

Macroinvertebrate Community Index (MCI) and Quantitative Macroinvertebrate Community Index (QMCI) Analysis: A Comparative Study between Le Afe and Mulivaifagatoloa Rivers, Upolu Island, Samoa

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Abstract

The diversity of Samoa's freshwater macroinvertebrates remains largely unexplored, with past studies focusing on specific species without comprehensive cataloguing. This research evaluated the health of Upolu Island's rural rivers through macroinvertebrate analysis, particularly in the Le Afe and Mulivaifagatoloa Rivers. Collaborating with Samoa's Water Resources Division in the Ministry of Natural Resources and Environment (MNRE), three sites along each river were sampled, representing a gradient from pristine to anthropogenically impacted areas. A total of 2953 macroinvertebrates were collected and classified into five categories using established identification keys. The Macroinvertebrate Community Index (MCI) and Quantitative Macroinvertebrate Community Index (QMCI) were applied for analysis. The results showed no clear pattern of pollutant-sensitive species prevalence or decline in less disturbed rivers. High MCI scores with low QMCI values indicated numerous low-scoring species, while the opposite suggested a richness of high-scoring taxa. Although MCI and QMCI are tools for monitoring freshwater health, this study lays the groundwork for future research to categorize Samoan macroinvertebrates and assign tolerance scores based on their presence in varying river conditions.

Keywords

Macroinvertebrates, Macroinvertebrate Community Index (MCI), Quantitative Macroinvertebrate Community Index (QMCI), Water Quality

1. Introduction

Macroinvertebrates are a diverse group of small, spineless insects found in freshwater ecosystems, especially in streams and rivers (Hussain, 2012). They are visible to the naked eye and can vary in appearance, with some having exoskeletons like crabs, while others, like snails, have shells. Macroinvertebrates are sensitive indicators of changes in their environment. Different species have varying tolerance levels to pollution, sedimentation, and habitat degradation (Woodcock & Huryn, 2006). Therefore, studying their presence or absence can help detect subtle environmental changes that might not be evident through traditional water quality testing methods alone. Healthy river ecosystems are characterized by diverse species interactions and functions. A rich diversity of macroinvertebrates indicates a balanced ecosystem, contributing to efficient nutrient cycling, decomposition of organic matter, and providing food for higher trophic levels. Their diversity is an indicator of the ecosystem's capacity to support various species and maintain ecological balance.

Assessing the health of river water is important for maintaining aquatic ecosystems and ensuring safe water resources for both human and ecological needs. The use of macroinvertebrates in monitoring the health of freshwater ecosystems is a well-established practice. Various methods of monitoring are employed, including assessing indicator species (Pelletier et al., 2010), measuring species diversity (Yoshimura et al., 2006), using biotic indices (Blakely et al., 2014; Stark, 1998), examining toxicology (Li et al., 2013), studying community composition, and evaluating ecosystem function (Beentjes et al., 2018). These approaches, collectively known as biomonitoring, help researchers and environmental scientists gauge the ecological well-being of aquatic environments. Cairns and Pratt (1993) have emphasized the significance of biological surveillance in characterizing taxonomic diversity and community composition as a highly sensitive tool for rapidly and accurately identifying changes in aquatic ecosystems. This means that by observing the types of macroinvertebrates present and their numbers, scientists can detect shifts or disturbances in the river's health and ecosystem.

Certain macroinvertebrates are highly sensitive to specific pollutants. Monitoring the presence or absence of these pollution-sensitive species can help pinpoint pollution sources and identify areas of concern. Their responses to pollutants make them effective indicators of water quality. The types of macroinvertebrates present in a river can provide insights into the quality of the habitat. Different species have specific habitat preferences, and their presence or absence can indicate changes in water flow, substrate, and vegetation. Minnesota (1970) reported the presence of mayflies (Ephemeroptera) suggesting good water quality due to their sensitivity to pollution and low oxygen levels. In a similar study conducted by Metzger and Grubbs (2023), Olkeba et al. (2022), and Segal (2023), it was documented that other fly orders such as stoneflies (Plecoptera), caddisflies (Trichoptera), dragonflies, and damselflies (Odonata) are frequently ob-

served in pristine, well-oxygenated waters. Their existence indicates well-preserved aquatic vegetation within aquatic ecosystems. [Bengu and Scientiae \(2017\)](#), [Hill et al. \(1981\)](#), [Kostygov et al. \(2021\)](#), and [Tomson et al. \(1999\)](#) documented similar findings and reported that the presence of aquatic worms (e.g., *Tubifex spp.*) and midges (Diptera, Family Chironomidae) indicates organic pollution where most of the worms thrive in oxygen-depleted, polluted environments, and midge larvae are found in pollution-tolerant areas and can dominate in degraded or polluted water systems. Therefore, good monitoring of macroinvertebrates aids in assessing habitat degradation and alterations.

In essence, macroinvertebrates serve as indicators of the overall ecological condition of freshwater ecosystems. Their presence, absence, and abundance can reveal the impacts of pollution, habitat degradation, and other environmental changes. By monitoring and analyzing these small creatures, scientists and conservationists can better understand and protect the delicate balance of life in our rivers and streams, ultimately contributing to the preservation and restoration of these vital natural resources. Studying macroinvertebrates can also help raise public awareness about the importance of clean water and healthy aquatic ecosystems. They serve as tangible and relatable indicators of environmental quality, making it easier to communicate the impacts of human activities on water resources. Governments and organizations responsible for water resource management often use macroinvertebrate assessments to guide conservation efforts and make informed decisions about pollution control and habitat restoration. The data generated from macroinvertebrate monitoring assists in setting regulatory standards and ensuring effective management strategies.

Macroinvertebrate analysis is a cost-effective and widely accepted tool in water quality monitoring ([Sanz et al., 2019](#)). Anthropogenic activities (domestic, industrial, and agricultural) strongly affect and change the species richness and abundance of aquatic macroinvertebrates. Biotic indices are common tools for the assessment and sustainable management of water resources ([Sanz et al., 2019](#)). The evaluation provides information about environmental stresses ([Ravi & Vaganan, 2016](#)). Each macroinvertebrate species is unique and possesses different tolerance to changes in environmental stress. Hence, macroinvertebrates are very sensitive to measuring environmental changes and stress of aquatic ecosystems. Therefore, the use of macroinvertebrates as a biomonitoring tool has been well-accepted throughout the world for effective water quality monitoring ([Bani et al., 2014](#)). They are essential tools to provide a coherent classification of water quality and a systematic evaluation of water health degradation that can be used to set improvement strategies using mitigation or rehabilitation measures ([Veeraraghavan et al., 2021](#)).

This study aimed to conduct an assessment of the Rural Rivers on Upolu Island using observed macroinvertebrates to determine the health status of the rivers.

Hypothesis: The distribution of macroinvertebrates in the pristine gradient

area (upper site) is anticipated to demonstrate either higher pollution tolerance or greater pollution sensitivity when compared to the most impacted area (coastal site).

2. Methodology

2.1. Study Rivers

The study was conducted in two rivers located in the rural areas of Upolu Island. These rivers are the Le Afe River and the Mulivaifagatoloa River (**Figure 1**). In the absence of piped water supply during heavy rain events, local communities rely on their natural water resources. These rivers serve as bathing spots and are used for domestic activities like laundry. However, there haven't been any prior studies on the water quality of these freshwater sources to ensure their safety for community use. Therefore, this study aims to assess river health by analyzing macroinvertebrates using the Macroinvertebrate Community Index (MCI) and the Quantitative Macroinvertebrate Community Index (QMCI). **Table 1** shows the main districts, villages, full names of the study rivers, river coordinates, sample collection sites, and the sample collection sites coordinates. Sampling locations are shown in **Table 1**. The letters and numbers of site codes are composed of the initials of the river, the province, and the sampling sites, for example, LAS01 indicates a sampled river of Le Afe in the village of Sataoa, at the upper site.

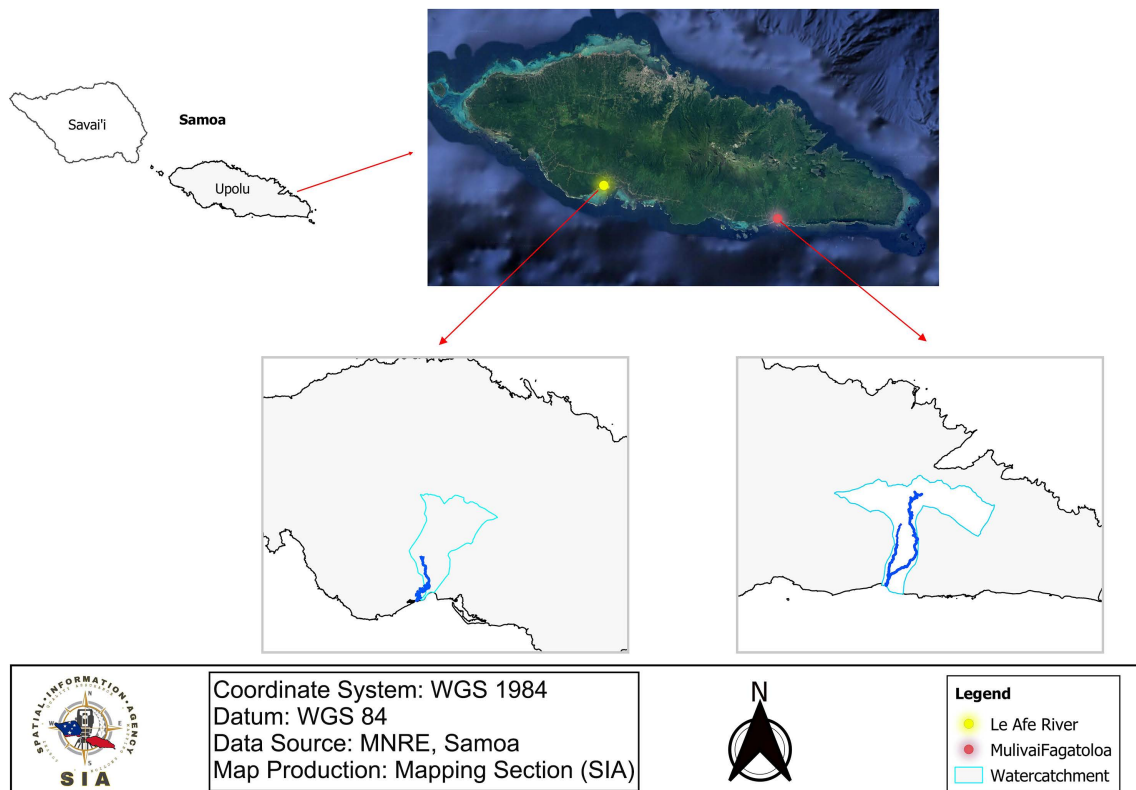


Figure 1. Map of Samoa showing the study rivers in Rural Upolu.

Table 1. General description of sampled sites using hard and soft-bottomed protocols.

| River sampled sites | s-b ¹ protocol | h-b ² protocol | Kick net | Sweep net |
|---------------------|---------------------------|---------------------------|----------|-----------|
| LAS01 | | ✓ | ✓ | |
| LAS02 | | ✓ | ✓ | |
| LAS03 | ✓ | | | ✓ |
| MFS01 | | ✓ | ✓ | |
| MFS02 | | ✓ | ✓ | |
| MFS03 | ✓ | | | ✓ |

s-b¹: soft-bottomed; h-b²: hard-bottomed. ✓: indication of sample sites using hard and soft-bottomed protocol.

2.1.1. Le Afe River

Le Afe River is located at Sataoa village on the central south coast with a co-ordinates of 13°59'S 171°50'W, and it is about 2.2 km from Apia (SBS, 2016). Le Afe River is named after the multiplanetary flow of different waterways from the upper land of Safata to the estuary's sites. Sataoa has two settlements, one inland (Sataoa Uta) and one by the coast (Sataoa Tai). Le Afe River supplies a total population of 1121 of Sataoa Uta and 239 of Sataoa Tai (SBS, 2016 Samoa Bureau of Statistics "Census 2016 Preliminary Count" MNRE-RIO Project) (Figure 2).

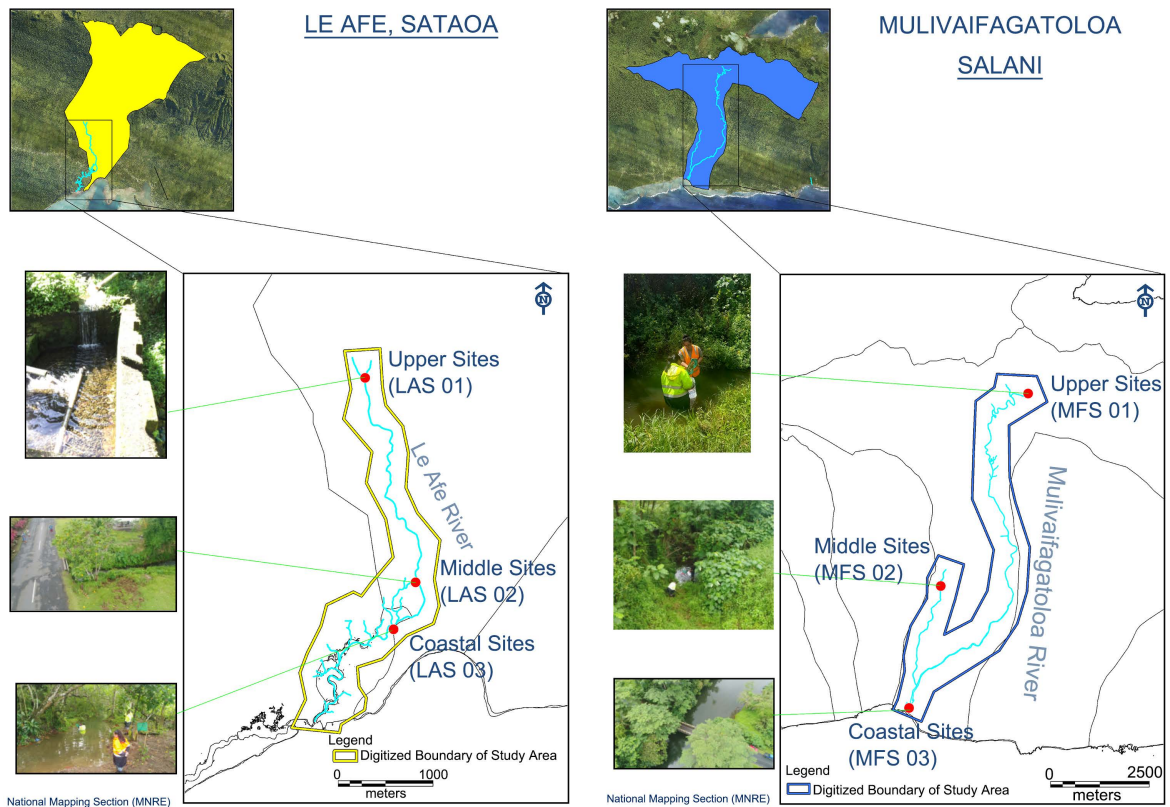


Figure 2. Maps showing the upper, middle, and coastal sites of Le Afe and Mulivaifagatoloa Rivers.

1) Upper site (LAS01)

The site was positioned at the water spring that supplies water to Sataoa village and some sections of Lotofagā village, predominantly without a residential population. The primary vegetation consisted of tamaligi trees (*Albizia falcataria*), vines, ferns, and a significant portion of the reforested area managed by the MNRE-DEC division. The stream bed mainly comprised loose particles of medium-sized pebbles and sand. Surrounding the riverbanks were primarily bedrock, boulders, large and small cobbles, and gravel. Sampling was primarily conducted in the flowing areas of the site.

2) Middle site (LAS02)

The central site was positioned in a densely inhabited residential area, approximately 10 meters away from the road bridge. Along the margins of the sampled site, the prevalent vegetation primarily comprised garden plants like teuila (*Alpinia purpurata*), fuefue saina (*Mikania micrantha*), taro, banana, coconut, and tamaligi (*Albizia falcataria*) trees. The presence of a pig farm was noticeable from the sampling locations. The riverbank bed was predominantly covered with short and long filamentous algae, likely belonging to the genera (*Bacillariophyceae*), entwined within larger stones and cobbles.

3) Coastal site (LAS03)

The coastal site was situated within a moderately inhabited residential area, approximately 10 meters from a pig farm and about 50 meters from the mangrove area, with only one family residing near the sample site. Vegetation along the sampled site mainly included tamaligi (*Albizia falcataria*), fuefue saina (*Mikania micrantha*), taro, banana, coconut, and teuila (*Alpinia purpurata*) trees predominantly found along the middle edges. The presence of the pig farm was observable from the sampling locations. The majority of the riverbank bed was covered with short and long filamentous algae, likely from the genera (*Bacillariophyceae*), interwoven within larger stones and cobbles. The bottom layers were predominantly soft clay sediment debris with log deposition.

The Le Afe River area claims diverse flora throughout its expanse. The upper site flourishes with abundant vegetation, featuring a mix of MNRE-forested areas and grassy landscapes. The upper site is characterized by a rich and varied flora, contributing to the environmental wealth surrounding the river. In contrast, the middle site, positioned at a more central location, stands as the most densely populated area along the river's course. Here, the presence of people is more prominent, altering the landscape to accommodate residential spaces. However, the coastal site, located closer to the river's end, hosts only a small number of families. The vegetation in this area reflects a slightly different pattern due to its proximity to the coast and the influence of a sparse human presence. Overall, the region showcases a unique tapestry of flora, from lush forestry in the upper reaches to a more human-influenced landscape in the middle site, and a subdued, coastal environment with a limited human footprint in the lower area of the Le Afe River.

2.1.2. Mulivaifagatoloa River

Mulivaifagaola River is located at Salani, situated on the south coast (14°S 171.5667°W) of Upolu Island, passing through largely rural areas of conservation reserves, including Togitogiga and O Le Pupu-Pu'e National Park. It is one of the largest rivers within the district of Falealili. Mulivaifagatoloa is, named after the biodiversity of *Anas superciliosa* (toloa bird species or waterfowl) mostly found in the coastal site of the river. Overall, the geographical surroundings of the Mulivaifagatoloa River are rich in flora (forest cover and grass). There is road infrastructure in the upper and the middle sites, and few families live along the coastal site (Figure 2).

1) Upper site (MFS01)

Mulivaifagatoloa was located across the bridge and the government road. During the examination of the sampling site, the riverbank was predominantly adorned with trees such as fau (*Hibiscus tiliaceus*), fuesaina (*Mikania micrantha*), tamaligi (*Albizia falcataria*), and covered with grass. At the upper section of Mulivaifagatoloa, a hard-bottomed method was utilized for sampling due to the presence of sturdy rocks and substantial sediments. The water current displayed notably high speed compared to the middle and coastal areas. Sampling was conducted approximately 20 meters away from the bridge.

2) Middle site (MFS02)

The site, situated across the bridge, was predominantly devoid of residential population. The vegetation primarily consisted of tamaligi trees (*Albizia falcataria*), pulu vao (*Funtumia elastica*), pulu mamoe (*Castilla elastica*), tavai (*Rhus taitensis*), and water primrose (*Ludwigia hexapetala*), alongside patches of grass, dominating the middle site of the sampling site. The stream bed primarily comprised loose particles of medium-sized pebbles and rocks. Along the riverbanks, there was mostly bedrock, boulders, and a mixture of large and small cobbles and gravel. Sampling activities were focused approximately 20 meters away from the bridge.

3) Coastal site (MFS03)

At the coastal site of Mulivaifagatoloa, a vast expanse was covered by a dense forest canopy comprising tamaligi trees (*Falcataria moluccana* and *Albizia falcataria*), pulu vao (*Funtumia elastica*), pulu mamoe (*Castilla elastica*), have tavai (*Rhus taitensis*), accompanied by soi (*Dioscorea bulbifera*) vines draping across these expansive trees. The area was marked by the prevalence of Dwarf Spikerush (*Eleocharis parvula*) and cattail plants. Sampling was confined to the riverbanks due to the significant depth, approximately 20 meters, across the central site of the river. The sampling techniques utilized a soft-bottomed protocol and sweep nets to collect samples, as the riverbed sediment mainly consisted of silt and clay deposits.

2.2. Sample Collection

Samples were collected from upper, middle, and coastal sites during the sampling months of June-August. Two methods were used to collect samples from

each site in each river. These methods are the kick nets and sweep nets and the type of method used depends on the characteristics of the river habitats and whether the river bottom or riverbed is soft or hard.

2.2.1. Hard-Bottomed and Soft-Bottomed Protocols

This study used the hard-bottomed and soft-bottomed protocol manual for invertebrate sampling in wadeable streams developed for the Ministry of the Environment in New Zealand (Stark et al., 2001). The appropriate sampling protocol applied for freshwater macroinvertebrates study depends on two types of river substrate. River substrates can be “hard” or “soft” which have significant consequences for macroinvertebrate community compositions. The sampling procedure was appropriate for the rivers selected for this study since some rivers have riverbeds with firm or hard bottoms and others with soft bottoms.

Hard-bottomed streams have substrates comprised mostly of gravel, cobble pebbles, and boulders and are stony in appearance. Riffle habitats are common in the hard bottom streams, with rational stream gradients (Stark et al., 2001). Soft-bottomed streams have more silt and clay in their stream beds and usually a low gradient with dominant pool habitats (Stark et al., 2001). The coverage of gravel, cobbles, and pebbles is low. As an alternative, soft-bottomed streams typically have accumulated debris in the forms of submerged or floating logs or roots that macroinvertebrates live on, with some burrowing into the stream sediment (Burdett et al., 2015; Davis, 2022; Stark et al., 2001).

The general description of the sampling rivers using the s-b and h-b protocol is shown in **Table 1** above. LAS and MFS were both sampled using the soft-bottomed and hard-bottomed protocol using the sweep and kick nets.

2.2.2. Zig-Zag Method

At each sampling site, samples were collected within a 20-meter radius using a zig-zag method. The zigzag method can provide valuable spatial distribution of macroinvertebrates within the study area. This means that the zigzag methods were distributed to depict the local macroinvertebrate community and also to represent the various arrangements of the river region’s physical features, such as the streambed composition (hard-bottomed or soft-bottomed) and river variables such as pH and temperature to apply the necessary sampling method and obtain a representation of the types of macroinvertebrates that are present in various parameter measured.

2.3. Statistical Analysis

The Macroinvertebrate Analysis is used to determine whether the species are tolerant or sensitive to aquatic ecosystem stress. MCI values as shown in Formular (1) are assessed from the macroinvertebrates that are present and absent during the sampling of river communities whereas QMCI is a variant of the MCI that not only measures species occurrence at a site but also measures their relative abundance as shown in Formular (2).

Calculating MCI and QMCI Scores for the Sampled Sites

An important assumption behind the MCI and comparable indices is that scores would fall when river quality deteriorates, which usually happens as rivers move from inland to more heavily populated coastal areas (Stark, 1998) for this reason, the focus was initially on the presentation of results within the three sites (upper, middle, and coastal) where samples were collected from the two selected rivers.

FORMULA FOR CALCULATING MCI AND QMCI

The MCI is the cumulative score for species found at a given site, not counting the species abundance (Falaniko, 2019). Prior allocation scores must be provided, with 1 representing low quality and 10 representing high quality or pollutant sensitivity (Stark & Maxted, 2007). Macroinvertebrate presence and absence during the sampling of river communities are used to determine MCI values. MCI values are assessed from the macroinvertebrates that are present and absent during the sampling of river communities. The formula for calculating MCI values in this study follows that proposed by Stark and Maxted (2007).

$$\text{MCI} = \frac{\text{total number of species}}{\text{number of taxa}} \times 20 \quad (1)$$

- The site score is the sum of individual taxon scores for all the taxa present in a sample.
- The number of scoring data is referred to the number of taxa collected or present in the sample.
- 20 in the formula is the scaling factor.

The Quantitative Macroinvertebrate Community Index (QMCI) is a variant of the MCI that not only measures species occurrence at a site but also measures their relative abundance using Formula (2) (Stark & Maxted, 2007).

$$\text{QMCI} = \frac{\sum_{i=1}^{i=S} (n_i \times a_i)}{N} \quad (2)$$

QMCI = number of taxa multiplied by the taxon scores/divided by the total number of individuals.

S = total number of taxa in the sample.

n_i = number of individuals in the i -th scoring taxon.

a_i = the score for the i -th taxon.

N = total number of individuals collected in the sample (Stark, 1998).

3. Results & Discussion

3.1. Calculating MCI and QMCI Scores for Sampled Sites

A key expectation of the MCI and similar indices is that scores will decrease as river quality declines, which tends to occur as rivers progress from inland to more densely populated coastal areas. For this reason, the calculations initially focused on the presentation of results from the two rivers of Le Afe and Muliva-ifagatoloa.

3.2. MCI and QMCI for the Intra-Sites of the Sampled Rivers

Hard-bottomed and soft-bottomed rivers have different MCI taxon scores. These were applied in assigning taxon scores for all the macroinvertebrates collected from the sampled sites. MCI and QMCI were calculated using the formulae by (Stark et al., 2001; Stark, 1998; Stark & Maxted, 2007). Le Afe and Mulivaifagatoloa River showed that the two rivers were sampled using both the hard-bottomed and soft-bottomed protocol.

3.2.1. Le Afe River

Eighteen (18) taxa were collected with a total of 1130 individuals from all the sites. Shrimp taxa (566) dominated macroinvertebrate taxa diversity, with 450 flies, 95 molluscs, and 19 prawns (shown in Figure 3).

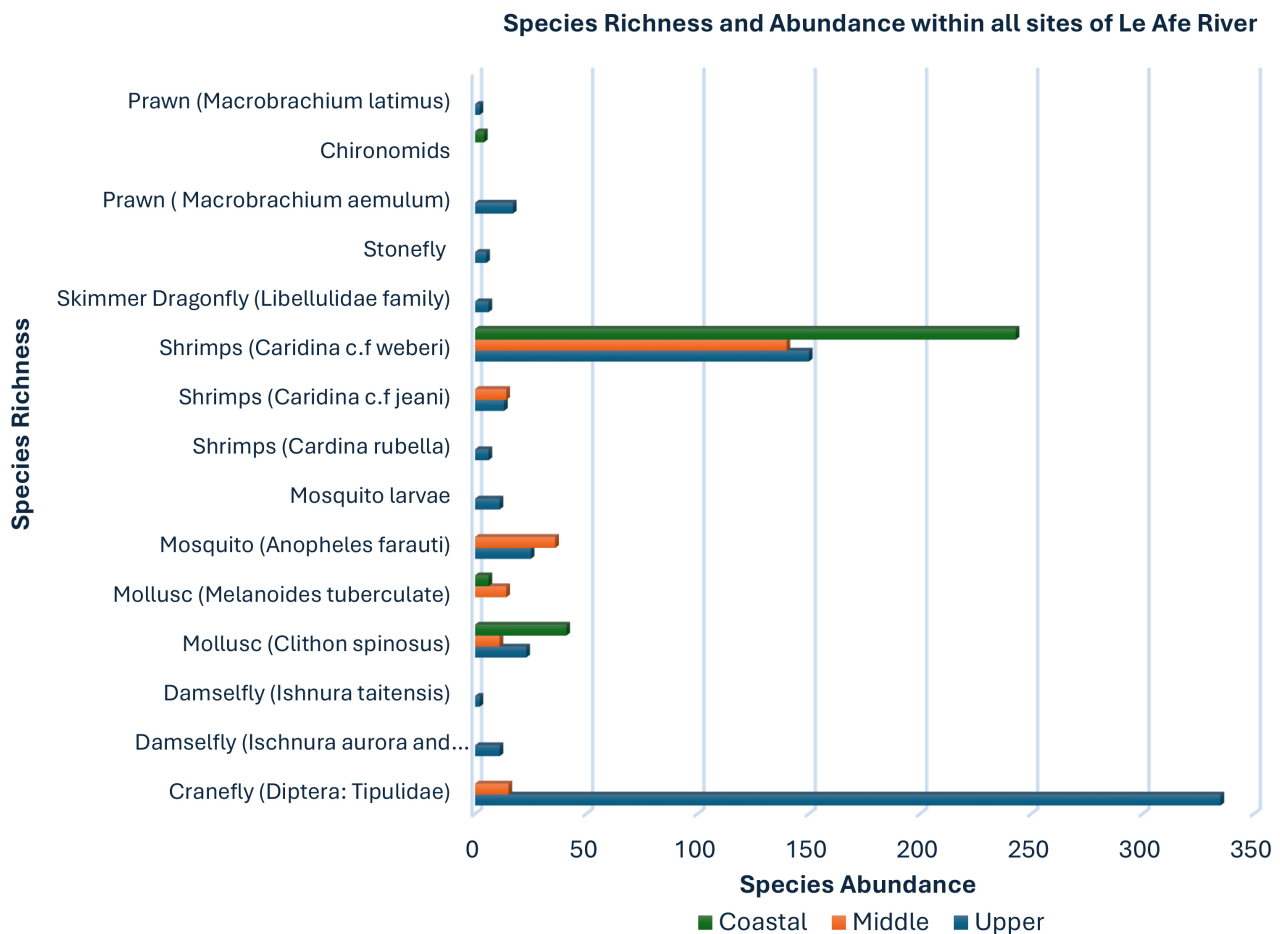


Figure 3. Species richness and abundance of Le Afe River.

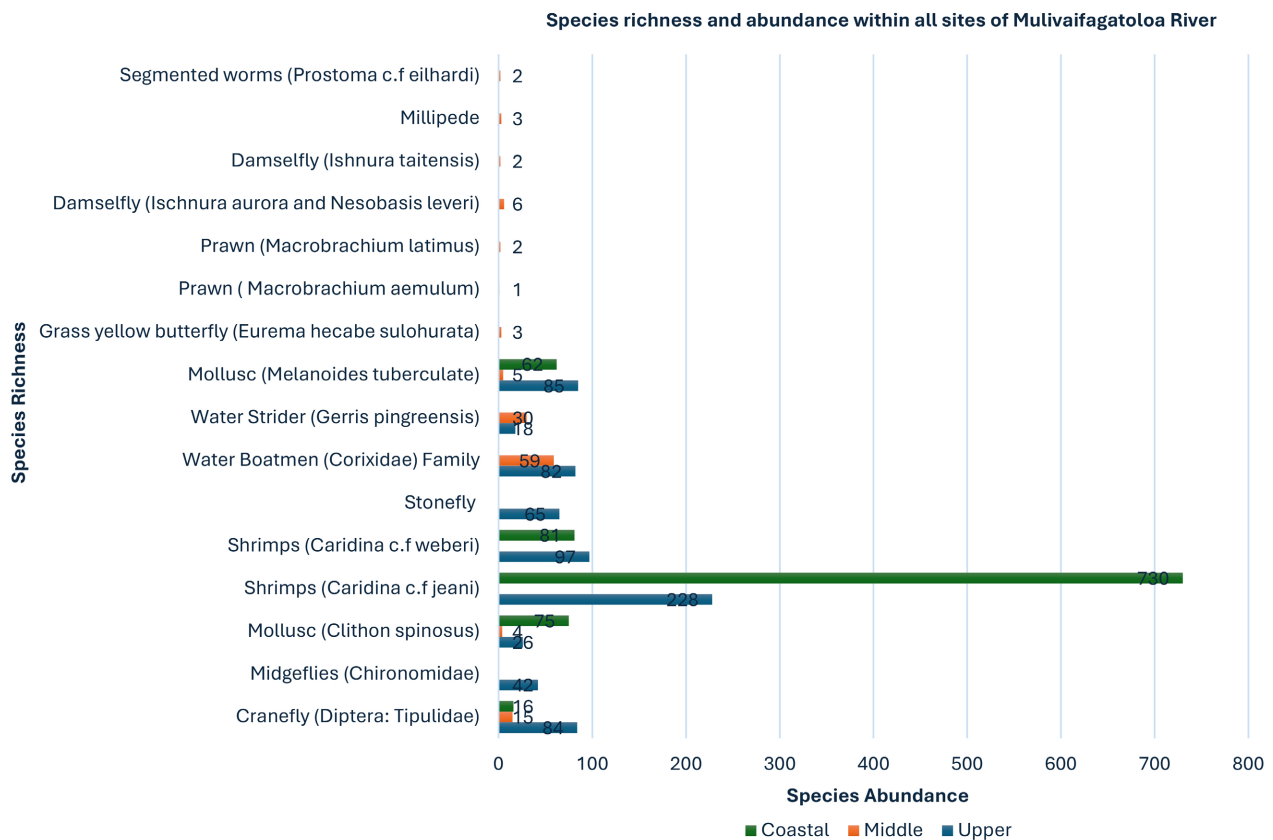
Table 2 summarises the findings from this river. The upper site had the highest MCI score of 115.4 while the coastal site had the highest QMCI of 5.9. This indicates that the upper site had the highest pollution tolerance of species abundance compared to the coastal site. The middle site had the lowest MCI score of 83.3 and QMCI score of 4.5.

Table 2. MCI and QMCI scores for the Le Afe river.

| | LAS01 | LAS02 | LAS03 |
|-----------------------|-------|-------|-------|
| Number of taxa | 13 | 6 | 4 |
| Number of individuals | 606 | 230 | 294 |
| MCI | 115.4 | 83.3 | 99.0 |
| QMCI | 5.0 | 4.5 | 5.9 |

3.2.2. Mulivaifagatoloa River

The overall abundance and richness distribution of Mulivaifagatoloa were sampled within three sites (upper, middle, and coastal). Overall, sixteen (16) taxa were collected with a total of thousand eight hundred and twenty-three (1823) individuals found and collected from all the sites. Shrimp taxa (1136) dominated macroinvertebrate taxa diversity, with 257 molluscs, 230 flies, 189 beetles and bugs, 6 other genera (Ant (*Lasius* spp), Myriapoda (millipede)), and 3 prawns (see **Figure 4**).

**Figure 4.** Species richness and abundance of Mulivaifagatoloa River.

The middle and the coastal sites both have similar QMCI scores of 5.8 indicating macroinvertebrates collected from these sites have moderate tolerance levels to pollution while the upper site had a QMCI score (4.9) less than 5 indicating the leniency of macroinvertebrates towards pollutant tolerant taxa.

3.3. Overall MCI and QMCI for the Two Sampled Rivers at the Upper, Middle, and Coastal Sites

Overall, the results given in **Table 4** show that Mulivaifagatoloa had the highest MCI score of 110.0 and the highest QMCI score of 5.0. These values imply that it is likely to be less impacted by anthropogenic disturbances compared to the Le Afe River.

Moreover, **Table 2** and **Table 3** suggest that the upper site of the Le Afe River, with its highest MCI score has the least polluted water, also indicated by the abundance of pollution-sensitive species. The middle site of the Le Afe River has both the lowest MCI and QMCI scores, indicating the poorest water quality and the highest proportion of pollution-tolerant species (**Figure 3**). The coastal site of the Le Afe River, with the highest QMCI score, suggests it has a greater abundance of pollution-tolerant species but also indicates better diversity.

Table 3. MCI and QMCI for the Mulivaifagatoloa River.

| | MFS01 | MFS02 | MFS03 |
|-----------------------|-------|-------|-------|
| Number of taxa | 8 | 10 | 5 |
| Number of individuals | 645 | 70 | 964 |
| MCI | 95.0 | 114.0 | 101.6 |
| QMCI | 4.9 | 5.8 | 5.8 |

In Mulivaifagatoloa, the upper site's QMCI score below 5 suggests a significant presence of pollution-tolerant taxa, indicating moderate water quality. Both the middle and coastal sites in Mulivaifagatoloa have similar and relatively higher QMCI scores (5.8), suggesting these sites have a moderate level of pollution tolerance (**Figure 4**), indicating better water quality compared to the upper site.

3.4. Implications of MCI and QMCI for Macroinvertebrates of the Study Rivers

The lack of described taxa found to be present in Samoa, and the limited research conducted on the local freshwater macroinvertebrates. Consequently, this study adopted the MCI scores assigned to taxa predominantly identified in New Zealand, as previously documented by **Stark et al. (2001)**, **Stark (1998)**, and **Stark and Maxted (2007)**. As a result, it becomes challenging to provide definitive tolerance values for water boatmen (*Corixidae spp.*) and two other unidentified taxa within the sampled sites, as their assessment is based on MCI scores related to biotic communities in both hard and soft-bottomed substrates.

More approaches could be considerably questioned since some of our taxa do not have much evidence to assign the representation of macroinvertebrate tolerance scores that are present from gradient pristine areas (minimally impacted areas) to the highly impacted areas. The interpretation of MCI and QMCI scores for the sampled sites and across the sampled rivers of this study used **Harding (2021)**; **Stark et al. (2001)**; **Stark (1998)**; **Stark & Maxted (2007)** scale (see **Figure 5** below).

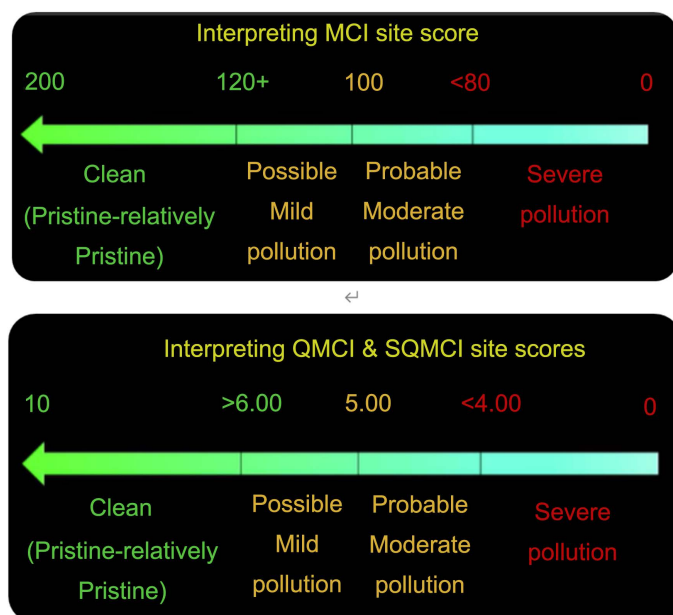


Figure 5. Interpreting MCI and QMCI site scores.

Table 4 shows that the overall MCI score of each sampled site lies within the range of 75 - 115. Most of the MCI scores were interpreted as *possible mild pollution* as indicated in **Figure 5**. This includes the upper site of Le Afe River and the middle and coastal site of Mulivaifagatoloa. This includes the middle and coastal site of Le Afe and the upper site of Mulivaifagatoloa. The QMCI scores lie within the range of 4.5 - 5.9. Most of the QMCI were interpreted as *probable moderate pollution*, this includes the upper and middle sites of Le Afe and the upper site of Mulivaifagatoloa. These findings may show the anthropogenic pressures that cause these values to occur, a study conducted by researchers in the rural rivers of Upolu, Samoa in 2020 revealed elevated concentrations of certain elements, which were associated with human activities such as herbicide and pesticide use, thus these findings raise concerns about water quality (Rabieh et al., 2020). Moreover, one key factor that caused these changes was microbial contamination as reported in the study by Ochsenkühn et al. (2021) samples collected from 124 various rivers in Upolu Island reported the presence of harmful bacteria in most of the freshwater, the presence of these harmful bacteria poses risks to human health causing skin and intestinal diseases.

Table 4. MCI and QMCI scores among the four rivers sampled at the upper, middle, and coastal sites only.

| | <i>Le Afe River—Sataoa</i> | <i>Mulivaifagatoloa River—Salani</i> |
|-----------------------|----------------------------|--------------------------------------|
| Number of taxa | 15 | 14 |
| Number of individuals | 1130 | 1679 |
| MCI | 105.3 | 110.0 |
| QMCI | 4.9 | 5.0 |

In **Table 2** and **Table 3**, even though both rivers were categorized with possible mild pollution based on the MCI score interpretation scales, there are discernible differences in the scale numbers for each river. Mulivaifagatoloa exhibited the highest MCI score, at 110.0, and Le Afe River with the lowest MCI score of 105.3. This variation indicates that, among the rural rivers assessed in Upolu, Le Afe River appears to be one of the most impacted in terms of water quality. Moreover, when considering the QMCI scores, Mulivaifagatoloa received the highest score of 5.0. These scores suggest that this river harbors a relatively high number of pollution-sensitive taxa. Conversely, Le Afe River scored 4.9, indicating that this river has a higher number of pollution-tolerant taxa.

Therefore, the primary source of MCI and QMCI data is the collection of macroinvertebrates from the studied rivers. However, the values of MCI and QMCI reflect on the abundance data collected to determine the population levels of different macroinvertebrate taxa. This involves counting the number of individuals from each species or group within the samples. Moreover, the tolerance and sensitivity values for various macroinvertebrate taxa are obtained from existing literature and research. These values reflect how different taxa respond to environmental stressors and pollutants. Some macroinvertebrates are more sensitive to pollution, while others are more tolerant.

MCI and QMCI scores are calculated based on a combination of abundance data and tolerance/sensitivity values. The scores are often used to assess the water quality and ecological health of the studied rivers. Higher MCI scores typically indicate better water quality and healthier ecosystems, while lower scores suggest poorer water quality and potential environmental stressors. The data is then compared across different rivers or sites to assess variations in water quality and ecological conditions. Additionally, further researchers may use MCI and QMCI scores to identify pollution sources, trends in water quality, and the impact of human activities on the studied ecosystems. However, the reasons for variations in MCI and QMCI data can be multifaceted and include factors such as land use practices (agriculture, urban development), pollution sources (industrial discharge, agricultural runoff), natural factors (climate, geology), and ecological interactions, documented as the next way forward of this study. These data can help researchers and environmental managers understand the health of freshwater ecosystems and the potential drivers of changes in macroinvertebrate communities.

For this study, New Zealand and Falaniko taxon scores for freshwater macroinvertebrates were adopted. As indicated in **Table 5**, it was discovered that Mulivaifagatoloa River had the highest MCI score of 110.0 and QMCI score of 5.0 among all the sampled rivers. The lowest MCI score of 105.3 was found at Le Afe River, whereas the lowest QMCI score of 4.8 was calculated among all the sampled rivers. However, this study found that sampling sites within each river with high MCI scores did not always have high QMCI. This suggests that rivers exhibiting a combination of high MCI (Macroinvertebrate Community Index) and low QMCI (Qualitative of Macroinvertebrate Community Index) tend to

harbor a greater abundance of low-scoring taxa, which are typically more tolerant to pollutants. On the other hand, when MCI is lower and QMCI is higher, it signifies that there is a lower overall abundance of macroinvertebrates, but the ones present tend to be higher-scoring taxa, indicating sensitivity to pollutants.

Table 5. Overall MCI and QMCI scores across the sample rivers and their interpretations.

| Name of River | River Code | Site | MCI | Interpreting MCI | QMCI | Interpreting QMCI |
|------------------------|------------|---------|-------|-----------------------------|------|-----------------------------|
| Le Afe River | LAS | Upper | 115.4 | Possible mild pollution | 5.0 | Probable moderate pollution |
| | | Middle | 83.3 | Probable moderate pollution | 4.5 | Probable moderate pollution |
| | | Coastal | 99.0 | Probable moderate pollution | 5.9 | Possible mild pollution |
| Mulivaifagatoloa River | MFS | Upper | 95.0 | Probable moderate pollution | 4.9 | Probable moderate pollution |
| | | Middle | 114.0 | Possible mild pollution | 5.8 | Possible mild pollution |
| | | Coastal | 101.6 | Possible mild pollution | 5.6 | Possible mild pollution |

4. Study Limitations

The main limitations of this study were:

- 1) The morphological identification of macroinvertebrates MCI and QMCI scores calculation. This was due to the lack of data available for the morphological identification of macroinvertebrates in Samoa and the Pacific region.
- 2) Improve taxonomic resolution in identifying macroinvertebrates, which can reduce the likelihood of underrepresentation of certain taxa in the MCI and QMCI scores.
- 3) Enhance the sampling strategy to include a wider range of microhabitats and account for different seasons. This could involve stratified randomized sampling methods to ensure a more representative sample of the macroinvertebrate community.
- 4) Conduct longitudinal studies to observe changes in macroinvertebrate communities over time. This helps identify seasonal patterns and the influence of temporal factors on community composition.

5. Conclusion: Key Findings

In summary, the MCI and QMCI scores indicate that the upper site of the Le Afe

River has the best water quality, while the middle site has the worst. In Muliva-ifagatoloa, the upper site has more pollution-tolerant taxa, indicating poorer water quality compared to the middle and coastal sites, which have moderate tolerance levels.

It is important to note that there was no consistent trend in the MCI across different river reaches in terms of detecting declining water quality. Specifically, middle sites and coastal sites displayed higher MCI values compared to upstream sites in rivers where data was collected from all three types of sites (upper, middle, and coastal).

Both the MCI and QMCI are valuable tools for assessing the ecological health of freshwater ecosystems, particularly in monitoring changes in response to environmental factors, pollution levels, and conservation efforts. Schellenberg et al. (2011) analysed the ecological health of rivers in New Zealand and showed the cumulative effects of MCI and QMCI considering the entire macroinvertebrate community rather than individual species, offering a holistic view of the ecosystem considering the cumulative impacts of multiple stressors, such as pollution and habitat degradation. A similar study by Ollis et al. (2006) carried out a bio-assessment of the ecological health of river ecosystems using macroinvertebrates in South Africa, using MCI and QMCI scores which serve as early warning signs of deteriorating water quality or ecological health, which prompt timely interventions to mitigate the impacts of pollution or other stressors. Meanwhile, it is also recorded and reported by Casanovas et al. (2022) and Hickey & Golding (2009) MCI and QMCI provide a standardized framework for comparing different ecosystems or monitoring sites. This allows for regional, national, and international comparisons, making them useful tools for policymakers and researchers. They provide a simple way to communicate the status of freshwater ecosystems to a broad audience, including the public, policymakers, and stakeholders. This can promote informed decision-making and conservation efforts. These indices provide quantitative measures that help environmentalists and the community to make informed decisions to protect and monitor river ecosystems. In addition and based on the methods used and findings of this study it is recommended that:

In Samoa, additional work is required to strongly support the identification and classification of clean and impacted location sites. When the classification of streams from clean to impacted is clear and well understood, this study will be able to assign tolerance scores for the taxa present in these sites to create an index that can be used for freshwater monitoring using macroinvertebrates and use this to sample the streams of other inhabited islands of Samoa.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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