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Used macroinvertebrates as bioindicators to compare water quality from different land uses in Watumokala and Nokambu Rivers, Southeast Sulawesi, Indonesia

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Abstract. *Kahirun, Basrudin, Siwi LO, Indriyani L, Bana S, Sudia LB, Erif LOM, Midi LO, Maulina N, Jamaluddin N. 2023. Used macroinvertebrates as bioindicators to compare water quality from different land uses in Watumokala and Nokambu Rivers, Southeast Sulawesi, Indonesia. Biodiversitas 24: 5693-5708.* Macroinvertebrates are animals that live in waters, both on the surface of the water, in riverbeds attached to substrates or mud, and in several biotypes, which are used as bioindicators of water quality due to anthropogenic disturbances that can change land use around rivers. This study aimed to describe the physicochemical parameters and macroinvertebrate community in the Watumokala and Nokambu rivers in Southeast Sulawesi, Indonesia, and to compare the water quality in the two rivers based on ecological index measurements. This study used a survey method at the upstream, middle, and downstream sampling locations for each river with different land use. Data collection on macroinvertebrates and physicochemical parameters was carried out at each station in each river. The data analysis carried out in this study was to calculate the Shannon-Wienner diversity index, species abundance index, uniformity index, Margalef richness index, and the Family Biotic Index (FBI). The results of this study indicated that in the Watumokala River, there were 17 families from 9 macroinvertebrate orders with an abundance of 1852 individuals, more than in the Nokambu River where 14 families were found from 8 orders with an abundance of 904 individuals. There is an influence of land use habitat on macroinvertebrates in the Watumokala and Nokambu Rivers. In the Watumokala River station 1 and station 3 are similar and have a significant correlation with several indicators indicating that the water quality is still good, while at station 2 there is a positive correlation with physicochemical parameters which indicates that the water quality is slightly polluted. Likewise, in the Nokambu River, at station 1 and station 2, there are similarities and significant correlations between physicochemical parameters and macroinvertebrate communities in providing indicators that water quality is still good, while station 3 shows a significant correlation with physicochemical parameters and macroinvertebrates as indicators of water quality polluted. So, the results of this research are useful in efforts to manage land and water in rivers that are experiencing pollution.

Keywords: Bioindicators, land use, macroinvertebrate community, physicochemical parameters, water quality

INTRODUCTION

River ecosystems have a vital role in determining environmental balance (Utami and Fajar 2022; Wang and He 2022). The river ecosystem is a complex system involving living and non-living factors. It includes the interactions between plants, animals, and microorganisms, as well as the physical and chemical characteristics of the water and surrounding landscape. Understanding these interactions is crucial for preserving the health of the ecosystem. Habitat conditions and land use in river ecosystems have a significant effect on aquatic organisms such as fish, amphibians, microorganisms and aquatic insects, particularly macroinvertebrates (Kath et al. 2018).

Macroinvertebrate organisms in river waters are organisms that live on the riverbed and attach to substrate or mud (Gething et al. 2020; Mcartor et al. 2021). Identifying macroinvertebrates is a simple process, and they have the ability to adapt to changes in their environment. They play a vital role in balancing the nutrient levels in aquatic environments and can be used as bioindicators to monitor water quality (Schumaker Chadde 2007; Seriño et al. 2018). Macroinvertebrates function as a balancer of nutrients in aquatic environments and can be used as bioindicators of water quality (Ojija and Laizer 2016). Environmental conditions such as bottom substrate and depth can represent enormous variations in the presence of macroinvertebrates so different species are often found in areas with different environmental conditions (Zelnik and Muc 2020). The adaptation of macroinvertebrates to environmental conditions such as hard substrates is different from macroinvertebrates that live on soft substrates (Gething et al. 2020). Changes in the environment and substrate greatly affect the number of species, diversity, and abundance of macroinvertebrates. Macroinvertebrates are highly dependent on the tolerance of ecological changes where the tolerance range of macroinvertebrates to different environments (Zelnik and Muc 2020).

Land use is crucial for human activities such as transportation, agriculture, settlements, parks, and commercial activities, but changing river bank land use can damage the environment (Clark et al. 2022; Rutkowska et al. 2022), by causing runoff and erosion, leading to water quality degradation and affecting the life of macroinvertebrates that can indicate good and bad water quality (Fierro et al. 2017). Therefore, we must take proactive measures to preserve natural resources and maintain sustainability. Assessment of river water quality based on macroinvertebrates has advantages over physical and chemical parameters (Kahirun et al. 2019). River water quality based on physical and chemical parameters is fluctuating so it must be re-measured periodically (Wang et al. 2022). In addition to affecting water quality, changes in land use also have an impact on decreasing water availability (Lima et al. 2020), which can affect the number and velocity of river flows (Achugbu et al. 2022). It's crucial to take into account the impact of land use changes on various factors that affect the diversity and abundance of macroinvertebrates in a river (Ko et al. 2021). These include water quality, flow rate, and turbidity, as well as physical and chemical parameters such as BOD, COD, TSS, and TDS. Maintaining a sustainable ecosystem requires an understanding of these factors and their interplay.

In Indonesia in general and in Southeast Sulawesi in particular, many rivers are experiencing degradation, decreasing in quality due to anthropogenic activities, including agricultural activities, animal husbandry, irrigation, and development of community settlements both in rural and urban areas. Among them are the Watumokala River which is in rural areas and the Nokambu River which is in urban areas. The Watumokala River is a rural river characterized by agriculture with anthropogenic land use activities around the riverbanks, forests, agriculture, fields, rice fields, and rural settlements (Castro-López et al. 2019). Meanwhile, the Nokambu River is a river that is characterized as an urban river with urban activities having dense residential development due to urbanization (Yuan et al. 2022), which causes an increase in the need for residential development (Ghaisani and Pigawati 2020), thus having an impact on river ecosystem disruption (Atharinafi and Wijaya 2021; Suprayogi et al. 2022), thus affecting the life of aquatic biota in rivers (Carrasco-Badajoz et al. 2022). Therefore, it is suspected that there are differences in ecosystem conditions between rivers with rural agricultural land use characteristics compared to rivers in urban areas. However, changes in agricultural land use due to community activities on land around riverbanks can have an impact on the emergence of several types of macroinvertebrates that are tolerant to the rice farming ecosystem (Ko et al. 2021; Aydın and Çamur-Elipek 2022). This is caused by the intensity of the use of fertilizers and pesticides for agriculture (Kurnianto et al. 2021; Mihaylova et al. 2022) which has an impact on changes in the environmental conditions of river water (Schürings et al. 2022). These community activities have an impact on water quality and the diversity of aquatic biota that live in that place, such as macroinvertebrates (Gholizade et al. 2021). Macroinvertebrate diversity can be used as a bioindicator and biomonitoring of water quality (Mello and Abessa 2021). Many studies have used the composition and abundance of macroinvertebrates to indicate the status of river water quality. Of course, rivers in rural areas with anthropogenic activities in the form of agriculture and livestock are different from rivers in urban areas with dense settlements due to high urbanization. These differences in activity have an impact on differences in river water quality, including aquatic biotic communities and changes in physicochemical parameters. Changes in river physicochemical variables can influence changes in the structure of macroinvertebrate communities as bioindicators of river water quality.

Thus, the purposes of this study were: (i) to analyze the physicochemical characteristics and structure of macro-invertebrate communities as a result of land use, (ii) to analyze the correlation between physicochemical parameters and ecological indices that determine differences in water quality and observation locations that represent land use. In addition, we hypothesize that there are physicochemical variations that influence the macroinvertebrate species assemblages in the two rivers. In addition, we hypothesized that there are physicochemical variations influencing the macroinvertebrate species assemblages in the two rivers.

MATERIALS AND METHODS

Study location

This research was conducted in the Watumokala and Nokambu Rivers, Southeast Sulawesi, Indonesia (Figure 1), for three (3) months from September to November 2022. The research location, like most areas in Indonesia, has a tropical climate, with average temperatures around 27.10°C-30.60°C, experiencing two seasons, namely the rainy season and the dry season. The season is influenced by the wind currents that blow in the area. From November to March, the wind blows from the west containing a lot of water vapor originating from the Asian continent and the Indian Ocean, during that month the rainy season occurs. Around April, wind currents are always erratic with uneven rainfall. This season is known as the transition season or the transition between the rainy season and the dry season. From May to August, the wind blows from the east, originating from the Australian continent, which contains less water vapor. This results in a lack of rainfall in this area, resulting in a dry season. As a result, from August to October there was a long dry season.

The sample locations for this research were 3 stations per river so there were six sampling location stations in total. The Watumokala River is one of the sub-watersheds of the Roraya Watershed which has an area of 148.40 km^2 (Kahirun et al. 2017). Anthropogenic activities in the Watumokala River consist of a secondary forest overgrown with natural trees with little illegal logging activity, placed as station 1 of the Watumokala River (Sta.1WR) located at 04°15' 54" S and 122°11' 39" E. Substrate conditions at station 1 are mud, sandy and rocky small rivers. Watumokala River Station 2 (Sta.2WR) is located at 04°16' 23" S and 122°10' 41" E, with the substrate type at this station being small and sandy river rocks. Anthropogenic activities include rice farming with lowland rice plants using pesticides and inorganic fertilizers. Then Station 3 Watumokala River (Sta.3WR) is located at 04°16' 49" S and 122°08' 58" E, with the substrate types at this station being Small and big rocks, and muddy. At this station, many garden plants grow in the form of mango (*Mangifera indica*), jackfruit (*Artocarpus heterophyllus*), cocoa (*Theobroma cacao*), and coconut (*Cocos nucifera*), marked by the activities of rural residents using the river for bathing, washing, and bathing livestock. Meanwhile, the Nokambu River is a river that is located in urban areas and is located in the Nokambu watershed which has an area of 25.15 km^2. Nokambu River Station 1 (Sta.1NR) is located at 04° 30' 10" S and 122°33' 21" E. The substrate types at this station are mud, sandy, and gravelly. Anthropogenic activity at this station is the use of secondary forest land which provides clean water for the population. Nokambu River Station 2 (Sta.2NR) is located at 04°28' 23" S and 122°33' 05" E. The substrate types at this station are mud, sandy, and gravelly. Anthropogenic activities at this station are the use of mixed dryland agricultural land in the form of annual crops such as corn (*Zea mays*), cassava (*Manihot esculenta*), and sweet potato (*Ipomea batas*), and annual crops such as cashew nuts (*Anacardium occidentale*), jackfruit (*Artocarpus heterophyllus*), cocoa (*Theobroma cacao*), and coconut (*Cocos nucifera*), which have been interspersed with the development of residential housing where a lot of household waste flows into the river. At station 3, the Nokambu River (Sta.3NR) has a sandy and muddy substrate type, with anthropogenic activities in the form of densely populated settlements where household waste is thrown into the river.

Data collection of physicochemical and macroinvertebrate

Measurement of physicochemical parameters was carried out simultaneously with sampling of aquatic insects. Each station was measured three times with the same method and duration of treatment. At each data sampling station, several physicochemical parameters were Dissolved Oxygen (DO), pH, Total Dissolved Sediment (TDS), Total Suspended Sediment (TSS), Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD) water temperature, and river flow speed are measured by three tests. TDS, pH, and water temperature are measured directly using AZ Instrument 8306 high precision portable (AZ8306), Dissolved oxygen (DO) is also measured directly using a portable tester in water (DO8401). BOD and COD were measured in the laboratory using the closed reflux method spectrophotometrically (SNI 6989.72-2009 and SNI 6989.2-2009). River flow speed is measured directly using a Flow Meter type tool measuring Global Water Flow FP 111 (Kahirun et al. 2019).

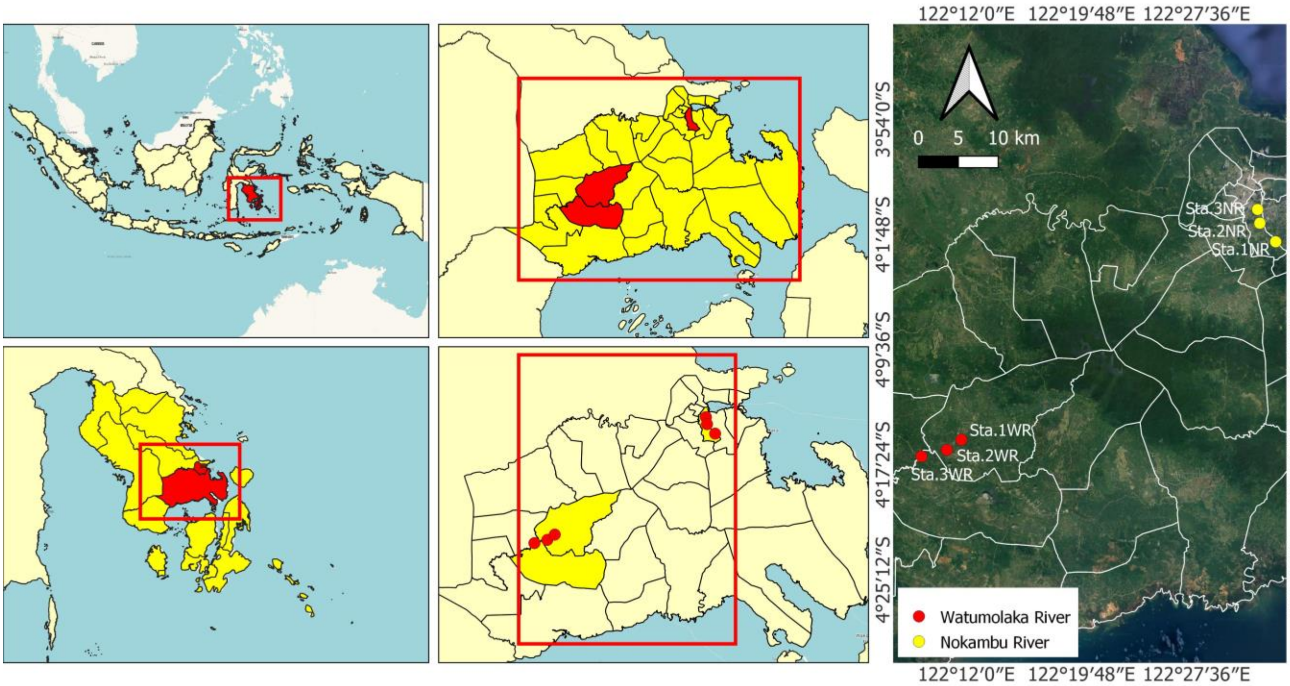


Figure 1. Study locations in the Watumokala and Nokambu Rivers, Southeast Sulawesi, Indonesia

Aquatic macroinvertebrates are sampled using aquatics D-hand mesh with frame dimensions 900 cm, 500 µm net, length 50 cm. In each river, both the Watumokala River and the Nokambu River, macroinvertebrate data collection is placed at each station with its respective characteristics which are influenced by forest areas (little anthropogenic disturbance), rice field and dry land farming areas, and rural residential areas or densely populated settlements. Each sampling location was covered by approximately 100 m of river water. The collection is carried out by searching for shelter habitats such as riffles, pools, leaf litter, aquatic vegetation, and rock substrates collected at each station, taking into account all possible micro-habitat sections that represent the flow. The sampling time at each sampling location is 60 minutes. All aquatic insects were collected in a container, then sorted and preserved in 80% ethanol. The water insects were identified at the family level using a guidebook (Grise 2008; Beauchene 2021). Types of aquatic insects that cannot be identified in the field are brought to the Biology Laboratory for identification (Ezenwa et al. 2023).

Data analysis

Data analysis was carried out in this research by calculating values using indices and formulas. The analysis data that has been obtained in the form of quantitative data has been processed using MS Excel software. The macroinvertebrate parameters used in this research are macroinvertebrate community biological parameters which consist of species diversity index, total abundance in the family, number and percentage of pollutant-sensitive biota taxa, namely Ephemeroptera, Plecoptera, and Tricoptera (EPT), Evenness, Margalef and Family Biotic Index (FBI).

Data analysis in this research was carried out using biological index values. The data that has been obtained in the form of quantitative data is processed and provided using MS Excel software. The macroinvertebrate parameters used in this research are the biological parameters of the macroinvertebrate community which consist of the Diversity Index (H Shannon index), dominance index, family abundance, number of pollutant-sensitive taxa of the Ephemeroptera, Plecoptera, and Tricoptera (EPT) families, evenness, Margalef index and Family Biotic Index (FBI). Shannon Index, Dominance, Evenness, and Margalef Index were calculated using PAST (Palaeontological Statistics Software Package for Education and Data Analysist) version 4.03 (Hammer et al. 2001). Determination of species diversity considers the following classification criteria (Shannon 1948). If H'>3, the species diversity is very high. If H' is between 1.6 and 3, the species diversity is high. If H' is between 1 and 1.5, the species diversity is moderate. If H'<1, the species diversity is low (Jalil et al. 2020; Larekeng et al. 2022). The value of the Shannon and Dominance index assessment indicates water quality, namely $H'<1$ or $D>0.75$ indicating very polluted water; $1.0<H'<2.0$ or $0.50<D<0.75$ indicates moderately polluted water; $2.0<H'<3.0$ or $0.25<D<0.50$ indicates the water is slightly polluted; $H'>3$ and $0<D<0.25$ indicates the water is not polluted (Du et al. 2017; Hettige et al. 2020). The abundance of macroinvertebrate species can be measured by counting the number of individuals per unit area (ind/m²). The Evenness Index criteria (E) (Hilsenhoff 1988) are: a. Low similarity (E = <0.4), b. Moderate similarity (E = 0.4>E<0.6), and c. High similarity (E = >0.6).

Family Biotic Index (FBI) is a water quality index calculation, if a high FBI value indicates organic pollution, while a low value indicates clear water conditions. The Family Biotic Index developed by Hilsenhoff (1988) is based on the tolerance value of each family, calculated as the equation. Calculation of the biotic index value uses the following formula: $FBI = \frac{Xi.ti}{n}$, where: FBI: Family Biotic Index value, Xi: Number of individuals in the ith family group, ti: Tolerance level of the ith family group, n: Total number of organisms in the sample. Classification of FBI values (Hilsenhoff 1988; Enawgaw and Lemma 2019), namely, if the value 0-3.75 indicates excellent water quality, 3.76-4.25 (very good), 4.26-5.00 (good), 5.01-5.75 (fair), 5.76-6.5 (fairly poor), 6.51-7.25 (poor) and 7.26-10 (very poor). According to Ogbeibu et al. (2013), show the assessment of river water quality with the FBI value, namely if FBI<4.50, the quality of non-impacted river water; 4.51<FBI<6.50 indicates slightly impacted water quality; 6.51<FBI<8.50 water quality moderately impacted; 8.51<FBI<10.00 indicates water quality is severely impacted. Likewise with the family EPT assessment, if the number of EPTs>10 is non-impacted; 6<EPT<10 is slightly impacted; 2<EPT<5 is moderately impacted, and; 0<EPT<1 is severely impacted.

Canonical Correlation Analysis (CCA) was used to test the relationship between sampling location stations, physico-chemistry, macroinvertebrate abundance and ecological indices of each station in each river studied (Legendre and Legendre 1998). With its ability to handle several variables at once, this method provides a more comprehensive understanding of their interrelationships. Meanwhile, to determine the differences in similarity of all variables, including physicochemical variables, macroinvertebrate abundance, and ecological indices between one station and another on the Watumokala River and Nokambu River, a similarity test can be carried out using the Hierarchical Clustering method in the Single Linkage Algorithm with the Bray-Curtis similarity index, using PAST 4.03 (Hammer et al. 2001). With the ability to handle several variables at once, this method provides a more comprehensive comprehension of their interrelationships. Family density data and environmental variables are transformed to log (x+1). Analysis of differences in physicochemical parameters and ecological indices at each sampling location was carried out using the Kruskal-Wallis One-Ways Anova test. The results of the ANOVA test can determine $p<0.05$ or significant and $p>0.05$ (not significant). If the ANOVA test results are significant, a further test is carried out with the Least Significant Difference (LSD) test (Ezenwa et al. 2023). Spearmans correlation analysis using IBM SPSS 27 was carried out to determine the correlation between physicochemical variables, macroinvertebrate abundance and ecological indices.

RESULTS AND DISCUSSION

Physical and chemical parameters of river water quality

Summary of the results of descriptive and inferential statistical tests for various water physicochemical variables in the Watumokala River and Nokambu River is presented in Table 1. Several variables that are similar in the two rivers are significantly different ($p<0.05$), including river flow rate, TDS, COD, and pH. While the variables TSS, BOD, and DO are significantly different at all stations on the Watumokala River, they are not significantly different in the Nokambu River. There is a tendency for the highest TSS and BOD in the Nokambu River to be found at station 2 (Sta.2NR), while the highest DO is at station 3 (Sta.3NR). Likewise, the water temperature variable in the two rivers shows that there is no real difference between the stations, but the highest water temperature in the two rivers is at station 3 respectively.

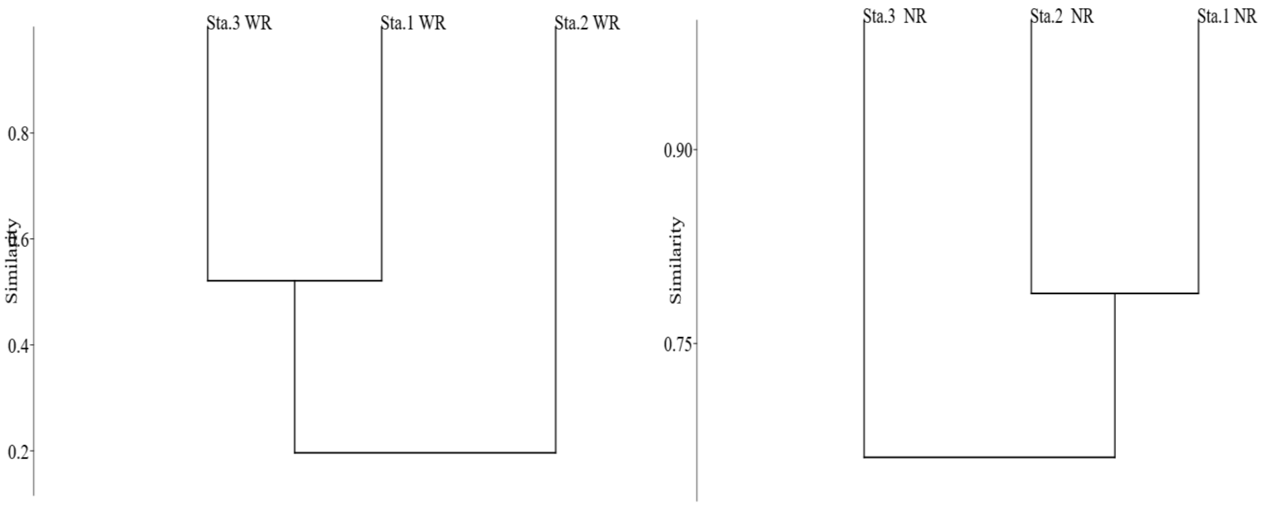
The river flow rate in the Watumokala River is highest at station 1 and is not significantly different from station 3, but is significantly different from station 2 which has the lowest flow rate. Meanwhile, the highest flow rate on the Nokambu River is at station 3 which is significantly different from station 2 and station 1 which have the lowest flow rate. The TDS value on both rivers has the lowest value at station 1 respectively, different in magnitude from station 2 and station 3 respectively. The highest TDS is found at stations 2 and 3 respectively. Likewise, the TSS, BOD and COD values on the Watumokala River are highest at station 3 and the lowest at station 1. Meanwhile, COD on the Nokambu River is highest at station 2 and lowest at station 1. The highest DO values on the Watumokala River are at stations 3 and not significantly different from station 1 but significantly different from station 2. The pH value in the two rivers is highest at station 1 and lowest at station 3 respectively.

Differences in physicochemical characters, macroinvertebrate abundance and ecological indices of the Watumokala River and Nokambu River were tested using a hierarchical clustering similarity test, resulting in the results as presented in Figure 2.

Table 1. Summary of physicochemical variables characterized at three sampling stations on the Watumokala River and Nokambu River respectively (values are the mean ± standard deviation; n=3)

Parameters	Watumokala Rivers (WR)				Nokambu Rivers (NR)			
	Sta.1WR	**Sta.2WR**	**Sta.3WR**	**p (LSD)**	**Sta.1NR**	**Sta.2NR**	**Sta.3NR**	**p (LSD)**
Temperature (°C)	28±1.15	31±0.58	32±0.33	0.22^{ns}	29±1.15	29±0.58	30±1.73	0.87^{ns}
Flow rate (ms^{-1})	$0.89^{b}\pm0.06$	$0.36^{a}\pm0.05$	$0.77^{b}\pm0.06$	0.001^{*} (0.18)	$0.32^{a}\pm0.03$	$0.41^{b}\pm0.06$	$0.71^{c}\pm0.04$	0.002^{*} (0.14)
TDS (mgL^{-1})	$197^{a}\pm5.48$	$236^{b}\pm12.12$	$243^{b}\pm8.66$	0.025^{*} (27.22)	$249^{a}\pm5.77$	$405^{b}\pm9.24$	$385^{b}\pm7.50$	0.001^{*} 24.06
TSS (mgL^{-1})	$17^{a}\pm2.03$	$14^{a}\pm2.89$	$28^{b}\pm3.46$	0.031^{*} (8.85)	25±4.04	30±4.04	27±2.89	0.65^{ns}
BOD (mgL^{-1})	$2.32^{a}\pm0.06$	$2.72a^{b}\pm0.06$	$2.76^{b}\pm0.07$	0.005^{*} (0.20)	1.86±0.07	2.11±0.05	1.97±0.13	0.23^{ns}
COD (mgL^{-1})	$20.8^{a}\pm3.42$	$19.2^{a}\pm4.20$	$27.2^{b}\pm4.62$	0.006^{*} (3.80)	$17.08^{a}\pm1.73$	$27.05^{b}\pm1.04$	$18.52^{a}\pm1.22$	0.004^{*} (4.30)
DO (mgL^{-1})	$3.92^{ab}\pm0.12$	$3.2^{a}\pm0.13$	$4.8\pm^{b}0.59$	0.05^{*} (1.04)	4.32±0.29	3.66±0.12	3.83±0.28	0.20^{ns}
pH	$7.62^{b}\pm0.03$	$7.53^{b}\pm0.03$	$7.26^{c}\pm0.06$	0.002^{*} (0.12)	$7.77^{b}\pm0.13$	$7.40^{a}\pm0.08$	$7.31^{a}\pm0.06$	0.03^{*} (0.28)

*Mean difference is significant at $p<0.05$ level using Kruskal-Wallis One-Way ANOVA



A B

Figure 2. The results of hierarchical clustering analysis location/station based on physicochemical, macroinvertebrate abundance and ecological indices with distance measures of the Bray-Curtis Similarity Index and the Single Linkage Algorithm, on A. Watumokala and B. Nokambu Rivers

Based on the results of a similarity analysis on physicochemical variables, macroinvertebrate abundance and ecological indices in the Watumokala River shows that Sta.1WR and Sta.2WR have high level of similarities or form the same group and are different from Sta.3WR. In contrast to the results of the similarity test between stations on the Nokambu River, Sta.1NR and Sta.2NR have a high level of similarity or are in the same group, which is different from Sta.3NR which has a low similarity.

Taxonomic composition and total abundance of macroinvertebrates

The abundance of macroinvertebrate species found in the Watumokala River and Nokambu River is presented in Table 2. Total of 1852 species were found in the Watumokala River, varying between stations, where the number of individuals found from Sta.1WR was 968 individuals, Sta.2WR was 320 individuals, and in Sta.3WR there were 562 individuals. In contrast to the abundance of macro-invertebrate species in the Nokambu River, 904 species were found distributed at each observation station, namely at Sta.1NR there were 406 individuals, at Sta.2NR there were 281 individuals, and at Sta.3NR there were 216 individuals.

In Table 3, it can be seen that the number of individuals originating from the Watumokala River is 10 orders and 17 families. The Gastropod order consists of three families, namely Pleuroceridae, Thiaridae-A, and Viviparidae; the Bivalvia order consists of two families, namely Corbiculidae and Spaeriidae; the Ephemeroptera order consists of two families, namely Leptophlebiidae-B, and Leptophlebiidae-C; The Plecoptera order is found in two families, namely the Chloroperlidae and Perlidae families; There are two families in the Trichoptera order, namely Hydropsychidae and Polycentropodidae; The Hemiptera order consists of two families, namely Vellidae and Nepidae. Meanwhile, the orders Coleoptera, Diptera, Cladocera, and Odonata each have one family, namely Gyrinidae, Tipulidae-B, Palaemonidae, and Lestidae. Of the 1850 abundances of individual families in the Watumokala River, the highest abundance of individuals came from the order Ephemeroptera, Trichoptera, and Plecoptera (EPT) amounting to 1267 (68.41%) of which 714 (8.55%) were found at station 1 (Sta.1WR) and 551 (29.75%) at station 3 (Sta.3WR), followed by the Gastropod order with 206 (11.12%) mostly found at station 2, and Bivalves with 184 (9.94%) generally found at station 1 (Sta.1WR).

Meanwhile, in the Nokambu River, there are 8 orders and 14 families. The Gastropod order has 3 families, namely the Pleuroceridae, Thiaridae-A, and Neritidae families. The Ephemeroptera order has one family, namely the Heptagennidae family; the Plecoptera order has one family, and the Tricoptera (EPT) has two families, namely the Philopotamidae family. The Odonata order has four families, namely the Gomphidae, Libellulidae, Lestidae, and Platystictidae families. The Gastropod order consists of three families, namely Pleuroceridae, Neritidae, and Thiaridae-A; The Hemiptera order consists of two families, namely Vellidae and Gerridae. The orders Haplotaxida, Diptera, and Decapoda each have one family, namely the Lumbricidae, Tipulidae-B, and Gecarciuncidae families respectively. Of the total abundance of individuals in the family of 904 in the Nokambu River, the highest abundance was in the order Odonata with 357 (39.51%) spread across three stations, namely 168 (18.56%) at station 1 (Sta.1NR), 87 (9.58%) at station 2 (Sta.2NR) and 103 (11.37%) at station 3 (Sta.3NR). The second most numerous is the Gastropod order with 184 (20.35%) spread across the three stations, namely 70 (7.78%) at station 1 (Sta.1NR), 81 (8.98%) at station 2 (Sta.2NR) and 32 (3.59%) at station 3 (Sta.3NR). Furthermore, the Hemiptera order has a total of 114 (12.57%) spread across three stations, namely station 1 with 38 (4.19%), station 2 with 54 (5.99%) and station 3 with 22 (2.39%). Meanwhile, the order that is not tolerant of pollution, namely Ephemeroptera, has a number of 60 (6.58%) which is mostly found at station 1 (Sta.1NR) and station 3 (Sta.3NR), while the order Tricoptera is found in 54 (5.99%) is only found at station 2 (Sta.2NR).

Ecological indices determine water quality in Watumokala and Nokambu rivers

Ecological indicators that indicate water quality in the Watumokala and Nokambu Rivers are the Shannon diversity index, dominace, abundance index, number of EPT families, eveness, Margalef richness index, and the Family Biotic Index (FBI), which varies between observation stations in the two rivers (Table 3).

In Table 3, all ecological index parameters in the Watumokala River show significant values ($p<0.05$), whereas in the Nokambu River, only two parameters are significant, namely abundance and FBI, while the others are not significant ($p>0.05$). Macroinvertebrate diversity in the Watumokala River is significant with the highest value at station 1, significantly different from station 2 but not significantly different from station 3. Meanwhile, diversity in the Nokambu River is not significant where the highest value is at station 1 and the lowest at station 2. Likewise, the dominance parameter on the Watumokala River is significant with the highest value found at station 2 which is significantly different from station 2 and station 1. The lowest dominance is at station 1 which is different from station 2 and station 3. Meanwhile, the Nokambu River has an insignificant and lower dominance. compared to the dominance of the Watumokala River. The number of individual abundances in the Watumokala River shows that it is greater than in the Nokambu River. The abundance in the two rivers shows significant values where the two rivers show the highest values at station 1 and are significantly different from station 2 and station 3 respectively. The number of EPT families in the Watumokala River is more numerous and significant than in the Nokambu River which is not significant. The highest number was found at station 1 (Sta.1WR) which was significantly different from station 3 and station 2, where it was not found at station 2 (Sta.2WR). The evenness value for each observation station on the Watumokala River is significantly different while on the Nokambu River, it is not significant. The highest evenness value in the Watumokala River is at station 1 which is not significantly different from station 3 but different from station 2. Likewise, Margalef richness appears to be higher in the Nokambu River compared to the value in the Watumokala River, but in the Nokambu River, it is not significant whereas in the Watumokala River, it is significant. The highest value of Margalef wealth in the Watumokala River is found at station 1 which is significantly different from station 2 and station 3. The results of FBI calculations show a significant value in both rivers. The highest FBI value in the Watumokala River is found at station 2 which is significantly different from station 1 and station 3, while at station 1 is not different from station 3. Meanwhile, in the Nokambu River the highest FBI value is found at station 3 which is significantly different from station 2 and station 1, while station 1 and station 2 are not significantly different.

Table 2. Number of Individuals from each family and macroinvertebrate order at each station on the Watumokala and Nokambu Rivers, Southeast Sulawesi, Indonesia

Order	Family	Watumokala River (WR)			Number	Nokambu River (NR)			Number
		Sta.1WR	Sta.2WR	Sta.3WR		Sta.1NR	Sta.2NR	Sta.3NR	
Gastropoda	Pleuroceridae	22	0	0	22	43	16	49	108
	Neritidae	0	0	0	0	11	0	11	22
	Thiaridae-A	32	0	0	32	16	16	22	54
	Viviparidae	0	152	0	152	0	0	0	0
Bivalvia	Corbiculidae	162	0	0	162	0	0	0	0
	Spaeriidae	22	0	0	22	0	0	0	0
Ephemeroptera	Leptophlebiidae-B	152	0	81	233	0	0	0	0
	Leptophlebiidae-C	0	0	135	135	0	0	0	0
	Heptageniidae	0	0	0	0	43	16	0	60
Plecoptera	Chloroperlidae	146	0	0	146	0	0	0	0
	Perlidae	103	0	0	103	0	0	0	0
Tricoptera	Hydropsychidae	189	0	162	352	0	0	0	0
	Philopotamidae	0	0	0	0	22	22	11	54
	Polycentropodidae	124	0	173	298	0	0	0	0
Hemiptera	Vellidae	0	22	0	22	38	22	16	76
	Gerridae	0	0	0	0	0	0	38	38
	Nepidae	0	60	0	60	0	0	0	0
Haplotaxida	Lumbricidae	0	0	0	0	16	16	22	54
Coleoptera	Gyrinidae	0	81	0	81	0	0	0	0
Diptera	Tipulidae-B	0	16	0	16	0	5	11	16
Decapoda	Gecarciuncidae	0	0	0	0	49	0	16	65
Cladocera	Palaemonidae	0	0	11	11	0	0	0	0
Odonata	Gomphidae	0	0	0	0	54	11	0	65
	Libellulidae	0	0	0	0	38	43	43	124
	Lestidae	0	5	0	5	32	16	16	65
	Platystictidae	0	0	0	0	43	32	27	103
Total		968	320	562	1852	406	216	282	904

Table 3. Biological indices measured and water quality in Watumokala and Nokambu Rivers, Southeast Sulawesi, Indonesia

Ecological indices	Watumokala Rivers (WR)			p (LSD)	Nokambu Rivers (NR)			P (LSD)
	Station				Station			
	Sta.1 WR	Sta.2 WR	Sta.3 WR		Sta.1 NR	Sta.2 NR	Sta.3 NR	
H' (Diversity index)	2.04^c±0.09	1.26^a±0.06	1.41^c±0.03	0.001*	2.40±0.04	2.28±0.07	2.35±0.06	0.08^{ns}
	Slightly polluted	Moderately polluted	Moderately polluted	(0.10)	Slightly polluted	Slightly polluted	Slightly polluted	
Dominance (D)	0.14^a±0.01	0.33^c±0.03	0.26^b±0.01	0.001*	0.10±0.01	0.11±0.01	0.11±0.02	0.23^{ns}
	Not polluted	Slightly polluted	Slightly polluted	(0.03)	Not polluted	Not polluted	Not polluted	
K_i (Abundance index) (ind m^{-2})	968.61^c±20	319.26^a±10	562.77^b±40	0.004* (41.08)	405.84^c±20	216.45^a±30	281.39^b±10	0.003* (34.37)
Number of EPT taxa richness	5.00^c±1.50	0.00^a±0.00	4.00^b±0.50	0.002*	2.00±2.00	2.00±1.00	1.00±1.73	0.65^{ns}
	Moderately impacted	Severely impacted	Moderately impacted	(1.48)	Moderately impacted	Moderately impacted	Severely impacted	
E (Eveness index)	0.78^b±1.50	0.71^a±1.50	0.83^b±1.50	0.02*	0.91±0.04	0.89±0.06	0.88±0.05	0.58^{ns}
	High similarity	High similarity	High similarity	(0.06)	High similarity	High similarity	High similarity	
D^{mg} (Margalef richness index)	1.31^b±1.17	0.69^a±0.69	0.63^a±0.63	0.007	1.83±0.20	1.86±0.35	1.95±0.44	0.96^{ns}
	Moderate	Low	Low	(0.25)	Moderate	Moderate	Moderate	
FBI (Family biotic index)	3.64^a±0.20	4.98^b±0.30	3.84^a±0.45	0.005	4.45^a±0.52	4.71^a±0.14	5.60^b±0.41	0.03*
	Not impacted	Slightly impacted	Not impacted	(0.57)	Not impacted	Slightly impacted	Slightly impacted	(0.57)

Correlation between ecological of water quality, macroinvertebrate community and environmental parameters

The relationship between environmental conditions and macroinvertebrate communities in the form of ecological indicators is shown in the correlation analysis at a significance of $p<0.05$ and $p<0.01$, for the Watumokala River (Table 4) and the Nokambu River (Table 5). In addition, to ensure the relationship between sampling locations, environmental conditions and biological indices, a multivariate CCA triplot test was carried out, and the results of the CCA plot diagram were for the Watumokala River (Figure 3) and Nokambu River (Figure 4).

In the Watumokala River, the results of Spearman's correlation analysis show that ecological index parameters and several macroinvertebrate abundances have a significant correlation with environmental parameters (physicochemical). The Shannon diversity index, abundance, and family EPT shown by the Leptophlebiidae-B and Hydropsychidae families have the same value in providing a very strong significant positive correlation with river flow rate, and have a fairly strong positive correlation with TSS, COD, and DO, but have quite strong negative correlation with temperature, TDS and BOD. Meanwhile, Dominance and FBI have a very strong significant negative correlation with river flow rate and a fairly strong negative correlation with TSS, COD, and DO, but have a fairly strong positive correlation with temperature, TDS, and BOD. Meanwhile, Eveness and the Polycentropodidae family have a very strong and significant positive correlation with TSS, COD, and DO and have a strong negative correlation with pH. In contrast, Margalef richness showed a very strong significant negative correlation with temperature, TDS, and BOD, and a strong positive correlation with pH. The families Pleuroceridae, Thiaridae-A, Corbiculidae, Spaeriidae, Chloroperlidae, Perlidae, and Tipulidae-B have the same values so they provide a strong positive correlation with river flow rate and a fairly strong positive correlation with pH, but provide a strong negative correlation with temperature, TDS, and BOD. The families Viviparidae, Vellidae, Nepidae, Gyrinidae, and Lestidae also have the same values, giving a strong negative correlation to river flow rate, TSS, COD, and DO, but giving a fairly strong positive correlation to pH. The Leptophlebiidae-C and Palaemonidae families have a very strong negative correlation with pH, but have a strong positive correlation with temperature, TDS, TSS, BOD, COD, and DO.

Table 4. Spearman's correlation between physicochemical condition and ecological indicators of water quality based on macroinvertebrates community in Watumokala Rivers, Southeast Sulawesi, Indonesia

Ecological indicators	Physicochemical							
	Temp.	Flow rate	TDS	TSS	BOD	COD	DO	pH
Measurement of ecological indicators of rivers water quality								
H'	-0.500	**1.000****	-0.500	0.500	-0.500	0.500	0.500	0.000
Dominance	0.500	**-1.000****	0.500	-0.500	0.500	-0.500	-0.500	0.000
Ki	-0.500	**1.000****	-0.500	0.500	-0.500	0.500	0.500	0.000
EPTs	-0.500	**1.000****	-0.500	0.500	-0.500	0.500	0.500	0.000
E	0.500	0.500	0.500	**1.000****	0.500	**1.000****	**1.000****	-0.866
Dmg	**-1.000****	0.500	**-1.000****	-0.500	**-1.000****	-0.500	-0.500	0.866
FBI	0.500	**-1.000****	0.500	-0.500	0.500	-0.500	-0.500	0.000
Family abundance								
Pleuroceridae	-0.866	0.866	-0.866	0.000	-0.866	0.000	0.000	0.500
Thiaridae-A	-0.866	0.866	-0.866	0.000	-0.866	0.000	0.000	0.500
Viviparidae	0.000	-0.866	0.000	-0.866	0.000	-0.866	-0.866	0.500
Corbiculidae	-0.866	0.866	-0.866	0.000	-0.866	0.000	0.000	0.500
Spaeriidae	-0.866	0.866	-0.866	0.000	-0.866	0.000	0.000	0.500
Leptophlebiidae-B	-0.500	**1.000****	-0.500	0.500	-0.500	0.500	0.500	0.000
Leptophlebiidae-C	0.866	0.000	0.866	0.866	0.866	0.866	0.866	**-1.000****
Chloroperlidae	-0.866	0.866	-0.866	0.000	-0.866	0.000	0.000	0.500
Perlidae	-0.866	0.866	-0.866	0.000	-0.866	0.000	0.000	0.500
Hydropsychidae	-0.500	**1.000****	-0.500	0.500	-0.500	0.500	0.500	0.000
Polycentropodidae	0.500	0.500	0.500	**1.000****	0.500	**1.000****	**1.000****	-0.866
Vellidae	0.000	-0.866	0.000	-0.866	0.000	-0.866	-0.866	0.500
Nepidae	0.000	-0.866	0.000	-0.866	0.000	-0.866	-0.866	0.500
Gyrinidae	0.000	-0.866	0.000	-0.866	0.000	-0.866	-0.866	0.500
Tipulidae-B	-0.866	0.866	-0.866	0.000	-0.866	0.000	0.000	0.500
Palaemonidae	0.866	0.000	0.866	0.866	0.866	0.866	0.866	**-1.000****
Lestidae	0.000	-0.866	0.000	-0.866	0.000	-0.866	-0.866	0.500

Note: **Correlation is significant at the 0.01 level (1-tailed)

Table 5. Spearman's correlation between physicochemical condition and ecological of water quality based on macroinvertebrates community in Nokambu Rivers, Southeast Sulawesi, Indonesia

Ecological indicators	Physicochemical							
	Temp.	**Flow rate**	**TDS**	**TSS**	**BOD**	**COD**	**DO**	**pH**
Measurement of ecological indicators of rivers water quality								
H'	**-1.000****	-0.866	0.000	0.000	0.000	0.000	0.000	0.500
Dominance	**1.000****	0.866	0.000	0.000	0.000	0.000	0.000	-0.500
Ki	-0.866	**-1.000****	-0.500	-0.500	-0.500	-0.500	0.500	0.866
EPTs	-0.866	**-1.000****	-0.500	-0.500	-0.500	-0.500	0.500	0.866
E	0.500	0.000	-0.866	-0.866	-0.866	-0.866	0.866	0.500
Dmg	0.000	0.500	**1.000****	**1.000****	**1.000****	**1.000****	**-1.000****	-0.866
FBI	0.866	**1.000****	0.500	0.500	0.500	0.500	-0.500	-0.866
Family abundance								
Pleuroceridae	-0.866	-0.500	0.500	0.500	0.500	0.500	-0.500	0.000
Neritidae	**-1.000****	-0.866	0.000	0.000	0.000	0.000	0.000	0.500
Thiaridae-A	-0.500	0.000	0.866	0.866	0.866	0.866	-0.866	-0.500
Heptageniidae	0.000	-0.500	**-1.000****	**-1.000****	**-1.000****	**-1.000****	**1.000****	0.866
Philopotamidae	0.500	0.000	-0.866	-0.866	-0.866	-0.866	0.866	0.500
Vellidae	0.000	-0.500	**-1.000****	**-1.000****	**-1.000****	**-1.000****	**1.000****	0.866
Gerridae	-0.500	0.000	0.866	0.866	0.866	0.866	-0.866	-0.500
Lumbricidae	-0.500	0.000	0.866	0.866	0.866	0.866	-0.866	-0.500
Tipulidae-B	0.000	0.500	**1.000****	**1.000****	**1.000****	**1.000****	**-1.000****	-0.866
Gecarciuncidae	-0.866	**-1.000****	-0.500	-0.500	-0.500	-0.500	0.500	0.866
Gomphidae	0.000	-0.500	**-1.000****	**-1.000****	**-1.000****	**-1.000****	**1.000****	0.866
Libellulidae	0.500	0.866	0.866	0.866	0.866	0.866	-0.866	**-1.000****
Lestidae	-0.500	-0.866	-0.866	-0.866	-0.866	-0.866	0.866	**1.000****
Platystictidae	0.000	-0.500	**-1.000****	**-1.000****	**-1.000****	**-1.000****	**1.000****	0.866

Note: **Correlation is significant at the 0.01 level (1-tailed)

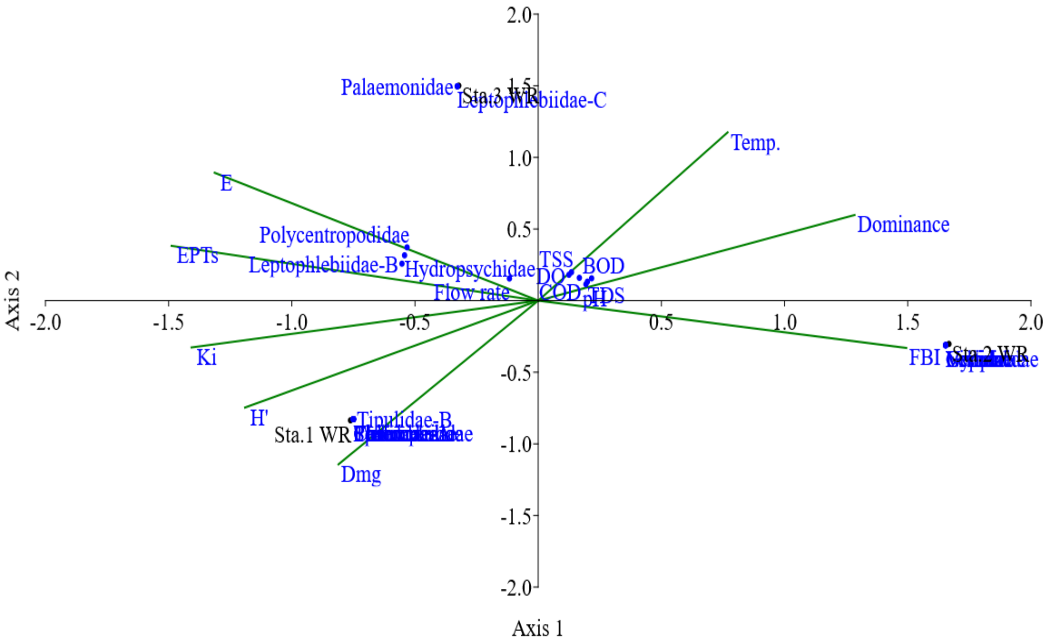


Figure 3. CCA triplot based on sample stations, physicochemical variables, family of macroinvertebrates, and ecological indicators of river water quality on Watumokala Rivers, Southeast Sulawesi, Indonesia

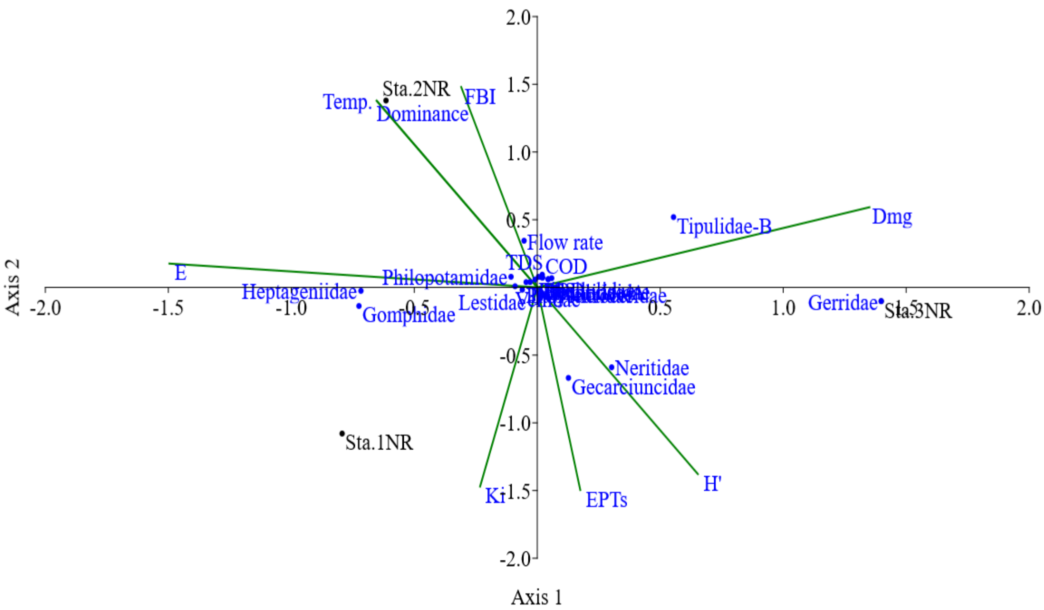


Figure 4. CCA triplot based on sample stations, physicochemical variables, family of macroinvertebrates, and ecological indicators of river water quality on Nokambu Rivers, Southeast Sulawesi, Indonesia

In the Watumokala River, the CCA triplot analysis (in Figure 3) between sampling location, ecological index, physicochemical parameters, and macroinvertebrate abundance which on axis 1 has an Eigenvalue of 0.574 with a variance of 65.06% shows that the Station (Sta.1WR) has high correlation with river flow rate, EPTs, Evennes (E), Margalef richness index (Dmg). Sta.1WR has a high correlation with many types of macro-invertebrate families such as the Pleuroceridae, Thiaridae-A, Corbiculidae, Spaeriidae, Leptophlebiidae-B, Leptophlebiidae-C, Chloroperlidae, Perlidae, Hydropsychidae, Polycentropodidae, Tipulidae-B, Palaemonidae, and Lestidae families. However, it has a far or low correlation with station 2 (Sta.2WR) and other physicochemical elements, namely TDS, BOD, COD, DO, pH, and water temperature. Likewise in several families including Viviparidae, Vellidae, Nepidae, and Gyrinidae as well as ecological indices such as dominance and FBI. Station 1 is close to or similar to Station 3, but is very different from Station 2 (as can also be seen from the Custer analysis in Figure 3). Meanwhile, axis 2 has an Eigenvalue of 0.308 with a variance of 34.94%, indicating that station 1 (Sta.1WR) has a strong correlation with the Pleuroceridae family Thiaridae-A, Viviparidae, Corbiculidae, Spaeriidae, Chloroperlidae, Perlidae, Vellidae Nepidae, Gyrinidae, Tipulidae-B, and Lestidae as well as the ecological index Shannon index, abundance of margalef, and FBI. On the other hand, station 1 has a relationship that is far from the influence of all physicochemical elements and the families Leptophlebiidae-B, Leptophlebiidae-C, Hydropsychidae, Polycentropodidae, and Palaemonidae. Station 1 is close to station 2, but very different from station 3.

In contrast to the Nokambu River, the results of Spearman's correlation analysis show that ecological index parameters and several macroinvertebrate abundances have a significant correlation with environmental parameters (physicochemical) and are different from those in the Watumokala River. The Shannon diversity index and the Neritidae family have the same value, a very strong significant negative correlation with temperature, and a strong negative correlation with river flow rate, and a fairly strong positive correlation with pH. On the other hand, Dominance has a very strong and significant positive correlation with temperature, and a strong positive correlation with water flow rate, and a fairly strong negative correlation with pH. Abundance, EPT family and family Gecarciuncidae have the same value, a very strong significant negative correlation with river flow rate, a strong negative correlation with temperature, and a fairly strong negative correlation with TDS, TSS, BOD, and COD, and a fairly strong positive correlation with DO and strongly positively correlated with pH. FBI has the opposite value with a very strong significant positive correlation with river flow rate, a strong positive correlation with temperature, a fairly strong positive correlation with TDS, TSS, BOD, and COD, and a fairly strong negative correlation with DO and a strong negative correlation with pH. Evenness and the Philopotamidae family have a strong negative correlation with TDS, TSS, BOD, and COD, and have a strong positive correlation with DO and a fairly strong positive correlation with temperature and pH. Margalef richness has the same value as the Heptagenidae, Vellidae, and Tipulidae-B families, giving a very strong significant positive correlation with TDS, TSS, BOD, and COD, a very strong significant negative correlation with DO and a fairly strong negative correlation with river flow rate and a strong negative correlation. with pH. On the contrary, the Gompidae and Platystictidae families show a very strong significant negative correlation with TDS, TSS, BOD, and COD, a very strong significant positive correlation with DO, and a quite strong positive correlation with river flow rate and a strong positive correlation with pH. Furthermore, the Libellulidae family has a very strong significant negative correlation with pH, a strong negative correlation with DO, and a quite strong positive correlation with temperature, and a strong positive correlation with flow rate, TDS, TSS, BOD, and COD. On the other hand, the Lestidae family has a very strong significant positive correlation with pH, a strong positive correlation with DO, a fairly strong negative correlation with temperature, and a strong negative correlation with flow rate, TDS, TSS, BOD, and COD.

When compared with the Nokambu River, the results of the CCA triplot analysis (in Figure 4) between sampling locations, ecological indices, physicochemical parameters, and macroinvertebrate abundance on axis 1 have an Eigenvalue of 0.0997 with a variance of 70.65%, showing that the Station (Sta.1NR) has a high correlation with station 2 (Sta.2NR), and physicochemical elements including river flow rate, DO, pH and water temperature as well as ecological indices such as dominance, abundance, evenness (E), and FBI. Sta.1NR also has a high correlation with various types of macroinvertebrate families such as the Heptageniidae, Philopotamidae, Vellidae, Gomphidae, Lestidae, and Platystictidae families. However, it has a far or low correlation with station 3 (Sta.3NR) and other physicochemical elements, namely TDS, TSS, BOD, and COD. Likewise in several families, including Pleuroceridae, Neritidae, Thiaridae-A, Gerridae, Lumbricidae, Tipulidae-B, Gecarciuncidae, and Libellulidae, as well as ecological indices such as the Shannon index, EPTs and margalef. Station 1 is close to or similar to Station 2, but very different from Station 3 (can also be seen from Custer's analysis in Figure 3.B). Meanwhile, axis 2 has an Eigenvalue of 0.0414 with a variance of 29.35% shows that station 1 (Sta.1NR) has a strong correlation with station 3 (Sta.3NR), and the abundance of macroinvertebrates such as Pleuroceridae, Neritidae, Heptageniidae, Gerridae, Gecarciunciundae, Gomphidae, and Lestidae as well as ecological indices including the Shannon index, abundance, and EPTs. On the other hand, station 1 has a relationship that is far from the influence of all physicochemical elements and the families Thiaridae-A, Philopotamidae, Vellidae, Lumbricidae, Tipulidae-B, Libellulidae, and Lestidae.

Discussion

Physical and chemical parameters of river water quality

The result from characterization of the selected physicochemical parameters in the Watumokala and Nokambu Rivers, showed that list the parameters differed significantly. The physicochemical parameters that differ significantly in each river and at each observation station in the river are associated with environmental conditions that are affected by different anthropogenic activities (Zelnik and Muc 2020; Liu et al. 2022; Ezenwa et al. 2023). Rivers have unique natural characteristics and besides being influenced by land use around the riverbanks (dos Reis Oliveira et al. 2020) they are also influenced by the width and depth of the river, the slope of the slopes (Mengen et al. 2020), the condition of canopy cover (Krisanti et al. 2020), and the substrates they contain (Kujanová et al. 2018; Gething et al. 2020). The land around the river has a relationship with the river ecosystem that flows in it (Dede et al. 2023). The land use type has a strong positive and adverse relationship with the physicochemical parameters of river water quality (Kahirun et al. 2019; Anh et al. 2023). The differences in physicochemical parameters directly affect the biological composition of streams and rivers (Tamiru et al. 2017; Krisanti et al. 2020), especially the presence and distribution of macroinvertebrates (Jonsson et al. 2017).

The water temperature conditions in the two rivers, although there is no significant difference, can be seen to be lower in the upstream part of the river. This is due to the influence of vegetation cover on the river body because, at the upstream station, there is still a lot of forest vegetation (Fierro et al. 2017; Rais et al. 2019). The optimal temperature range for the life of aquatic organisms, including macroinvertebrates, ranges from 26°C to 32°C (Orozco-González and Ocasio-Torres 2023). In the Watumokala River, there is a tendency for low temperatures to affect low TDS and BOD values causing high DO (Rais et al. 2019). Meanwhile, the Nokambu River shows high water temperature due to a lack of vegetation cover so it is also in line with the increase in water flow rate which causes an increase in the values of TSS, TDS and BOD, and COD (Labajo-Villantes and Nuñeza 2015). The increase in these parameters causes DO to decrease (Mena-Rivera et al. 2017) so that in line with the speed of water flow from a body of water it also determines the distribution of organisms including macroinvertebrates that live in the water body (Mamun et al. 2022; Anh et al. 2023). The TSS value has a positive relationship with TDS, COD, and BOD, caused by sediment (from soil erosion and household waste pollution (Dirisu et al. 2017; Shim et al. 2018), especially in the Nokambu River in urban areas.

Taxonomic composition and total abundance of macroinvertebrates

Both the composition and abundance of macroinvertebrate species in the river have differences where the Watumokala River has more species composition and abundance compared to the Watumokala River. Some of the families that have the highest abundance in the Watumokala River are from the EPT family, compared to those in the Nokambu River which are less (Labajo-Villantes and Nuñeza 2015). This is closely related to the type of mud, sandy and rocky substrate which is small because the current speed at this location is quite high, which is a very suitable habitat for the EPT order of the Leptophlebiidae-B family, Chloroperlidae, Hydropsychidae, and the Bivalvia order of the Corbiculidae family (Espinosa et al. 2020; Liu et al. 2022) on the Watumokala River, especially at Sta.1WR. Meanwhile, Sta.2WR, where the substrate is sandy and with small river rocks, is a suitable habitat for organisms from the Gastropod and Coleoptera orders. The existence of Gastropods and Coleoptera shows a close relationship with the presence of substrate and river flow

(Bartkowska et al. 2023). Whereas Sta.3WR with muddy and rocky substrates, the macroinvertebrates that were found were the Orders Tricoptera and Ephemeroptera from the Polycentropodidae and Leptophlebiidae-C families. Meanwhile, in the Nokambu River, which is in an urban area, you can find the EPT order in a small number of individuals, especially from the Heptageniidae family and the Tricoptera order from the Philopotamidae family (Onana et al. 2021). The orders that are commonly found in the Nokambu River are the Odonata Order from the families Gomphidae, Libellulidae, Lestidae, and Platystictidae and the Gastropod Order from the families Pleurocerida, Neritidae, and Thiaridae-A. The Gastropod order has increased and invasions have occurred in agricultural and urban areas (Bae and Park 2020) and the Odonata order is mostly associated with moderate water pollution, and in agricultural areas, the order Hemiptera is also found in the families Vellidae and Gerridae (Kahirun et al. 2019).

Ecological indices determine water quality in Watumokala and Nokambu Rivers

There are differences in ecological index characteristics between the Watumokala River and the Nokambu River. All ecological index parameters in the Watumokala River show significant differences between stations, whereas in the Nokambu River, only the abundance and FBI parameters differ significantly between stations (Anh et al. 2023). This difference is caused by differences between rivers which are still influenced by the characteristics of rural agriculture upstream of the river (Espinosa et al. 2020), and rivers which are heavily influenced by urban settlements (Mena-Rivera et al. 2017).

Based on the Hilsenhoff (1988) evenness index, the evenness index values for both the Watumokala River and the Nokambu River show a high uniformity index. The high evenness values from the three stations indicate that individuals tend to be distributed among each species, or that the community is not dominated by certain species (Krebs 2014). On the other hand, a smaller evenness index value indicates that the distribution of the number of individuals for each species or family is not the same and indicates a tendency for one species to dominate in the population (Makumbe et al. 2022). The Margalef wealth value does not have a specific value limit but varies at each observation station and is related to the diversity value. If the Shannon and Margalef diversity indices are low, it reflects a decrease in species composition caused by environmental degradation due to human anthropogenic pressure (Bassey et al. 2020). This can be seen from the anthropogenic influence on the Watumokala River, namely activities related to lowland rice farming and rural settlements which are still dominated by plantation crop farming, whereas on the Watumokala River, there is already the influence of pressure from urban activities which are less agricultural (Anh et al. 2023; Ezenwa et al. 2023). So the results of the FBI assessment show that at stations that are disturbed by human anthropogenic activities, the water quality is slightly impacted and fairly substantial pollution is likely (Ogbeibu et al. 2013; Enawgaw and Lemma 2019).

The FBI value of the water quality of the Watumokala River at the three stations shows the level of pollution in the good to very good category. Meanwhile, in the Nokambu River, the level of pollution is in the moderate to good category. In general, station 1 in the two rivers is the upper reaches of the river where the vegetation cover around the river is secondary dryland forest (Labajo-Villantes and Nuñeza 2015). The forest in the upper reaches of the river contributes relatively small amounts of organic matter to the river because it only comes from leaves and tree branches that enter the river (Gerth et al. 2017). This condition supports the presence of macroinvertebrates in rivers. Station 1 and station 3 on the Watumokala River are dominated dominated by taxa that are intolerant of pollution, namely members of the family from the order Ephemeroptera (family Leptophlebiidae B), the order Plecoptera (family Chloroperlidae and family Perlidae), and Tricoptera (family Hydropsychidae and Polycentropodidae). This indicates that the water quality at the station is still good (Espinosa et al. 2020). In contrast, the Diptera order (Tipulidae B family) which is tolerant of pollution is found at station 2 of the Watumokala River and in the Nokambu River. There were also many Odonata orders found in the Nokambu River spread across all stations, giving an indication that the river has experienced a lot of human disturbance (Ezenwa et al. 2023). This research shows that there is no difference in water quality between the use of forest land and agricultural land and rural settlements (Fierro et al. 2017), especially in the Watumokala River because it is still in the good category, but in the Nokambu River in dense settlements, the water quality is already at medium status (Orozco-González and Ocasio-Torres 2023).

Correlation between ecological of water quality, macro-invertebrate community and environmental parameters

The results of correlation tests between ecological indicators, family abundance, and physicochemical parameters in the Watumokala River show that several parameters are significantly correlated. Water temperature, TDS, and BOD provide a significant negative correlation to ecological indices including Shannon diversity and Margalef richness (Anh et al. 2023). Increasing the values of TDS, BOD, and water temperature correlate with the presence of human activity in the use of paddy fields (Mamun et al. 2023). Likewise, these three environmental parameters have a significant negative effect on the richness of several macroinvertebrate communities such as Pleuroceridae, Thiaridae-A, Corbiculidae, Spaeriidae, Chloroperlidae, Perlidae, and Tipulidae-B (Nugrahaningrum et al. 2017). River flow rate has a significant positive correlation with the abundance and number of EPT families (Camacho and Taniegra 2019), but a significant negative correlation with FBI. Also, the river flow rate is positively correlated with the families Leptophlebiidae-B, Hydropsychidae, and Polycentropodidae, which are families from the orders Ephemeroptera and Trichoptera which are intolerant of pollution and really need flowing, clean water and cold temperatures (Ezenwa et al. 2023). On the other hand, the river flow rate is positively correlated with the families Vellidae, Nepidae, Gyrinidae, and Lestidae, which are families from the Order Hemiptera and Odonata which are tolerant to pollution. TSS and COD have a significant positive correlation with evenness, and the families Leptophlebiidae-C, and Palaemonidae (Hamid and Rawi 2017; Lu et al. 2022). DO gave significant positive correlation with evenness, while pH gave significant negative correlation with Leptophlebiidae-C and Palaemonidae.

Likewise, in the Nokambu River, the influence of water temperature and river flow rate is very significantly negative on Shannon diversity, the number of EPT families, and the abundance of several families such as Pleuroceridae, Neritidae, and Gecarciuncidae. However, water temperature has a significant positive effect on dominance and FBI. This indicates a lack of diversity and EPT families as well as the presence of a dominant family shows an increase in the FBI value so that it becomes an indicator of increasing organic pollution from river water (Lu et al. 2022). This can be seen from the influence of other physicochemical elements such as TDS, TSS, BOD, and COD which have a negative influence on the evenness value and the abundance of several macroinvertebrate families such as Thiaridae-A, Heptageniidae, Philopotamidae, Lestidae and Platystictidae and have a positive correlation with the richness of the Margalef and Lumbricidae, Tipulidae-B and Libellulidae family (Tessema and Tesfahun 2018). DO had a significant negative influence on the richness of Margalef, the family Tipulidae-B, and Libellulidae, but had a positive correlation with the families Vellidae, Lestidae, and Platystictidae. The pH value is positively correlated with the dominance value of the Vellidae, Lestidae, and Platystictidae families, but negatively correlated with the Tipulidae and Libellulidae families. Low DO and low pH are a result of the increase in the above polluting elements which can reduce diversity, and the number of EPTs that are intolerant of pollution, but the abundance of macroinvertebrates that are tolerant of pollution can persist and increase (Lima et al. 2020; Sinche et al. 2023).

Based on the results of the CCA triplot analysis between sampling location, ecological index, macroinvertebrate abundance, and environmental parameters, in the Watumokala River, it shows that the location of Station 1 of the Watumokala River (Sta.1WR) has a very strong or significant positive relationship with several ecological index parameters such as Shannon diversity, abundance, wealth of Margalef, EPTS and Evenness (Nugrahaningrum et al. 2017). Likewise, station 1 has a significant positive correlation with river flow rate and several EPT families such as the Leptophlebiidae-B, Polycentropodidae, Hydropsychidae, Chloroperlidae, and Perlidae (Sudarso et al. 2021; Garba et al. 2022). Station 1 has significant negative relationship with dominance, and FBI as well as several environmental parameters such as water temperature, TDS, TSS, BOD, COD, DO, and water pH (Fekadu et al. 2022). The low level of physicochemical elements that are pollutants has an impact on increasing diversity, richness, and abundance as well as the number of EPT families (Garba et al. 2022). This is also supported by the low water temperature at station 1, causing the development of several families who are intolerant of water pollution so that the FBI value becomes low as an indicator that water quality is still good or is experiencing little pressure from the impact of environmental change (Ogbeibu et al. 2013). The conditions of station 1 have similarities or strong correlations with the conditions of station 3 but are different from the conditions of station 2. Station 2 has a strong relationship with dominance and high FBI, water temperature, and physicochemical parameters as indicators of water pollution such as TDS, TSS, BOD, COD, and DO as well as several families Viviparidae from the order Gastropoda, Vellida, Nepidae and Gerridae from the order Hemiptera. This condition is caused by different land uses around the river, where at station 1 the land cover is forest vegetation (Martel et al. 2007; Keke et al. 2021) and at station 3 the land cover is mixed garden vegetation whose plants have a canopy that already resembles a forest, whereas at station 2 around the river is used as rice fields with open land conditions (Fu et al. 2016; Arimoro and Keke 2017; Kurnianto et al. 2022).

Meanwhile, in the Nokambu River, the results of CCA triplot analysis between sample location, ecological index, macroinvertebrate abundance, and environmental parameters show that the location of station 1 (Sta.1NR) has a strong positive significant relationship with station 2 (Sta.2NR) and the ecological index parameters, namely FBI, Dominance, evenness and abundance of macroinvertebrates as well as physicochemical parameters, namely water temperature, river flow rate, DO and pH. Also significantly positively correlated with several families including Heptagenidae, Gompidae, Lestidae, Philopotamidae, Vellidae, and Platystictidae. This family has sensitive values or low tolerance for environmental changes (Nugrahaningrum et al. 2017). Meanwhile, station 3 (Sta.3NR) has a significant negative correlation with station 1 and station 2, but a strong positive and significant correlation with ecological index parameters such as the Shannon index, EPTs, and Margalef and physicochemical parameters including, TDS, TSS, BOD, and COD. These chemical parameters are indicators that station 3 or downstream of the river is an urban residential area, indicating high pollution (Castro-López et al. 2019; Yao et al. 2022). Likewise, station 3 has a positive correlation with the families Pleuroceridae, Neritidae, Gecarciuncidae, Gerridae, Thiaridae, Lumbricidae, Tipulidae-B, and Libellulidae. Some of these families are families that have strong tolerance to environmental changes, such as Pleuroceridae, Neritidae, Gerridae, and Thiaridae (Krisanti et al. al. 2020).

In conclusion, the two rivers have different characteristics, namely the Watumokala River is a river in a watershed characterized by rural agriculture and the Nokambu River is a river in a watershed in urban areas. Differences in land use characteristics and disturbance from human activities indicate that there are differences in macroinvertebrate communities, both in composition and abundance, as well as in the richness of macroinvertebrate taxa. These differences are caused by differences in the physicochemical factors of river water. The differences in environmental conditions in the two rivers are caused by land cover which has a direct impact due to anthropogenic activities. The Watumokala River has very good water quality in the upstream section with forest land cover, water quality that is somewhat disturbed by pollution in rice fields, and very good quality in rural settlements. Meanwhile, the Nokambu River has good water quality for forest land use and mixed plantation land use, and the quality is somewhat disturbed by pollution for dense urban residential land use. Therefore, the results of this research are very useful in land and water management to overcome pollution in rivers.

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