Unit	Station Effect (df = 2, 96), p-value	Season Effect (df = 3, 96), p-value
Water temperature	°C	< 0.001**	0.041*
Water transparency	cm	0.017*	0.026*
Water depth	cm	0.001**	0.099
Current velocity	m/s	< 0.001**	0.001**
Dissolved oxygen (DO)	mg/L	0.957	0.005*
pH	-	0.403	0.030*
NO <sub>2</sub>	mg/L	0.158	0.229
NO <sub>3</sub>	mg/L	0.003**	0.004**
PO <sub>4</sub>	mg/L	0.005*	0.000**
Ca	mg/L	< 0.001**	0.000**
Mg	mg/L	< 0.001**	0.071
Na	mg/L	< 0.001**	0.000**
K	mg/L	0.004**	0.013*
Hardness	mg/L CaCO <sub>3</sub>	0.169	0.170
Alkalinity	mg/L CaCO <sub>3</sub>	< 0.001**	0.101
NH <sub>3</sub>	mg/L	< 0.001**	0.009*

Notes: Two-way ANOVA was performed to evaluate the effects of sampling station and season on water quality parameters. Degrees of freedom were 2 and 96 for station effects and 3 and 96 for season effects. \*  $p < 0.05$ ; \*\*  $p < 0.01$ .

### Water temperature and transparency

Significant differences in water temperature were found between seasons ( $p < 0.05$ ) and stations ( $p < 0.01$ ). The highest temperature was recorded at Pombakka during TS2 ( $26.667 \pm 0.707$  °C), and the lowest at Waelawi during WM ( $24.556 \pm 0.527$  °C). Transparency also differed significantly between seasons and stations ( $p < 0.05$ ), with the highest value recorded in Salujambu during TS1 ( $42.222 \pm 10.929$  cm) and the lowest in Waelawi during EM ( $28.889 \pm 5.465$  cm).

### Depth and current velocity

Water depth varied significantly between stations ( $p < 0.01$ ) but not between seasons. The deepest measurement was recorded at Waelawi ( $151.111 \pm 9.611$  cm), and the shallowest at Pombakka ( $122.222 \pm 28.186$  cm). Current velocity showed significant variation across both seasons and stations ( $p < 0.01$ ), with the highest recorded at P during TS1 ( $0.322 \pm 0.026$  m/s), and the lowest at Salujambu during TS2 ( $0.254 \pm 0.015$  m/s).

### DO and pH

DO and pH both differed significantly across seasons ( $p < 0.05$ ). The highest DO level was observed during WM ( $5.750 \pm 1.654$  mg/L), and the lowest during TS2 at Pombakka ( $4.390 \pm 0.481$  mg/L). The highest pH was recorded in Salujambu during TS2 ( $7.023 \pm 0.699$ ), and the lowest in Pombakka

during WM ( $6.090 \pm 0.660$ ).

### Nutrients and ions

NO<sub>3</sub> levels varied significantly across both seasons and stations ( $p < 0.01$ ), with the highest value observed in Pombakka during WM ( $0.092 \pm 0.039$  mg/L), and the lowest in Waelawi during TS2 ( $0.020 \pm 0.010$  mg/L). PO<sub>4</sub> also differed significantly ( $p < 0.01$  for seasons;  $p < 0.05$  for stations), with the highest concentration recorded in Pombakka during EM ( $1.034 \pm 0.111$  mg/L), and the lowest in Salujambu during WM ( $0.426 \pm 0.312$  mg/L).

### Calcium and sodium

Both Ca and Na showed significant differences across seasons and stations ( $p < 0.01$ ). The highest Ca level was recorded in Pombakka during EM ( $4.18 \pm 0.67$  mg/L), whereas the lowest was recorded in Salujambu during TS2 ( $1.63 \pm 0.57$  mg/L). The highest Na concentration was found in Waelawi during TS2 ( $8.477 \pm 2.274$  mg/L), while the lowest was in Salujambu during WM ( $5.423 \pm 0.529$  mg/L).

### Magnesium and potassium

Mg differed significantly across stations ( $p < 0.01$ ), but not across seasons. The highest Mg level was found in Pombakka ( $4.180 \pm 0.511$  mg/L), and the lowest in Waelawi ( $3.276 \pm 0.643$  mg/L). K showed significant differences between both stations and seasons ( $p < 0.01$  and  $p < 0.05$ , respectively). The

highest K concentration was observed in Pombakka during WM ( $3.630 \pm 1.059$  mg/L), and the lowest in Salujambu during TS1 ( $2.160 \pm 0.769$  mg/L).

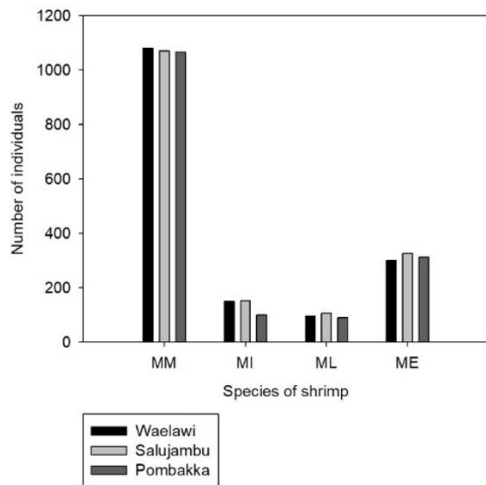
**Alkalinity and ammonia**

Alkalinity varied significantly between stations ( $p < 0.01$ ), with the highest value in Pombakka ( $62.000 \pm 8.789$  mg/L  $\text{CaCO}_3$ ) and the lowest in Waelawi ( $31.778 \pm 4.969$  mg/L  $\text{CaCO}_3$ ).  $\text{NH}_3$  showed significant differences between both stations ( $p < 0.01$ ) and seasons ( $p < 0.05$ ). The highest  $\text{NH}_3$  concentration was found in Salujambu during WM ( $0.0004 \pm 0.0003$  mg/L), and the lowest in Pombakka during EM ( $0.0002 \pm 9.72\text{E-}05$  mg/L).

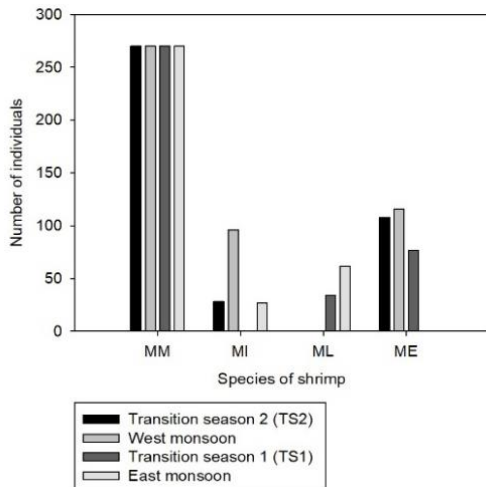
**Species diversity and seasonal abundance of shrimp**

Four shrimp species belonging to the genus *Macrobrachium* were recorded from the three river stations: MM, *M. idae* (MI), ML, and ME. MM was the most abundant species, accounting for 67.99%, 66.34%, and 64.58% of total abundance in P, W, and the Salujambu, respectively (Figure 2).

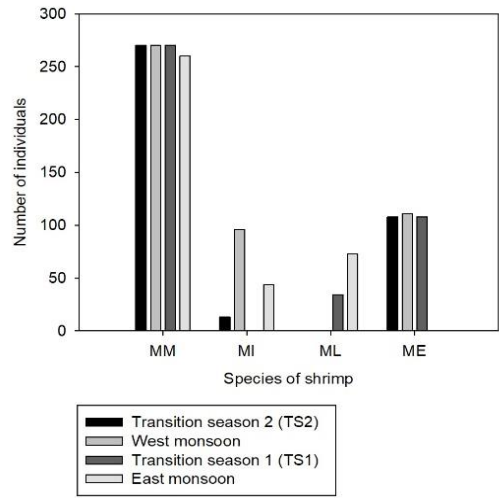
Following MM, the next most abundant species was ME, followed by MI, which was found at all three sites. The least abundant species overall was ML, which accounted for 5.89% in W, 6.46% in Salujambu, and 5.74% in Pombakka. Figure 3 shows the seasonal abundance of each species by station. MM was present in all seasons and at all stations, while the other three species were not consistently present across all seasons.



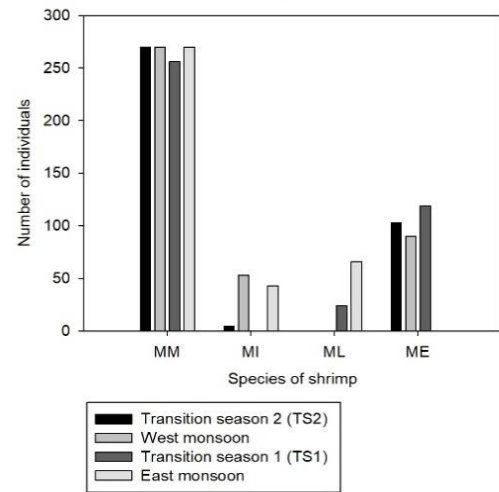
**Figure 2.** Diversity and abundance of different *Macrobrachium* species were collected from the Waelawi (W), Salujambu (SJ), and Pombakka (P) Rivers



(a) W — Waelawi River



(b) SJ — Salujambu River

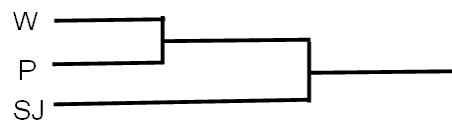


(c) P — Pombakka River

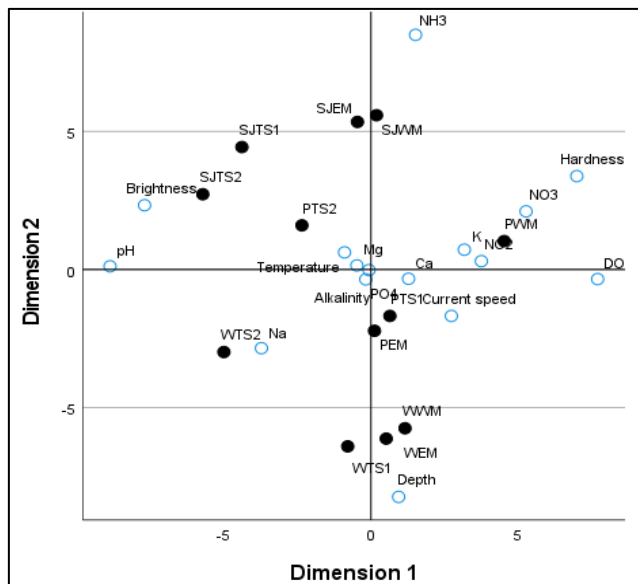
**Figure 3.** Total abundance of prawn species across four seasons: Transition Season 2 (TS2), West Monsoon (WM), Transition Season 1 (TS1), and East Monsoon (EM) at three sampling stations

**3.2 Cluster analysis and non-metric multidimensional scaling**

The cluster analysis (Figure 4) based on species abundance at different stations revealed that stations Waelawi and Pombakka were more similar to each other, forming a single cluster, whereas Salujambu formed a separate branch. The nMDS analysis (Figure 5) produced a stress value of 0.019, indicating a very good model fit. Pombakka–West Monsoon (PWM) and Salujambu–West Monsoon (SJWM) were located within the same quadrant. PWM was positioned close to  $\text{NO}_3$ , K, and  $\text{NO}_2$ , indicating that these parameters were highest in Pombakka during the WM. SJWM was near  $\text{NH}_3$ , suggesting that  $\text{NH}_3$  concentration peaked at Salujambu during this season.



**Figure 4.** Dendrogram showing the similarity among sampling stations based on the abundance of shrimp species



**Figure 5.** Non-metric multidimensional scaling (nMDS) plot of physicochemical parameters across different locations and seasons

Notes: SJTS2 = Salujambu Transition Season 2; SJWM = Salujambu West Monsoon; SJTS1 = Salujambu Transition Season 1; SJEM = Salujambu East Monsoon; WTS2 = Waelawi Transition Season 2; WWM = Waelawi West Monsoon; WTS1 = Waelawi Transition Season 1; WEM = Waelawi East Monsoon; PTS2 = Pombakka Transition Season 2; PWM = Pombakka West Monsoon; PTS1 = Pombakka Transition Season 1; PEM = Pombakka East Monsoon.

SJTS2, SJTS1, SJEM, and PTS2 were also grouped in the same quadrant. SJTS2 and SJTS1 were close to the transparency vector, indicating higher water clarity at these stations. SJEM was not near any specific parameter, implying no dominant environmental influence. PTS2 was located near Mg and temperature, suggesting that magnesium concentration and temperature were highest at Pombakka during TS2. The vectors for pH and DO were aligned with the

x-axis and distant from all stations, indicating relatively uniform values across sites.

WTS2 and WTS1 were clustered together, and WTS2 was close to the sodium (Na) vector, indicating the highest sodium concentration occurred at Waelawi during TS2. PEM and PTS1 were in the same quadrant as WWM and WEM. PEM and PTS1 were close to current velocity, phosphate (PO<sub>4</sub>), and calcium (Ca), indicating elevated values of these parameters at those stations. WWM and WEM were close to the depth vector, indicating deeper water levels at Waelawi during the west and east monsoons.

### 3.3 Karl Pearson correlation coefficient

Table 3 presents the Karl Pearson correlation coefficients between water quality parameters and prawn species abundance. Significant negative correlations ( $p < 0.05$ ) were found between: pH and DO ( $r = -0.67$ ); NO<sub>3</sub> and pH ( $r = -0.59$ ); Hardness and Na ( $r = -0.61$ ); MI abundance and PO<sub>4</sub> ( $r = -0.59$ ); ML abundance and transparency ( $r = -0.59$ ). Significant positive correlations ( $p < 0.05$ ) included: Ca and DO ( $r = 0.58$ ); Ca and NO<sub>3</sub> ( $r = 0.62$ ); Mg and temperature ( $r = 0.65$ ); Mg and NO<sub>3</sub> ( $r = 0.58$ ); K and NO<sub>2</sub> ( $r = 0.59$ ); K and NO<sub>3</sub> ( $r = 0.58$ ); K and Mg ( $r = 0.69$ ); Hardness and NO<sub>2</sub> ( $r = 0.69$ ); Hardness and NO<sub>3</sub> ( $r = 0.63$ ); Alkalinity and NO<sub>3</sub> ( $r = 0.64$ ); Alkalinity and K ( $r = 0.67$ ); NH<sub>3</sub> and hardness ( $r = 0.63$ ); MI abundance and hardness ( $r = 0.67$ ); ML abundance and PO<sub>4</sub> ( $r = 0.655$ ); ME abundance and transparency ( $r = 0.606$ ).

Highly significant negative correlations ( $p < 0.01$ ) were observed between: Depth and temperature ( $r = -0.79$ ); NO<sub>2</sub> and pH ( $r = -0.78$ ); Hardness and pH ( $r = -0.76$ ); PO<sub>4</sub> and hardness ( $r = -0.76$ ); NH<sub>3</sub> and Na ( $r = -0.745$ ); ME and ML abundances ( $r = -0.89$ ). Highly significant positive correlations ( $p < 0.01$ ) were recorded for: Ca and current velocity ( $r = 0.77$ ); Alkalinity and temperature ( $r = 0.75$ ); Alkalinity and Mg ( $r = 0.94$ ).

**Table 3.** Karl Pearson correlation coefficient (r) between physicochemical parameters and prawn abundance

	T	B	D	CS	DO	pH	NO <sub>2</sub>	NO <sub>3</sub>	PO <sub>4</sub>	Ca	Mg	Na	K	HN	A	NH <sub>3</sub>	M	MI	ML	M	
																	M	MI	ML	M	
T	1																				
B	0.19	1																			
D	0.79**	-0.31	1																		
CS	0.06	-0.52	0.30	1																	
DO	0.43	-0.56	0.36	0.51	1																
pH	0.15	0.17	-0.01	-0.57	0.67*	1															
NO <sub>2</sub>	0.01	-0.24	-0.23	0.47	0.52	0.78*	1														
NO <sub>3</sub>	0.34	-0.39	-0.24	0.51	0.45	-0.59*	0.43	1													
PO <sub>4</sub>	0.41	-0.27	-0.13	0.15	-0.20	0.53	-0.32	-0.16	1												
Ca	0.24	-0.53	-0.02	0.77**	0.58*	-0.45	0.39	0.62*	0.44	1											
Mg	0.65*	0.27	-0.37	0.50	-0.07	-0.40	0.25	0.58*	-0.02	0.43	1										
Na	0.16	0.14	0.11	0.12	-0.54	0.38	-0.18	-0.54	0.42	0.10	0.08	1									
K	0.54	-0.03	-0.46	0.39	0.19	-0.42	0.59*	0.58*	-0.01	0.45	0.69*	0.01	1								
HN	0.14	-0.06	-0.10	0.22	0.49	0.76*	0.69*	0.63*	0.76*	0.08	0.29	-0.61*	0.48	1							
A	0.75**	0.07	-0.44	0.56	-0.02	-0.36	0.25	0.64*	0.21	0.57	0.94*	0.02	0.67*	0.19	1						

NH <sub>3</sub>	0.2 2	0.28	-0.44	-0.28	0.08	-0.19	0.09	0.45	-0.45	0.1 7	0.28	-	0.27	<b>0.63</b> *	0.2 6	1					
MM	-	0.1 3	0.41	0.08	-0.35	-0.20	0.10	0.00	-0.19	-0.41	0.4 1	-0.04	0.19	0.16	0.13	0.3 1	-0.10	1			
MI	-	0.3 6	0.01	0.23	0.07	0.41	-0.33	0.24	0.26	<b>-0.59</b> *	0.0 4	0.11	-0.37	0.31	<b>0.67</b> *	0.0 8	0.49 1	0.20	1		
ML	-	0.1 7	<b>0.59</b> *	0.22	0.11	0.45	0.23	-0.15	-0.07	<b>0.66</b> *	0.4 9	-0.46	-0.06	-0.15	-0.45	0.2 5	-0.37	0.32	0.1 9	1	
ME	0.1 3	<b>0.61</b> *	-0.13	-0.17	-0.40	-0.24	-0.05	0.07	-0.55	-	0.3 9	0.45	-0.06	-0.12	0.29	0.2 9	0.35	0.08	0.0 1	<b>0.89</b> *	1

Notes: \* indicates a significant correlation ( $p < 0.05$ ), \*\* indicates a very significant correlation ( $p < 0.01$ ). T = water temperature, B = brightness, D = depth, CS = current speed, DO = dissolved oxygen, NO<sub>2</sub> = nitrite, NO<sub>3</sub> = nitrate, PO<sub>4</sub> = phosphate, Ca = Calcium, Mg = Magnesium, Na = Sodium, K = Potassium, NH = hardness, A = alkalinity, NH<sub>3</sub> = ammonia, MM = *Macrobrachium mammillodactylus*, MI = *Macrobrachium idae*, ML = *Macrobrachium latidactylus*, ME = *Macrobrachium esculentum*.

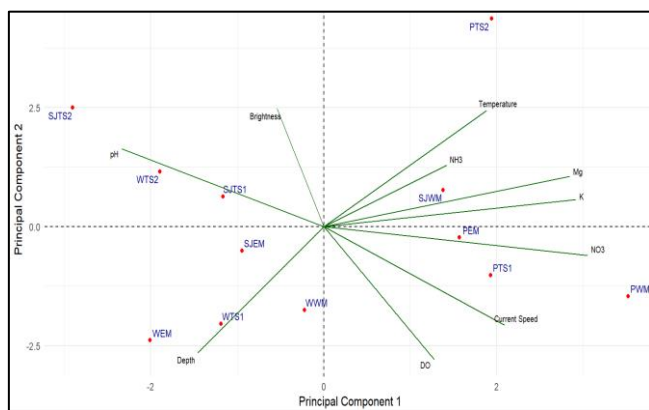
### 3.4 Principal Component Analysis

The PCA results identified three principal components (PCs) with eigenvalues greater than 1, cumulatively explaining 80.02% of the total variance: PC1 (36.98%), PC2 (30.41%), and PC3 (12.63%). The loading scores of the environmental variables for each principal component are presented in Table 4.

**Table 4.** Principal Component Analysis (PCA) of ten water quality parameters across different sampling sites

Variable	PC1	PC2	PC3
Temperature	0.5371	<b>0.6950</b>	0.3641
Transparency	-0.1542	<b>0.7084</b>	-0.2072
Depth	-0.4163	<b>-0.7562</b>	0.0914
Current velocity	0.5970	-0.5926	0.4607
DO	0.3650	<b>-0.7979</b>	-0.3322
pH	<b>-0.6670</b>	0.4646	0.2848
NO <sub>3</sub>	<b>0.8719</b>	-0.1729	-0.1558
Mg	<b>0.8125</b>	0.3008	0.2433
K	<b>0.8324</b>	0.1600	0.1127
NH <sub>3</sub>	0.4058	0.3676	<b>-0.7610</b>

Notes: Significant loading scores ( $>0.60$ ) are indicated in bold for the first two principal components (PCs with eigenvalues  $> 1$ ).



**Figure 6.** Principal Component Analysis (PCA) biplot of the first two principal components showing the relationship between physicochemical parameters across various locations and seasons

The biplot in Figure 6 shows sampling station distribution based on the first two principal components (PC1 and PC2) derived from PCA. PC1 (horizontal axis) accounts for 36.98% of the total variance, while PC2 (vertical axis) accounts for 30.41%, together explaining 67.39% of the total variation. The scatter plot focuses on PC1 and PC2, as these components represent the highest variation and allow for an intuitive two-

dimensional interpretation. The positioning of stations reflects the environmental similarities among sampling sites; SJTS1, SJTS2, and WTS2 align with the pH vector, indicating relatively high pH levels at these locations; WEM, WTS1, WWM, and SJEM cluster in the same quadrant, suggesting a strong influence of depth in these areas; PWM, PTS1, and PEM are closely associated with the vectors for NO<sub>3</sub> and current velocity, indicating higher values of these parameters at those sites; SJWM is situated near the arrows for temperature, NH<sub>3</sub>, Mg, and K, suggesting elevated levels of these variables in this location; PTS2, though located further from the plot center, is directed toward the vectors for temperature and NH<sub>3</sub>, indicating likely high values for those parameters. In contrast, transparency and DO show shorter arrows and no clear association with specific stations, implying a lower contribution in differentiating site characteristics.

### 3.5 Canonical Correspondence Analysis

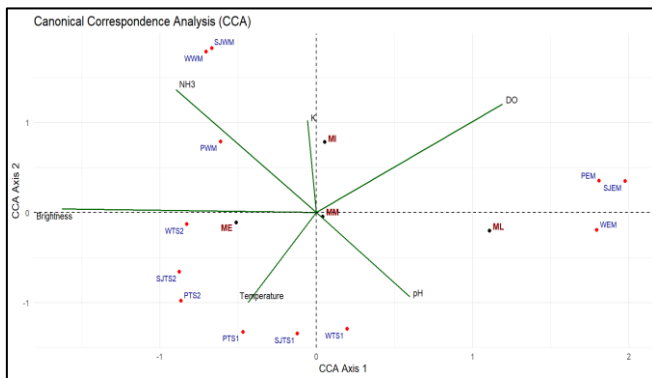
The CCA yielded a total inertia of 0.219, with 85.49% of the variation (0.18723) explained by environmental (constrained) variables, and the remaining 14.51% (0.03177) attributed to unexplained (unconstrained) variation. The first component (CCA1) accounted for 57.77% of the variation, followed by CCA2 (26.15%) and CCA3 (1.57%). Cumulatively, these three components explained 85.49% of the total variation, indicating that the CCA model effectively captures the relationship between shrimp abundance and environmental variables. The NO<sub>3</sub> variable was excluded from the VIF analysis because it was used as the dependent variable in the regression model.

Several environmental variables were excluded from the final CCA model because they showed high intercorrelation and contributed redundant ecological information. The variable reduction approach was intended to minimize multicollinearity effects and improve model interpretability. Variables retained in the final model represented the strongest environmental gradients identified by PCA and showed the highest ecological relevance to shrimp distribution patterns.

As shown in Table 5, eight environmental variables identified from the PCA results were initially evaluated for multicollinearity using the VIF. Mg and current velocity exhibited high VIF values ( $>10$ ), indicating substantial multicollinearity. Therefore, these variables were excluded from the final CCA model. The final CCA analysis retained six environmental variables (K, temperature, DO, pH, transparency, and NH<sub>3</sub>) that showed lower multicollinearity and greater ecological relevance.

**Table 5.** Preliminary Variance Inflation Factor (VIF) screening of eight environmental variables selected from the PCA results prior to Canonical Correspondence Analysis (CCA)

Variable	VIF
Mg	17.513
Current Velocity	13.167
DO	5.147
Transparency	5.850
Temperature	4.768
pH	3.371
K	2.895
NH <sub>3</sub>	2.872



**Figure 7.** Canonical Correspondence Analysis (CCA) biplot illustrates the relationship between environmental parameters and the abundance of shrimp species across different sampling locations

The VIF analysis indicated relatively high multicollinearity for Mg (17.513) and current velocity (13.167), suggesting potential redundancy among several environmental predictors. In contrast, K, pH, temperature, and NH<sub>3</sub> exhibited lower VIF values, indicating more stable contributions to the CCA model. Despite some residual multicollinearity, the retained variables represented ecologically important gradients influencing shrimp abundance and habitat distribution.

The CCA biplot (Figure 7) illustrates the relationships among physicochemical parameters, shrimp species abundance, and sampling locations. NH<sub>3</sub> was concentrated in PWM, SJWM, and WWM. Sampling sites WTS2, SJTS2, and PTS2 were positioned between the vectors for transparency and temperature, indicating higher levels of both parameters. PTS1, SJTS1, and WTS1 were located between temperature and pH vectors, suggesting elevated values of both at these sites. Transparency and potassium (K) contributed significantly to their respective dimensions.

Locations PEM, SJEM, and WEM were not closely associated with any environmental vectors or species, indicating more uniform or lower environmental conditions during the east monsoon. ME was more abundant in clearer waters, particularly during TS2, as supported by the positive correlation ( $r = 0.606$ ). MM was evenly distributed and not associated with any specific environmental variable. ML was more prevalent in WEM, PEM, and SJEM and showed a negative correlation with transparency ( $r = -0.595$ ). MI tended to be associated with potassium (K), though the correlation was weak ( $r = 0.309$ ).

As shown in Figure 3 and Table 1, MI was abundant during the west monsoon (WM) but absent in TS1, likely due to increasing K levels from TS1 to WM.

**Table 6.** Significance test results of the Canonical Correspondence Analysis (CCA) model

Component	df	ChiSquare	F	Pr(>F)
Model	6	0.1872	4.9111	0.003 **
Residual	5	0.0318		

Notes: df = degrees of freedom; Chi-Square = chi-square statistic; F = test statistic; Pr(>F) = p-value based on permutation distribution.

The significance test for the CCA model indicated a statistically significant relationship between environmental variables and shrimp abundance. As shown in Table 6, a high F-value (4.9111) and a low p-value (0.003) suggest that the model meaningfully explains the variation in shrimp distribution. At a 1% significance level ( $\alpha = 0.01$ ), the results strongly support the conclusion that the six environmental variables used in the model—K, temperature, DO, pH, transparency, and NH<sub>3</sub>—play a significant role in influencing shrimp distribution at the study sites. Thus, it can be concluded that the relationships identified between environmental factors and shrimp abundance patterns are not random but reflect genuine ecological associations.

## 4. DISCUSSIONS

### 4.1 Physicochemical parameters

Water quality plays a critical role in natural environments, as it helps organisms maintain optimal physiological conditions. Poor physicochemical characteristics can lead to reduced productivity and economic losses [34]. DO concentrations of 4–5 mg/L or higher are considered optimal for aquaculture production [35], whereas levels below 2.0 mg/L are generally associated with limited growth and increased mortality risk [36].

In this study, DO concentrations varied significantly across seasons. Higher DO levels during the rainy season compared to the dry season may be attributed to seasonal stratification, driven by temperature-dependent water density. This indicates that cooler water is more capable of retaining DO [37].

Species of *Macrobrachium* exhibit variable minimum and maximum temperature thresholds depending on life stage, with a tolerance range of 13–43 °C [38]. Temperature is a key factor regulating growth rate, feed intake, feed conversion, survival rate, and disease resistance in prawns [39]. In this study, water temperature was highest during Transition Season 2 (TS2).

According to Booker and Whitehead [40], there is an inverse relationship between river temperature and flow rate. Lower flow rates are typically associated with warmer water, especially when other factors such as season, solar radiation, air temperature, and soil temperature remain constant. Reduced flow leads to a disproportionate reduction in surface area because river width and flow decrease exponentially, resulting in narrower channels that tend to warm more quickly [41].

The higher water temperature observed in the Pombakka River may be explained by several interacting factors. River morphology, particularly depth, influences thermal dynamics, as shallow systems tend to warm more rapidly due to smaller water volumes that are more sensitive to atmospheric conditions. Low flow velocity further enhances heat accumulation through prolonged solar exposure. In addition, local environmental conditions, such as higher ambient

temperatures and reduced riparian vegetation cover, can increase heat absorption. Anthropogenic activities, including agriculture and settlement development, may also contribute through thermal inputs and the removal of shading vegetation. Furthermore, elevated nutrient concentrations may stimulate algal photosynthesis, indirectly influencing thermal conditions. These combined factors likely account for the higher temperatures observed in the Pombakka River relative to other sites.

Seasonal changes were also found to affect water pH, as noted in other studies [42-44]. In this study, pH tended to be lower during the rainy season. This is likely due to increased surface runoff following rainfall events, which carry more organic material into rivers, thereby lowering pH values [45].

Natural factors such as rainfall, wind speed, and temperature also influence Secchi Disk Depth (SDD). Increased rainfall contributes to higher river runoff, which in turn transports more suspended solids like sediment into the water, resulting in reduced transparency [46]. The dry season can also affect water quality due to higher temperatures, longer water residence time, and increased nutrient concentrations—conditions that promote algal growth [47]. This growth reduces water clarity, further lowering SDD. Elevated nutrient levels during dry periods are linked to reduced dilution capacity of water bodies [48].

Natural surface water typically contains less than 5 mg/L of potassium (K) [49]. In this study, concentrations of K and NH<sub>3</sub> were generally higher during the rainy season. Increased rainfall may reduce potassium fixation and uptake in soils, thereby promoting leaching, runoff, and erosion that transport potassium into aquatic ecosystems [50]. Additionally, rainfall-induced runoff during the wet season mobilizes fertilizers from agricultural fields, increasing the concentrations of NO<sub>3</sub>-N and NH<sub>3</sub>-N in surface waters [51].

The NH<sub>3</sub> concentrations observed in this study were extremely low, indicating relatively low NH<sub>3</sub> contamination in the studied rivers. These low concentrations may reflect the oligotrophic characteristics of the freshwater system and limited organic waste inputs during the sampling period.

## 4.2 Variation in abundance of prawn species

In this study, variation in prawn species abundance was observed across different locations and seasons. Among the four species recorded, MM was the most dominant, contributing 67.99%, 66.34%, and 64.58% of total abundance in Pombakka, Waelawi, and the Salujambu River, respectively. This was followed by ME, with relative abundances of 18.49%, 19.74%, and 19.89% in Waelawi, Salujambu River, and Pombakka, respectively.

MM exhibited high abundance across all seasons, suggesting that the aquatic environment in these rivers provides suitable habitat conditions for this species [18]. A study by Jurniati et al. [52] on the morphometric and meristic characteristics of MM from the Waelawi, Salujambu, and Pombakka rivers concluded that the observed weights were higher than predicted values. The mean condition factor ( $Wr > 100$  and  $k > 1$ ) indicated adequate food availability and low predation pressure. MM has also been reported as a dominant species in the Petagas River, along with *M. rosenbergii* [53]. Specimens of MM were collected from freshwater-submerged tree roots in the lower river zones, with water temperatures around 26.5 °C [54].

ME has only been documented in Indonesia, the Philippines, and Taiwan [55]. It showed high abundance

during TS2, WM, and TS1, but was absent during the east monsoon (EM). MI was found during TS2, WM, and EM, but was not recorded in TS1. ML was found during TS1 and EM, but was absent during TS2 and WM. These seasonal appearances may be explained by temporal ontogenetic separation, as prawn species exhibit distinct migration periods and recruitment patterns. Such seasonal distributions suggest interspecific strategies to reduce ecological interactions. Seasonal peaks in abundance are influenced by habitat suitability and environmental factors, each with varying strengths [18]. Seasonal change has been shown to significantly affect *Macrobrachium* distribution and habitat preferences [56].

In general, prawn abundance increased during the rainy season, consistent with findings by Kingdom et al. [57]. Increased freshwater flow into estuarine areas likely stimulates seasonal migration of prawns toward the sea, resulting in a preliminary rise in adult prawn abundance in adjacent marine waters. It is hypothesized that disturbance of estuarine sediments, routine burrowing, and respiration activities due to enhanced river discharge contribute to this emigration. This early increase in adult abundance enhances reproductive potential, while high rainfall indirectly supports juvenile recruitment, growth, and survival, ultimately increasing prawn populations in the following year.

Extended dry conditions negatively impact prawn populations and often result in reduced population sizes [58-60]. It was reported that a lower percentage of adult individuals of *Atya lanipes* and *Xiphocaris elongata* were gravid during drought conditions. Even in tropical rainforest biomes, prolonged drought can significantly alter aquatic communities through local density effects due to habitat shrinkage, ultimately resulting in long-term reproductive declines.

## 4.3 Influence of water quality on the abundance of prawn species

In tropical regions, key factors influencing the distribution and abundance of prawns include temperature, salinity, nutrient levels, and substrate composition [61]. In this study, MM was found across all seasons and sites, indicating a wide tolerance range to variations in water quality parameters. ME was more abundant in clearer waters, particularly during Transition Season 2 (TS2). This is similar to *M. macrobrachion*, which prefers higher water visibility and shows a positive correlation with Secchi disk transparency [57].

Secchi disk transparency influences light penetration in the water column, affecting photosynthesis and algal growth. Highly turbid waters limit light penetration, reducing both water temperature and photosynthetic activity. In such conditions, algal growth on the pond bottom tends to decrease [62, 63]. A Secchi disk depth between 30 and 60 cm is recommended for freshwater aquaculture [64].

The presence of ME was negatively correlated with the presence of ML [65]. We observed similar ontogenetic temporal partitioning between *Farfantepenaeus paulensis* and *F. brasiliensis*, with one species more abundant in summer and the other in autumn, likely due to differing migration and recruitment patterns. Such seasonal species distributions may represent strategies to reduce interspecific competition.

ML was mostly found at WEM, PEM, and SJEM and was negatively correlated with transparency. *M. rosenbergii*

prefers turbid conditions, with phytoplankton contributing to the Secchi disk transparency. Phytoplankton abundance is strongly and heterogeneously related to orthophosphate levels [66, 67]. It is reported that prawns tend to prefer filamentous green algae and may avoid certain periphyton species such as diatoms. An optimal abundance and composition of phytoplankton contribute positively to water quality—not only through shading the benthos but also via oxygenation,  $\text{NH}_3$  reduction, and by forming the base of the food web, which ultimately benefits prawn stock [68].

ML populations in the Gililana River were found on sandy, gravelly, and root-bound substrates. This species inhabits fast-flowing, shallow waters. According to research [69], ML was also found in the Andaman Islands in river depths of 2–3 cm with sandy and muddy substrates [70]. Its microhabitats include macrophytes, sago roots, leaf litter, and woody debris. Reported conditions include water temperature of 25–28 °C, DO of 5.2–8.8 mg/L, and pH between 7.0 and 9.3, with substrates composed of mud and sand [71].

*Macrobrachium idae* (MI) was weakly correlated with potassium (K) ( $r = 0.309$ ). MI was abundant during WM and absent in TS1, likely due to the gradual increase in K from TS1 to WM. MI is a freshwater prawn species with facultative euryhalinity and is typically more abundant during and shortly after the rainy season (October–February). Prawns are commonly found in estuarine niches, deep water, and mangrove areas. They migrate to brackish water zones for spawning and sometimes for larval hatching, with post-larval individuals returning to freshwater habitats [19, 20].

Potassium plays a key role in post-molting processes, which influence survival rates in *Litopenaeus vannamei* [72, 73]. The uptake of sodium (Na) ions is influenced by K, and magnesium (Mg) uptake is affected by calcium (Ca) concentrations [74]. Previous studies have reported that a Na ratio of 27:1 in freshwater media significantly influences the growth and survival of *L. vannamei* [75].

Ituarte found that  $\text{Na}^+/\text{K}^+$ -ATPase enzyme activity was present at all developmental stages of *Palaemonetes argentinus*, being lowest during early egg development (stage SI), highest at the late embryonic stage (SIII), and moderate during newly hatched zoea (ZI) and in adults [76].

Nevertheless, the present study was limited to three rivers and a one-year sampling period. Therefore, caution should be applied when generalizing the findings to other tropical river systems with different hydrological and ecological characteristics. Future studies involving broader geographical coverage and longer monitoring periods are needed to validate the applicability of these findings across larger watershed systems.

#### 4.4 Management implications

The ecological relationships identified in this study provide important implications for watershed management and freshwater biodiversity conservation. Maintaining riparian vegetation, reducing agricultural fertilizer runoff, controlling sedimentation, and improving water transparency may help sustain suitable habitat conditions for *Macrobrachium* spp. These findings may support local river management policies and community-based conservation programs aimed at maintaining freshwater ecosystem health in the Rongkong Sub-Watershed.

Shrimp abundance is an important indicator for assessing

the health and ecological balance of river ecosystems. In this study, variations in the abundance of *Macrobrachium* spp. indicate that changes in environmental conditions, particularly water quality parameters, can influence the distribution and population dynamics of the species. Given the high economic value of *Macrobrachium* spp., changes in habitat quality can impact not only the sustainability of aquatic ecosystems but also the social and economic aspects of communities dependent on these resources.

The results indicate that environmental factors such as Secchi disk transparency, DO, potassium, and nutrients are related to species distribution patterns. Fluctuations in these parameters likely affect habitat availability, food sources, and physiological processes that play a role in shrimp growth, development, and survival. Changing environmental conditions due to increased anthropogenic activity, land use changes, and increased pollutant loads have the potential to degrade natural habitat quality and alter the community structure of aquatic organisms.

These findings indicate that habitat conservation and management efforts need to consider the ecological characteristics and physiological tolerances of each *Macrobrachium* species. In line with the Law of the Republic of Indonesia No. 32 of 2009 concerning Environmental Protection and Management and supported by Government Regulation No. 22 of 2021 concerning the Implementation of Environmental Protection and Management, in general to specific, it mentions the efforts that can be made to maintain environmental quality and biodiversity. Such management can be directed at reducing sources of environmental stress, maintaining supportive habitat conditions, and regularly monitoring water quality and population dynamics. Furthermore, further research on the species' biology, life cycle, and response to environmental change is needed to support more effective and sustainable management strategies [77, 78].

## 5. CONCLUSIONS

This study demonstrated that water quality parameters significantly influence the abundance and distribution of *Macrobrachium* spp. in the Waelawi, Salujambu, and Pombakka rivers of the Rongkong Sub-Watershed. Four *Macrobrachium* species were identified, with MM being the dominant species across all sampling sites and seasons, indicating broad ecological adaptability. In contrast, ME was associated with higher water transparency, whereas ML showed a negative relationship with transparency and was more abundant during the EM season. MI was associated with higher potassium concentrations during the WM period. CCA showed a significant relationship between environmental variables and shrimp distribution patterns ( $F = 4.9111$ ;  $p = 0.003$ ), with K, temperature, DO, pH, transparency, and  $\text{NH}_3$  identified as the most influential parameters. These findings highlight the important role of hydrological seasonality and water quality in shaping freshwater shrimp ecology. Therefore, maintaining river water quality through watershed conservation, reduction of agricultural runoff, riparian vegetation protection, and continuous monitoring of nutrient inputs is recommended to support sustainable freshwater shrimp populations and biodiversity conservation in tropical river ecosystems.

## ACKNOWLEDGMENT

This research is funded by the Indonesian Endowment Fund for Education (LPDP) on behalf of the Indonesian Ministry of Higher Education and managed under the EQUITY Program (Contract No. 4300/B3/DT.03.08/2025; No. 297/UN3/HK.07.00/2025; and No. 5537/B/UN3.LPPM/P.T.01.03/2025).

The authors would like to express their sincere gratitude to the “Indonesia Endowment Fund for Education (LPDP), the Ministry of Finance of the Republic of Indonesia, and the Ministry of Research, Technology, and Higher Education (Kemenristekdikti)” for providing the *Beasiswa Unggulan Dosen Indonesia–Dalam Negeri* (BUDI-DN) scholarship.

## AUTHOR CONTRIBUTION

Jurniati: Conceptualization, Methodology, Validation, Investigation, Resource, Writing – original draft, Project administration, Funding acquisition. Asmanik: Conceptualization, Methodology, Validation, Investigation, Resource, Data curation, Writing – original draft, Supervision. Aditya Prana Iswara: Validation, Writing – review & editing, Supervision. Anita Restu Puji Raharjeng: Writing – original draft, Writing – review & editing. Sonny Kristianto: Conceptualization, Methodology, Validation, Writing – original draft, Supervision. Daniar Kusumawati: Software, Formal analysis, Data curation. Mohammad A. Adam: Conceptualization, Methodology, Investigation, Resource, Writing – original draft, Visualization. Reagan Septory: Software. Hasriani Ayu Lestari: Software, Validation. Apri I. Supii: Investigation. Riza Zulkarnain: Software, Formal analysis, Data curation. Suhardi A. B. Susilo: Software, Formal analysis, Data curation. Dendy Mahabrur: Software, Formal analysis, Data curation. Shahbaz Abbas: Validation, Investigation, Writing – review & editing. Acbellita Ayu Zevhiana: Data curation, Writing – original draft, Writing – review & editing. Yudi Prastiyono: Writing – original draft.

## REFERENCES

- [1] Jufri, A., Ihsan, M.N. (2020). Spatial and temporal distribution of ocean surface currents in the Makassar Strait. *SIGANUS: Journal of Fisheries and Marine Science*, 1(2): 69-73. <https://doi.org/10.31605/siganus.v1i2.655>
- [2] Government of South Sulawesi Province. (2014). Report on the Environmental Status of South Sulawesi Province in 2014.
- [3] BPS North Luwu Regency. (2019). North Luwu Regency in Figures 2019, North Luwu. <https://luwukab.bps.go.id/en/publication/2019/08/16/a46e57e55fc08118b0486023/kabupaten-luwu-dalam-angka-2019.html>.
- [4] BPS North Luwu Regency. (2020). North Luwu Regency in Figures 2020, North Luwu. <https://luwuutarakab.bps.go.id/en/publication/2020/02/28/fdac668f19ad7310777e83f1/kabupaten-luwu-utara-dalam-angka-2020-penyediaan-data-untuk-perencanaan-pembangunan.html>.
- [5] Wulandari, R., Iswara, A.P., Qadafi, M., Prayogo, W., et al. (2024). Water pollution and sanitation in Indonesia: A review on water quality, health and environmental impacts, management, and future challenges. *Environmental Science and Pollution Research*, 31(58): 65967-65992. <https://doi.org/10.1007/s11356-024-35567-x>
- [6] Ji, Z.G. (2017). *Hydrodynamics and Water Quality: Modeling Rivers, Lakes, and Estuaries*. John Wiley & Sons.
- [7] Arfao, A.T., Onana, M.F., Koji, E., Mounqang, L.M., et al. (2021). Using principal component analysis to assess water quality from the landing stages in coastal region. *American Journal of Water Resources*, 9(1): 23-31. <https://doi.org/10.12691/ajwr-9-1-4>
- [8] Vasistha, P., Ganguly, R. (2020). Water quality assessment of natural lakes and its importance: An overview. *Materials Today: Proceedings*, 32: 544-552. <https://doi.org/10.1016/J.MATPR.2020.02.092>
- [9] Rahman, A., Dabrowski, J., McCulloch, J. (2020). Dissolved oxygen prediction in prawn ponds from a group of one step predictors. *Information Processing in Agriculture*, 7(2): 307-317. <https://doi.org/10.1016/j.inpa.2019.08.002>
- [10] Ngodhe, S.O., Raburu, P.O., Achieng, A. (2014). The impact of water quality on species diversity and richness of macroinvertebrates in small water bodies in Lake Victoria Basin, Kenya. *Journal of Ecology and the Natural Environment*, 6(1): 32-41. <https://doi.org/10.5897/jene2013.0403>
- [11] Liew, H.J., Rahmah, S., Tang, P.W., Waiho, K., et al. (2022). Low water pH depressed growth and early development of giant freshwater prawn *Macrobrachium rosenbergii* larvae. *Heliyon*, 8(7): e09989. <https://doi.org/10.1016/j.heliyon.2022.e09989>
- [12] Dallas, H. (2009). The effect of water temperature on aquatic organisms: A review of knowledge and methods for assessing biotic responses to temperature. *Water Research Commission Report KV*, 213(9).
- [13] Walkuska, G., Wilczek, A. (2010). Influence of discharged heated water on aquatic ecosystem fauna. *Polish Journal of Environmental Studies*, 19(3): 547-552.
- [14] Adam, M.A., Talbia, H.S., Ariyanti, D., Kristianto, S., et al. (2024). Microplastics contamination in environment and marine animals at Kodek Bay, Lombok, Indonesia. *Water, Air, & Soil Pollution*, 235(12): 789. <https://doi.org/10.1007/s11270-024-07607-2>
- [15] Chairunnisa, N.K., Adam, M.A., Kristianto, S., Candri, D.A., et al. (2025). Linking the tourism activity to the occurrence and distribution of microplastics. *Civil Engineering Journal*, 11(7): 2811-2825. <https://doi.org/10.28991/CEJ-2025-011-07-010>
- [16] Kitsiou, D., Karydis, M. (2011). Coastal marine eutrophication assessment: A review on data analysis. *Environment International*, 37(4): 778-801. <https://doi.org/10.1016/J.ENVINT.2011.02.004>
- [17] Alssgeer, H.M.A., Gasim, M.B., Hanafiah, M.M., Abdulhadi, E.R.A., Azid, A. (2018). GIS-based analysis of water quality deterioration in the Nerus River, Kuala Terengganu, Malaysia. *Desalination and Water Treatment*, 112: 334-343. <https://doi.org/10.5004/dwt.2018.22335>
- [18] Amanat, Z., Sahera, N.U., Qureshi, N.A. (2021). Seasonal variation in the abundance and species diversity of penaeid shrimps from the coastal area of Sonmiani Bay Lagoon, Balochistan, Pakistan. *Indian Journal of*

- Geo-Marine Sciences, 50(3): 228-235. <https://doi.org/10.56042/ijms.v50i03.66132>
- [19] Subramanian, P., Sambasivam, S., Krishnamurthy, K. (1980). Experimental study on the salinity tolerance of *Macrobrachium idae* larvae. *Marine Ecology Progress Series*, 3(1): 71-73. <https://www.jstor.org/stable/24813302>.
- [20] Sudhakar, S., Soundarapandian, P., Varadharajan, D., Dinakaran, G.K. (2014). Embryonic development of *Macrobrachium idae* (Heller, 1862). *Journal of Coastal Zone Management*, 17: 380. <https://doi.org/10.4172/1410-5217.1000380>
- [21] Edwards, T.M., Puglis, H.J., Kent, D.B., Durán, J.L., Bradshaw, L.M., Farag, A.M. (2024). Ammonia and aquatic ecosystems—A review of global sources, biogeochemical cycling, and effects on fish. *Science of the Total Environment*, 907: 167911. <https://doi.org/10.1016/j.scitotenv.2023.167911>
- [22] Hagage, M., Hewaidy, A.G.A., Abdulaziz, A.M. (2025). Groundwater quality assessment for drinking, irrigation, aquaculture, and industrial uses in the waterlogged northeastern Nile Delta, Egypt: A multivariate statistical approach and water quality indices. *Modeling Earth Systems and Environment*, 11(1): 59. <https://doi.org/10.1007/s40808-024-02242-6>
- [23] Musselman, R. (2012). Sampling procedure for lake or stream surface water chemistry. *Research Note RMRS-RN-49*. Fort Collins, CO: US Department of Agriculture, Forest Service, Rocky Mountain Research Station. <https://doi.org/10.2737/rmrs-rn-49>
- [24] Short, J.W. (2004). A revision of Australian river prawns, *Macrobrachium* (Crustacea: Decapoda: Palaemonidae). *Hydrobiologia*, 525(1): 1-100. <https://doi.org/10.1023/b:hydr.0000038871.50730.95>
- [25] Adite, A., Abou, Y., Sossoukpe, E., Gbaguidi, M.H.A.G., Fiogbe, E.D. (2013). Meristic and morphological characterization of the freshwater prawn, *Macrobrachium macrobathion* (Herklots, 1851) from the Mono River - Coastal Lagoon system, Southern Benin (West Africa): Implications for species conservation, *International Journal of Biodiversity and Conservation*, 5(11): 704-714.
- [26] Munasinghe, D.H.N., Thushari, G.G.N. (2010). Analysis of morphological variation of four populations of *Macrobrachium rosenbergii* (de man, 1879) (Crustacea: Decapoda) in Sri Lanka. *Ceylon Journal of Science (Biological Sciences)*: 39(1): 53-60. <https://doi.org/10.4038/cjsbs.v39i1.2353>
- [27] Cuvin-Aralar, M.L.A. (2014). Embryonic development of the caridean prawn *Macrobrachium mammillodactylus* (Crustacea: Decapoda: Palaemonidae). *Invertebrate Reproduction & Development*, 58(4): 306-313. <https://doi.org/10.1080/07924259.2014.944674>
- [28] Geller, J., Meyer, C., Parker, M., Hawk, H. (2013). Redesign of PCR primers for mitochondrial cytochrome c oxidase subunit I for marine invertebrates and application in all-taxa biotic surveys. *Molecular Ecology Resources*, 13(5): 851-861. <https://doi.org/10.1111/1755-0998.12138>
- [29] Ahmed, S., Ibrahim, M., Nantasenamat, C., Nisar, M.F., et al. (2022). Pragmatic applications and universality of DNA barcoding for substantial organisms at species level: A review to explore a way forward. *BioMed Research International*, 2022(1): 1846485. <https://doi.org/10.1155/2022/1846485>
- [30] Kumar, S., Stecher, G., Tamura, K. (2016). MEGA7: Molecular evolutionary genetics analysis version 7.0 for bigger datasets. *Molecular Biology and Evolution*, 33(7): 1870-1874. <https://doi.org/10.1093/MOLBEV/MSW054>
- [31] Dormann, C.F., Elith, J., Bacher, S., Buchmann, C., et al. (2013). Collinearity: A review of methods to deal with it and a simulation study evaluating their performance. *Ecography*, 36(1): 27-46. <https://doi.org/10.1111/j.1600-0587.2012.07348.x>
- [32] Azarov, A., Polesny, Z., Darr, D., Kulikov, M., Verner, V., Sidle, R.C. (2022). Classification of mountain silvopastoral farming systems in walnut forests of Kyrgyzstan: Determining opportunities for sustainable livelihoods. *Agriculture*, 12(12): 2004. <https://doi.org/10.3390/agriculture12122004>
- [33] James, G. (2013). An introduction to statistical learning with applications in R. <https://doi.org/10.1080/24754269.2021.1980261>
- [34] Rasid, R., Tajuddin, A.L., Zarim, M.A.U.A.A., Thanakodi, S., et al. (2023). Tolerance limit of physicochemical water parameters in giant freshwater prawn (*Macrobrachium rosenbergii*) in a captive condition. *Turkish Journal of Zoology*, 47(5): 291-298. <https://doi.org/10.55730/1300-0179.3142>
- [35] Boyd, C.E. (2003). Guidelines for aquaculture effluent management at the farm-level. *Aquaculture*, 226(1-4): 101-112. [https://doi.org/10.1016/S0044-8486\(03\)00471-X](https://doi.org/10.1016/S0044-8486(03)00471-X)
- [36] Ferreira, N.C., Bonetti, C., Seiffert, W.Q. (2011). Hydrological and water quality indices as management tools in marine shrimp culture. *Aquaculture*, 318(3-4): 425-433. <https://doi.org/10.1016/J.AQUACULTURE.2011.05.045>
- [37] Kamarudin, M.K.A., Abd Wahab, N., Bati, S.N.A.M., Toriman, M.E., Saudi, A.S.M., Umar, R. (2020). Seasonal variation on dissolved oxygen, biochemical oxygen demand and chemical oxygen demand in Terengganu River Basin, Malaysia. *Journal of Environmental Science and Management*, 23(2). [https://doi.org/10.47125/jesam/2020\\_2/01](https://doi.org/10.47125/jesam/2020_2/01)
- [38] Manush, S.M., Pal, A.K., Chatterjee, N., Das, T., Mukherjee, S.C. (2004). Thermal tolerance and oxygen consumption of *Macrobrachium rosenbergii* acclimated to three temperatures. *Journal of Thermal Biology*, 29(1): 15-19. <https://doi.org/10.1016/J.JTHERBIO.2003.11.005>
- [39] Bastos, A.M., Lima, J.F., Tavares-Dias, M. (2018). Effect of increase in temperature on the survival and growth of *Macrobrachium amazonicum* (Palaemonidae) in the Amazon. *Aquatic Living Resources*, 31: 21. <https://doi.org/10.1051/alr/2018010>
- [40] Booker, D.J., Whitehead, A.L. (2022). River water temperatures are higher during lower flows after accounting for meteorological variability. *River Research and Applications*, 38(1): 3-22. <https://doi.org/10.1002/rra.3870>
- [41] Morel, M., Booker, D.J., Gob, F., Lamouroux, N. (2020). Intercontinental predictions of river hydraulic geometry from catchment physical characteristics. *Journal of Hydrology*, 582: 124292. <https://doi.org/10.1016/J.JHYDROL.2019.124292>

- [42] Indivero, J., Myers-Pigg, A.N., Ward, N.D. (2021). Seasonal changes in the drivers of water physico-chemistry variability of a small freshwater tidal river. *Frontiers in Marine Science*, 8: 607664. <https://doi.org/10.3389/fmars.2021.607644>
- [43] Hashim, M., Setyowati, D.L., Suroso, Yohanes, K.D.A. (2022). Water quality during the rainy seasons and drought seasons in the Garang River Basin (Semarang, Indonesia). *IOP Conference Series: Earth and Environmental Science*, 986(1): 012076. <https://doi.org/10.1088/1755-1315/986/1/012076>
- [44] Wiranegara, P., Sunardi, S., Sumiarsa, D., Juahir, H. (2023). Characteristics and changes in water quality based on climate and hydrology effects in the Cirata Reservoir. *Water*, 15(17): 3132. <https://doi.org/10.3390/w15173132>
- [45] Ling, T.Y., Soo, C.L., Liew, J.J., Nyanti, L., Sim, S.F., Grinang, J. (2017). Influence of rainfall on the physicochemical characteristics of a tropical river in Sarawak, Malaysia. *Polish Journal of Environmental Studies*, 26(5): 2053-2065. <https://doi.org/10.15244/pjoes/69439>
- [46] Yang, X., Tong, R., Ma, L., Li, J., Wang, S., Tian, L. (2022). Monitoring water color anomaly of lakes based on an integrated method using Landsat-8 OLI images. *International Journal of Digital Earth*, 15(1): 1567-1587. <https://doi.org/10.1080/17538947.2022.2122609>
- [47] Anh, N.T., Nhan, N.T., Schmalz, B., Le Luu, T. (2023). Influences of key factors on river water quality in urban and rural areas: A review. *Case Studies in Chemical and Environmental Engineering*, 8: 100424. <https://doi.org/10.1016/j.cscee.2023.100424>
- [48] Peña-Guerrero, M.D., Nauditt, A., Muñoz-Robles, C., Ribbe, L., Meza, F. (2020). Drought impacts on water quality and potential implications for agricultural production in the Maipo River Basin, Central Chile. *Hydrological Sciences Journal*, 65(6): 1005-1021. <https://doi.org/10.1080/02626667.2020.1711911>
- [49] Skowron, P., Skowrońska, M., Bronowicka-Mielniczuk, U., Filipek, T., Igras, J., Kowalczyk-Juško, A., Krzepińko, A. (2018). Anthropogenic sources of potassium in surface water: The case study of the Bystrzyca river catchment, Poland. *Agriculture, Ecosystems & Environment*, 265: 454-460. <https://doi.org/10.1016/J.AGEE.2018.07.006>
- [50] Siwek, J.P., Żelazny, M., Chełmicki, W. (2013). Environmental and land use determinants of stream water chemistry during flood events in small Carpathian Foothill catchments in Poland. In *the Carpathians: Integrating Nature and Society Towards Sustainability*, pp. 161-178. <https://doi.org/10.1007/978-3-642-12725-0>
- [51] Pakoksung, K., Inseepong, N., Chawaloephonsiya, N., Punyapalakul, P., Chaiwiwatworakul, P., Xu, M., Chuenchum, P. (2025). Seasonal dynamics of water quality in response to land use changes in the Chi and Mun River Basins Thailand. *Scientific Reports*, 15(1): 7101. <https://doi.org/10.1038/s41598-025-91820-4>
- [52] Jurniati, J., Arfiati, D., MS Hertika, A., Kurniawan, A. (2021). Morphometric-meristic characters and length-weight relationships of *Macrobrachium mammillodactylus* (Thallwitz, 1892) inhabiting downstream of Rongkong watershed, South Sulawesi, Indonesia. *Egyptian Journal of Aquatic Biology and Fisheries*, 25(1): 91-110. <https://doi.org/10.21608/ejabf.2021.138346>
- [53] Maidin, M.S.R., Yong, A.S.K., Anton, A., Wei, G.J., Chin, L. (2023). Distribution patterns of freshwater prawn, *Macrobrachium* spp. following stock enhancement programme in Sabah, Malaysia. *International Journal of Environment, Agriculture and Biotechnology*, 8(1): 9-23. <https://doi.org/10.22161/ijeab>
- [54] Fuke, Y., Maruyama, T. (2023). First record of *Macrobrachium mammillodactylus* (Thallwitz, 1891) (Crustacea, Decapoda, Palaemonidae) from Japan. *Check List*, 19(6): 821-826. <https://doi.org/10.15560/19.6.821>
- [55] Kusuma, B., Prayitno, S.B., Sabdaningsih, A., Tjahja Soedibya, P.H., Saputra, S.W. (2024). Threat of extinction of *Macrobrachium esculentum* in the Serayu River (Central Java, Indonesia) confirmed by DNA barcoding. *Biodiversitas: Journal of Biological Diversity*, 25(10): 3531. <https://doi.org/10.13057/biodiv/d251015>
- [56] Mejia-Ortiz, L.M., Alvarez, F. (2010). Seasonal patterns in the distribution of three species of freshwater shrimp, *Macrobrachium* spp., along an altitudinal river gradient. *Crustaceana*, 83(4): 385-397. <https://doi.org/10.1163/001121610X489368>
- [57] Kingdom, T., Hart, A.I., Erundu, E.S. (2013). Effects of environmental factors on the abundance of shrimps, *Macrobrachium* species in the lower Taylor Creek, Niger Delta, Nigeria. *African Journal of Environmental Pollution and Health*, 10: 71-79.
- [58] Pratiwi, R., Sukardjo, S. (2018). Effects of rainfall on the population of shrimps *Penaeus monodon* Fabricius in Segara Anakan lagoon, Central Java, Indonesia. *Biotropia*, 25(3): 156-169. <https://doi.org/10.11598/btb.2018.25.3.830>
- [59] Nieuwolt, S. (1977). The influence of rainfall on rural population. *The Journal of Tropical Geography*, 44: 43-56.
- [60] Covich, A., Crowl, T., Scatena, F. (2003). Effects of extreme low flows on freshwater shrimps in a perennial tropical stream. *Freshwater Biology*, 48: 1199-1206. <https://doi.org/10.1046/j.1365-2427.2003.01093.x>
- [61] Costa, R.C., Fransozo, A. (2004). Abundance and ecologic distribution of the shrimp *Rimapenaeus constrictus* (Crustacea: Penaeidae) on the northern coast of São Paulo State, Brazil. *Journal of Natural History*, 38(7): 901-912. <https://doi.org/10.1080/0022293021000046441>
- [62] MacGibbon, D.J. (2008). The effects of different water quality parameters on prawn (*Macrobrachium rosenbergii*) yield, phytoplankton abundance and phytoplankton diversity at New Zealand prawns limited, Wairakei, New Zealand. Doctoral dissertation, Open Access Te Herenga Waka-Victoria University of Wellington.
- [63] Makhamisi, H.J. (2019). The use of a scoring card system to assess the suitability of underground and surface water for the farming of warm water fish species in five districts in Limpopo Province. Doctoral dissertation, Stellenbosch: Stellenbosch University. <http://hdl.handle.net/10019.1/106065>.
- [64] Aquaculture, S.A. (2003). Water quality in freshwater aquaculture ponds. *Aquaculture SA of Primary Industries and Resources South Australia (PIRSA)*.
- [65] Lüchmann, K.H., Freire, A.S., Ferreira, N.C., Daura-

- Jorge, F.G., Marques, M.R.F. (2008). Spatial and temporal variations in abundance and biomass of penaeid shrimps in the subtropical Conceição Lagoon, southern Brazil. *Journal of the Marine Biological Association of the United Kingdom*, 88(2): 293-299. <https://doi.org/10.1017/S0025315408000556>
- [66] Fitrianesia, F., Hertika, A.M.S., Yanuhar, U., Shiddiq, M.F.A. (2024). The relationship between water quality and phytoplankton abundance with different showing density in *litopenaeus vannamei* ponds in Bayeman Village, Probolinggo District, East Java. *Jurnal Penelitian Pendidikan IPA*, 10(2): 749-756. <https://doi.org/10.29303/jppipa.v10i2.4364>
- [67] Guo, Y., Zhang, P., Chen, J., Xu, J. (2022). Freshwater snail and shrimp differentially affect water turbidity and benthic primary producers. *Water Biology and Security*, 1(1): 100004. <https://doi.org/10.1016/j.watbs.2021.100004>
- [68] Burford, M. (1997). Phytoplankton dynamics in shrimp ponds. *Aquaculture Research*, 28(5): 351-360. <https://doi.org/10.1046/j.1365-2109.1997.00865.x>
- [69] Costa, H. (1984). Results of the Austrian-Indian hydrobiological mission 1976 to the Andaman-Islands. Taxonomy and ecology of the Decapoda-Caridea. *Annalen des Naturhistorischen Museums in Wien. Serie B für Botanik und Zoologie*, 86: 205-211.
- [70] Laewa, N.H., Fahri, F., Annawaty, A. (2018). The freshwater prawn *macrobrachium latidactylus* (Decapoda, Caridea, Palaemonidae) from Gililana River, Morowali Utara, Sulawesi, Indonesia. *Natural Science: Journal of Science and Technology*, 7(2): 205-216.
- [71] Annawaty, A., Lapasang, N.H.E., Rahayu, P., Hairul, H., Tadeko, F.R.I., Dwiyanto, D. (2022). Checklist of the freshwater shrimps (Crustacea, Decapoda, Caridea) from the Banggai Archipelago, Central Sulawesi, Indonesia. *Check List*, 18(2): 341-355. <https://doi.org/10.15560/18.2.341>
- [72] Nehru, E., Chandrasekhara Rao, A., Pamanna, D., Ranjith, P., Lokesh, B. (2018). Effect of aqueous minerals supplementation on growth and survival of *Litopenaeus vannamei* in low salinity water. *International Journal of Current Microbiology and Applied Sciences*, 7(1): 1706-1713. <https://doi.org/10.20546/ijcmas.2018.701.206>
- [73] Widigdo, B., Wiyoto, W., Ekasari, J., Isnansetyo, A. (2018). Correlation of major mineral properties in brackish water ponds environment and Pacific white shrimp *Litopenaeus vannamei* survival, growth and production. <https://doi.org/10.3923/jest.2019.38.46>
- [74] Suguna, T. (2020). Application of minerals in low saline water culture systems of *L. vannamei*. *International Journal of Current Microbiology and Applied Sciences*, 9(9): 516-521. <https://doi.org/10.20546/ijcmas.2020.909.065>
- [75] Supono, S., Fidyandini, H.P. (2023). Effect of different ratios of sodium and potassium on the growth and survival rate of Pacific white shrimp (*Litopenaeus vannamei*) cultured in freshwater. *AAFL Bioflux*, 16(1): 128-134. <http://repository.lppm.unila.ac.id/id/eprint/47651>.
- [76] Ituarte, R.B., Mañanes, A.A.L., Spivak, E.D., Anger, K. (2008). Activity of Na<sup>+</sup>, K<sup>+</sup>-ATPase in a 'freshwater shrimp', *Palaemonetes argentinus* (Caridea, Palaemonidae): Ontogenetic and salinity-induced changes. *Aquatic Biology*, 3: 283-290. <https://doi.org/10.3354/ab00089>
- [77] Government of Indonesia. (2021). Government Regulation (PP) Number 22 of 2021 concerning the Implementation of Environmental Protection and Management. <https://peraturan.bpk.go.id/Details/161852/pp-no-22-tahun-2021>.
- [78] Government of Indonesia. (2009). Law Number 32 of 2009 concerning Environmental Protection and Management. <https://peraturan.bpk.go.id/details/38771/uu-no-32-tahun-2009>.