

Diversity of benthic macroinvertebrates in Quiaoit and Baroro River Watersheds, Ilocos Region, Philippines

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ABSTRACT. Benthic macroinvertebrates are small, aquatic, and bottom-dwelling animals found in lakes, rivers, and streams. Its sensitivity to environmental changes makes them important for assessing an aquatic ecosystem's water quality and health. This study mainly explored the benthic macroinvertebrates communities of two important watersheds in the Ilocos Region. Thirty-seven families were collected from 54 samples in eight sites in two different seasons. Family Thiaridae, specifically *Melanoides* species, was dominant in both watersheds during the dry season, 79% in Baroro River Watershed and 42% in Quiaoit River Watershed. *Melanoides* and *Martesia* species were present during the wet season, with 44% in Baroro River Watershed and 17% in Quiaoit River Watershed. The presence of diagnostic taxa in both study areas and during both seasons was also observed. *Limnodrilus hoffmeisteri* and *Chironomus* species were collected along the Quiaoit River Watershed, specifically in the sampling station near the forested area or the middle stream. These two aquatic organisms are classified as pollution-tolerant organisms that can survive in areas with poor water quality. The result revealed fewer macroinvertebrates fauna collected in sampling sites near the forest. Conversely, the diversity of macroinvertebrates was higher in stations near settlement and estuary. These findings showed the sensitivity of macroinvertebrates at different levels, which could be attributable to anthropogenic activities.

Keywords: diagnostic taxa, forest, land cover, pollution-tolerant organism, water quality

INTRODUCTION

The benthic macroinvertebrates assemblages are widely recognized as the most important group living in rivers and lakes (Covich *et al.* 1999; Kaboré *et al.* 2016). They play a key role in the understanding of the structure and functioning of these rivers and lakes ecosystems due to their wide distribution and limited migration ability and resiliency (Fierro *et al.* 2015; Dos Santos *et al.* 2011; Barbour & Gerritsen 1999; Karr & Chu 2000; Ollis *et al.* 2006). Benthic macroinvertebrates are commonly used in water quality

assessments because of their close link to their habitats' chemical and physical states (Karr 1981; Resh *et al.* 1996; Simon & Stewart 1999; Sawyer *et al.* 2004). The benthic macroinvertebrates are widely used because of the large number of diverse species that have different tolerances to water quality, long life cycles, and a well-known taxonomy (Resh *et al.* 1996). Hutchison & Iyengar (2003) explained how macroinvertebrates could be seen as an “ecological memory” in aquatic habitats. By looking at the composition

of benthic macroinvertebrates concerning pollution tolerance scores, the health of streams and rivers within a watershed can be evaluated, and the effect of habitat conditions on water quality can be determined (Resh *et al.* 1996; Sawyer *et al.* 2004). The systematic and comprehensive monitoring and evaluation of watershed health can be useful to assess impacts of development, protect wildlife and habitats, and provide stakeholders with important planning information (ACCWP 2004). Despite the benefits and services they provide to humans, water quality and its living organism are threatened by human activities such as the rapid expansion of urban areas and agriculture (Moore & Palmer 2005; Kaboré *et al.* 2016; Brraich & Kaur 2017).

The Quiaoit River and Baroro River are both important ecosystems that play a key role in sustaining the agricultural production in Ilocos Region. The Quiaoit River Watershed is the major source of domestic water supply and irrigation for thousands of Ilocanos in the City of Batac and the towns of Paoay and Currimao (Manzano & Alibuyog 2014). Baroro River Watershed is also the main source of water for both irrigation and domestic purposes in all municipalities of San Gabriel, San Juan, Bacnotan, and San Fernando except Bagulin and Santol (Ramirez *et al.* 2019). Some studies explored the relationship between land cover and water quality in rivers of Ilocos. However, knowledge of these organisms and their ecology is still fragmentary.

In addition, a basin-wide scale across seasons is still lacking due to monitoring difficulties in a large area with different municipalities. Recognizing the spatial and seasonal variability of land cover effects on water quality represents a significant challenge for understanding the impacts of land cover on water quality. Moreover, biological methods are valuable for determining natural and anthropogenic influences on water resources and habitats because ecology responds to stresses from multiple spatial or time scales (Weigel & Robertson 2007; Resende *et al.* 2010). The use of aquatic organisms such as fishes, macroinvertebrates, diatoms, and macrophytes have been widely used as biological indicators to identify and quantify stressors effects (Canobbio *et al.* 2013). It is also more effective in ecological research than environmental variables due to its ability to integrate structural and functional characteristics that reflect the health of streams (Rosenberg & Resh 1993; Bonada *et al.* 2006). Addressing this environmental issue is critical for assessing the future development risks and the cost-beneficial of water management at the watershed scale.

This study explored the composition and diversity of benthic macroinvertebrates in the middle and downstream sections of Quiaoit and Baroro Rivers. The findings of this study could serve as important baseline information for future research on the influences of changes in land use on water quality.

MATERIALS AND METHODS

Study area and sampling sites

The Quiaoit River Watershed has a total land area of 18,909 ha covering the City of Batac and the municipalities of Paoay and Currimao, Ilocos Norte (**Figure 1**). The level lowland areas are intensively cultivated and planted with rice during the wet season. During the dry season, tobacco, corn, and vegetables are planted. Agricultural activities, such as tapping water for irrigation, are also common along the river in hilly and upland areas, especially during the dry season. Most commercial activities are situated in the central and western parts of the watershed.

Similarly, the Baroro River Watershed is also located in the Ilocos Region, specifically in the province of La Union (**Figure 1**). It covers the municipalities of Santol, Bagulin, San Gabriel, Bacnotan, San Juan, and San Fernando. The watershed has a total land area of 19,063 ha, and like the Quiaoit River Watershed, it is the water source for domestic and irrigation purposes.

These two river watersheds represent most watersheds in the Philippines in terms of anthropogenic pressures and changes in land use/land cover. Production forests, agricultural areas, and protection forests are mainly part of the present land uses in the watershed.

This study collected water samples from the middle stream up to downstream sections of the two rivers. The sampling points are located along four sections of the rivers, *i.e.* near forest areas, between farm/rice fields, near settlement areas, and mouth/estuary (**Figures 2 to 3** and **Table 1**).

Physicochemical parameters

Water samples used for macroinvertebrate analysis were collected simultaneously from four different stations along the rivers of Quiaoit Watershed (**Figure 2**) and Baroro Watershed (**Figure 3**). **Table 1** summarizes the key geographic features of Quiaoit and Baroro Watersheds. The water sample collection was done 0.5 m below the water surface and at least 5 m from the riverbank. Triplicate samples were taken at each sampling site. Determination of *in situ* water characteristics, namely: 1) water temperature, 2) pH, 3) dissolved oxygen (DO), 4) conductivity, 5) total dissolved solids (TDS), and 6) PO₄ were carried out using a probe or water quality checker (during the dry season) and Portable Datalogging Spectrophotometer Hack DR/2010 (or the wet season). These parameters are important indicators of water pollution influenced by anthropogenic activities.

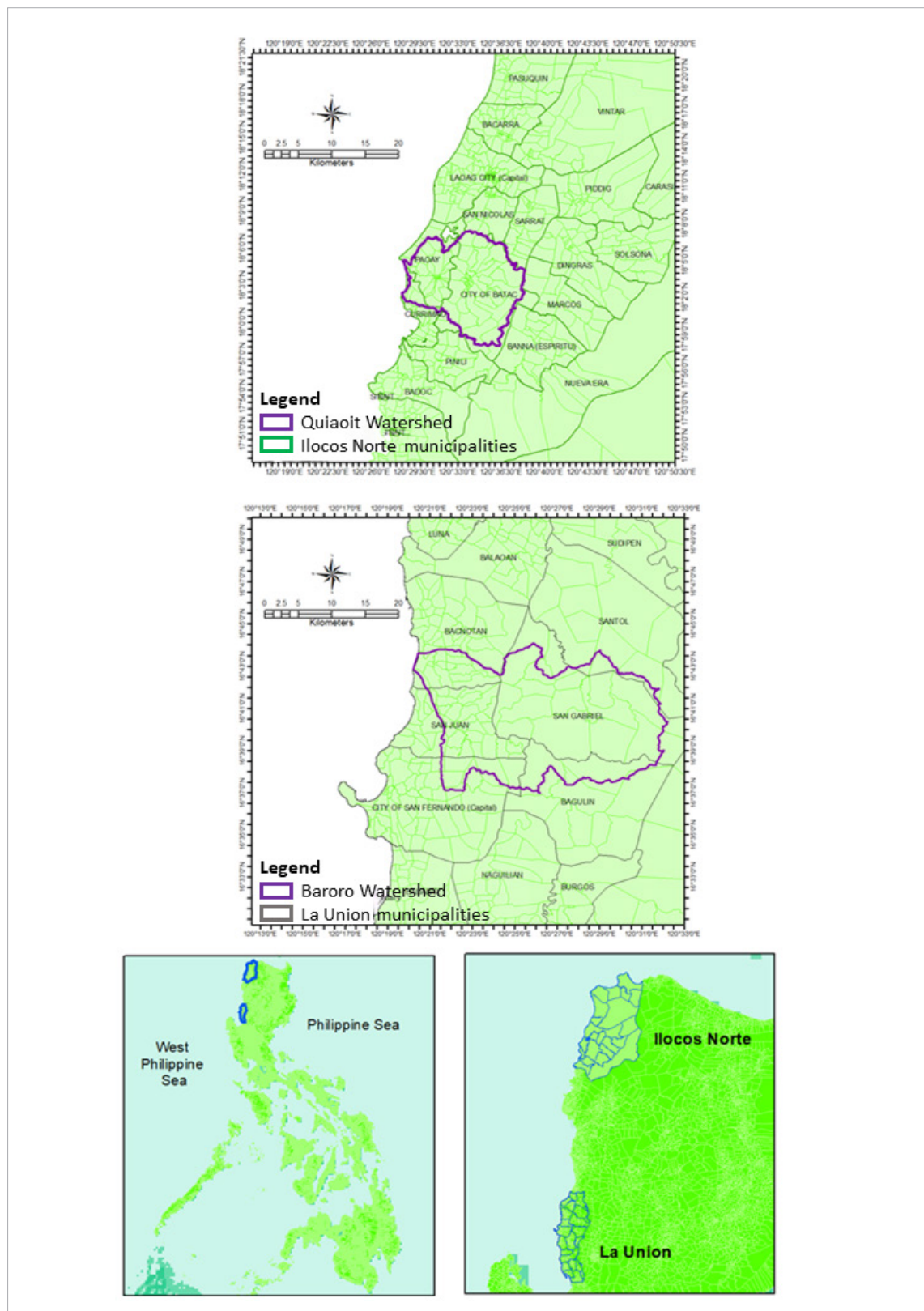


Figure 1. Map of study areas showing the Quiaoit River Watershed in Batac, Ilocos Norte, and the Baroro River Watershed in La Union (Source: Philippine Statistics Authority).

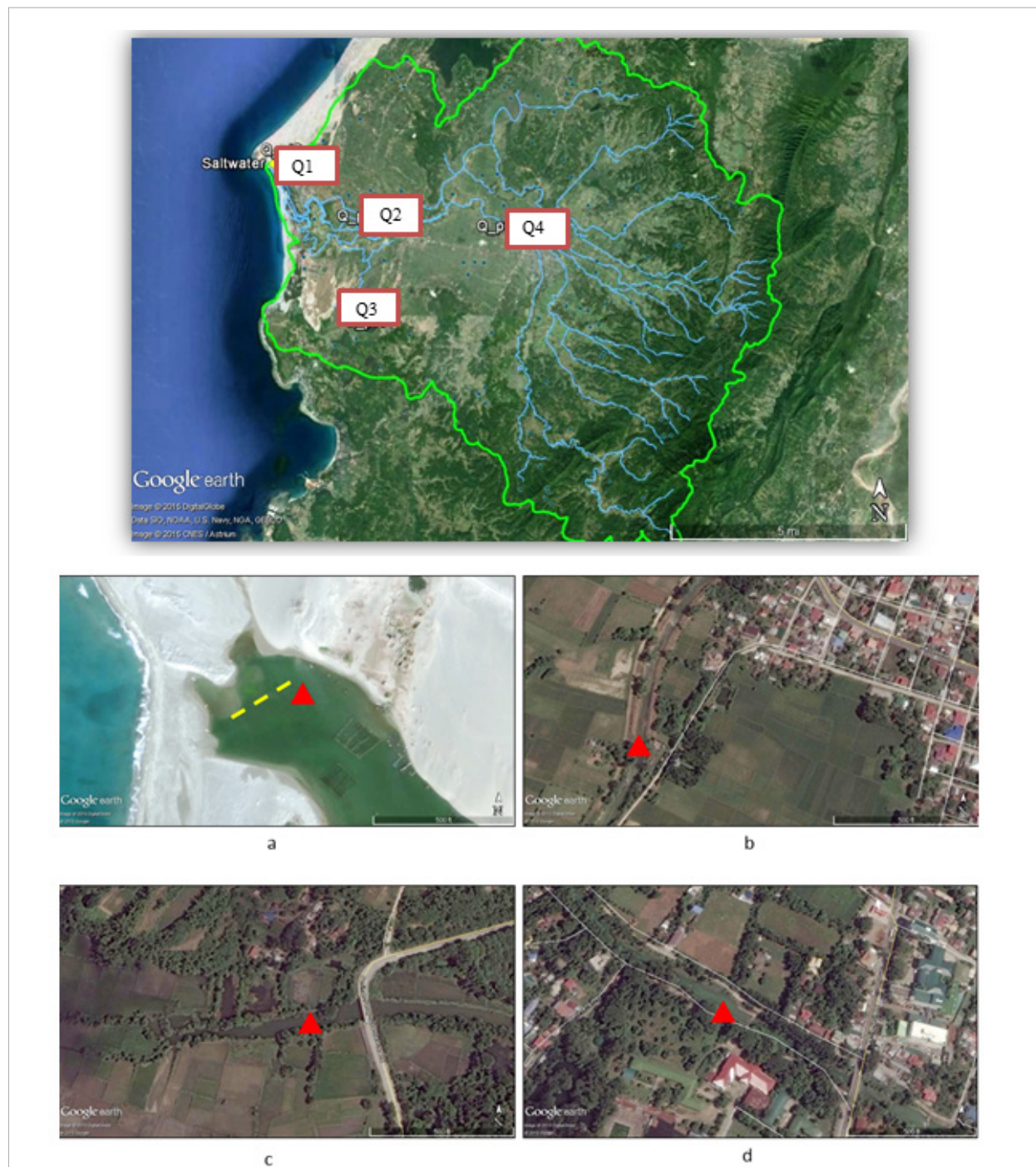


Figure 2. Google Earth image of the four sampling stations in Quiaoit River Watershed, Batac, Ilocos Norte: a) Q1 - Mouth/ Estuary; b) Q2 - Brgy. San Roque, Paoay, Ilocos Norte; c) Q3 - Brgy. Paratong, Paoay, Ilocos Norte; and d) Q4 - Brgy. Callaguip, Paoay, Ilocos.

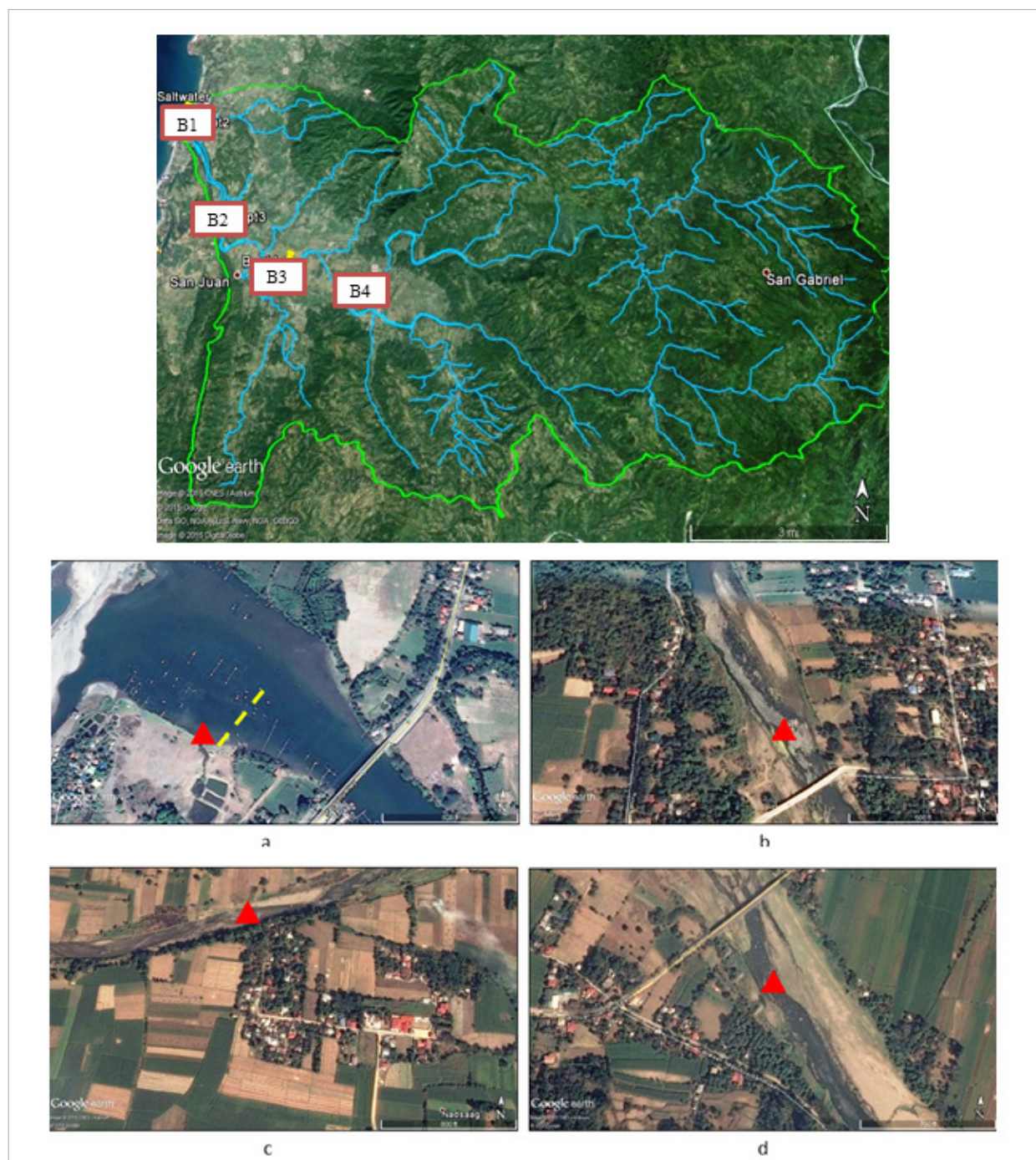


Figure 3. Google Earth image of the four sampling stations in Baroro River Watershed, San Juan, La Union: a) B1– Mouth/ Estuary; b) B2 – Brgy. Sto. Rosario, San Juan La Union; c) B3 – Brgy. Nadsaag, San Juan, La Union; and d) B4 – Brgy. Naguirangan, Cabaroan, San Juan, La Union.

Table 1. GPS reading of sampling stations in Baroro River and Quiaoit River Watersheds.

Sampling station	Location	GPS reading	Elevation (m)
Baroro River			
B1 – Mouth/ Estuary	Brgy. Baroro, Bacnotan, La Union	N 16°42'43'.40 E 120°20'30.50	0
B2 – Near settlement area	Brgy. Sto. Rosario, San Juan, La Union (near bridge)	N 16°41'02'.60 E 120°21'23.30	5
B3 – Between farm/ rice field	Brgy. Nadsaag, San Juan, La Union	N 16°40'24'.80 E 120°22'32.00	7
B4 – Near forest area	Brgy. Naguirangan, Cabaroan, San Juan, La Union (near San Juan–San Gabriel Road)	N 16°40'02'.80 E 120°23'32.50	10
Quiaoit River			
Q1– Mouth/ Estuary	Brgy. 19, Masintoc, Paoay, Ilocos Norte	N 18°04'50'.40 E 120°28'45.70	0
Q2 – Near built-up area	Brgy. San Roque, Paoay, Ilocos Norte	N 18°03'46'.80 E 120°31'48.00	10
Q3 – In-between farm fields	Brgy. Paratong, Paoay, Ilocos Norte (near Curimao-Paoay-Suba-Balacao Rd)	N 18°20'15'.00 E 120°30'24.40	12
Q4 – Near forest area	Brgy. Callaguip, Batac Ilocos Norte	N 18°04'19'.20 E 120°29'20.40	26

Benthic macroinvertebrates sampling

The modified Veen Grab tool was used to collect the benthic macroinvertebrates. Three grab samples were obtained at each station as replicates for each sampling point. All samples were sieved in the field using 0.50 mm wire mesh. Macroinvertebrates retained in the mesh were sorted from trays and fixed in a bottle containing 70% ethyl alcohol to prevent deterioration of specimens and keep the tissue intact for taxonomic purposes. All samples were labeled to include the collection site, stream name, and collection date. Collected specimens were submitted to the Zoology and Department of the Philippine National Museum for proper identification at the family level (and, if possible, up to the genus level). Benthic samples were collected in December 2014 (dry season) and July 2015 (rainy season).

Data analysis

Analyses were based on descriptive and non-parametric statistics and were performed using the BioDiversity Professional, Real Statistic, and XLStat in Excel. BioDiversity Pro software is a statistical package program for Windows PC enabling many measures of diversity to be calculated for a data set of taxa by samples.

The diversity indices are quantitative descriptors of community composition, scarcity, and commonness of species in a given community; the Shannon-Wiener index (H), Evenness index are commonly used to characterize species diversity in a community. This study also applied XLStat in pairwise comparison tests to compare taxa richness, Shannon-Wiener Diversity (H), and Evenness between two rivers and seasons.

RESULTS AND DISCUSSION

Physicochemical parameters

Figures 4-5 and Tables 2-3 summarize the physical and chemical conditions at the different sampling stations along the Quiaoit River and Baroro River. Water temperature in the Baroro River was generally higher as expected during the dry season than during the wet season because of higher air temperature during the dry season (Table 2). Among the four stations, the water temperature was lowest in the estuary, likely due to the inflow of seawater followed by the forest station. Water temperature was highest in the station in between farms as this station was most exposed to the sun due to the absence of vegetation covering the stream, followed by stations near built-up areas.

The pH recorded was generally alkaline, higher in the rainy season (7.82–7.90) than in the dry season (7.08–7.58), likely due to the greater flow volume dilution effect during the rainy season than during the wet season. However, the pH near the forest station is highest, followed by the station near farms and built-up areas. The pH slightly increased at the estuary station. The increasing alkalinity of the river from the forest to downstream stations is likely due to the increase in the volume of river flow that tends to dilute the loading of organic acids from farms and built-up areas (Jansson & Ivarsson 1994).

The conductivity and TDS in Baroro River are similarly higher in the rainy season than in the dry season, likely due to greater sediment loading in the river during the rainy season than in the dry season (Fondriest Environmental, Inc. 2014). Variations in conductivity and TDS among the stations near forests, farms, and built-up areas are slight but are highest in the estuary, where the amount of sediments of upstream regions could have converged. It is also possible that the salt minerals from the sea could have traveled inland into the estuary.

Salinity in the Baroro River is generally higher in the dry season than in the rainy season, likely due to the dilution effect of the greater river flow volume during the rainy season. Salinity is highest in the estuary due to the inflow of seawater bearing salt minerals. In the stations near the forests, between farms, and near built-up areas, salinity does not vary significantly and is much lower than in the estuary. This may indicate less human-induced erosion of salt minerals in rocks (DWER–Government of Western Australia 2021).

The mean concentration of DO in the Baroro River is higher during the dry season (8.23 mg L^{-1}) than during the rainy season (3.30 mg L^{-1}). The result showed the highest DO value near the forests, followed by the station in the estuary and similarly lower in the stations between farms and near the built-up areas. The lower DO in stations between farms and near built-up areas could be attributed to greater loading of organic matter into the river coming from cultivated areas and residential areas and higher temperature that increases oxygen-demanding biological activities in water (USU 2021). The PO_4 in Baroro River ranged from 0.25 mg L^{-1} to 0.78 mg L^{-1} , with a mean value of 0.73 mg L^{-1} in the dry season and 0.31 mg L^{-1} in the rainy season. The lower PO_4 concentration during the rainy season than in the dry season could be due to dilution of PO_4 in water due to greater volume of river flow in the rainy season than in the dry season (USGS Water Science School 2018). In general, PO_4 concentration is lowest in the station near the forests than the other stations due to greater PO_4 loading in the downstream stations coming from agricultural, residential, and commercial areas.

According to the Department of Environment and Natural Resources (DENR) No. 2016–08 (Water Quality Guidelines and General Effluence Standards of 2016), the water quality of samples from the Baroro River generally belongs to Class C, which meets the minimum standards required for water bodies fit for the fishery, non-contact recreational activities, and irrigation. However, it is notable that DO and PO_4 parameters in all stations do not meet Class C standards during the dry season.

In Quaoit River, there were only two sampling stations in the dry season: between farm lots and estuary. There was no river flow in the sampling sites near the forested area and settlement areas during the dry season. The mean temperature in the dry season was 23.72°C and 27.37°C in the rainy season (Table 3). Water temperature in the Quaoit River was generally higher during the wet season than during the dry season, likely because of above-average heavy rainfall. Water samples were collected during the day. Amongst the four stations, the water temperature was lowest in the near forest, followed by the station in the estuary, between farms and near built-up areas. The presence of more vegetation near the forest station than in the downstream stations likely explains the temperature recorded in the Quaoit River.

Water samples from the four Quaoit River stations were generally alkaline with pH within Class C standards (6.5–9.0). The pH during the dry season is lower than the rainy season, likely due to the dilution effect of a greater flow volume during the rainy season than during the wet season. Among the four stations, the pH near the forest station is lower than the pH stations in between farms, near built-up areas, and estuary. The increasing alkalinity of the river from the forest to downstream stations is likely due to the increase in dilution of organic acids from farms and built-up areas associated with an increase in river flow volume (Jansson & Ivarsson 1994).

The TDS in all stations in Quaoit River is much higher during the rainy season than during the dry season. This indicates the high amount of sediments mobilized by surface runoff during the rainy season (Ling *et al.* 2017). The TDS was highest in the estuary among the four sampling stations, where the water is normally loaded with high amounts of dissolved organic matter, salt minerals, and sediments carried by runoff from upstream areas (Moran 2018). The TDS in the other stations were considerably much less than that of the water in the estuary.

Similar to TDS, the conductivity in all stations in the Quaoit River is higher during the rainy season than during the dry season. The conductivity is correlated with TDS (Rusydi 2018). However, the correlation is not always linear, which could explain why the conductivity trend does not directly match the trend of TDS. Water samples from the near forests station have lower conductivity than downstream sampling stations, indicating an increasing concentration of sediments and organic materials as these materials from upstream areas accumulate downstream.

In the Quaoit River, the salinity is generally higher in the dry season than in the rainy season, likely due to the dilution effect of the greater volume of river flow during the rainy season. Salinity is highest in the estuary station like in the Baroro River due to the inflow of seawater bearing salt minerals (Garcia 2012). This is followed by salinity near the forest station and the lowest in stations between farms and built-up areas. In the stations near the forests, salinity is likely induced by weathering rocks high in salt minerals. Salinity in stations between farms and near built-up areas is the lowest, indicating relatively fewer salt minerals from weathering of rocks and the dilution effect of the greater volume of river flow (DWER–Government of Western Australia 2021).

The DO concentration was comparatively higher during the dry season than the rainy season at all stations in Quaoit River, with a mean of 6.38 mg L^{-1} . This is likely due to the lower water temperature during the dry season than during the wet season. The temperature, in general, is indirectly correlated with DO (Kemker 2013). The greater amount

of organic matter from the forests, agricultural areas, and residential zones is transported to the river by surface runoff. In the rainy season, the DO in all stations was lower than the minimum standards for Class C water bodies, indicative of a high amount of organic matter loading during the rainy season.

The mean PO_4 in Quiaoit River is higher in the dry season (0.51 mg L^{-1}) than in the rainy season (0.12 mg L^{-1}), but both values are within the maximum limits for Class C standards. The lower PO_4 concentration during the rainy season could be due to dilution of PO_4 in water due to greater volume of river flow in the rainy season marked with the occurrence of one typhoon before water sampling was conducted (USGS Water Science School 2018). From the between farms' station to the estuary, PO_4 increased due to its accumulation from upstream areas to the estuary. The

PO_4 increased in these areas due to the local farmers using inorganic fertilizer on their farm lots.

In 2014, the Quiaoit and Baroro estuaries became an intermittently closed system that temporally disconnected the fresh water from the seawater. Brito (2012) described these intermittently closed estuaries as mostly in regions with high climate temperatures. With the occurrence of typhoon *Egay* during the sample collection in July 2015, the swift flow of the river down to the coastal area was observed. Likely, the water's salinity and other physicochemical properties in both rivers could have been affected (Dunlop *et al.* 2005).

The concentration levels of DO below 5.0 mg L^{-1} and other parameters such as PO_4 did not meet the required minimum level in class C waters. This can adversely affect the functioning, survival of biological communities and other aquatic life (Fonteh *et al.* 2017; Sinha & Biswas 2011).

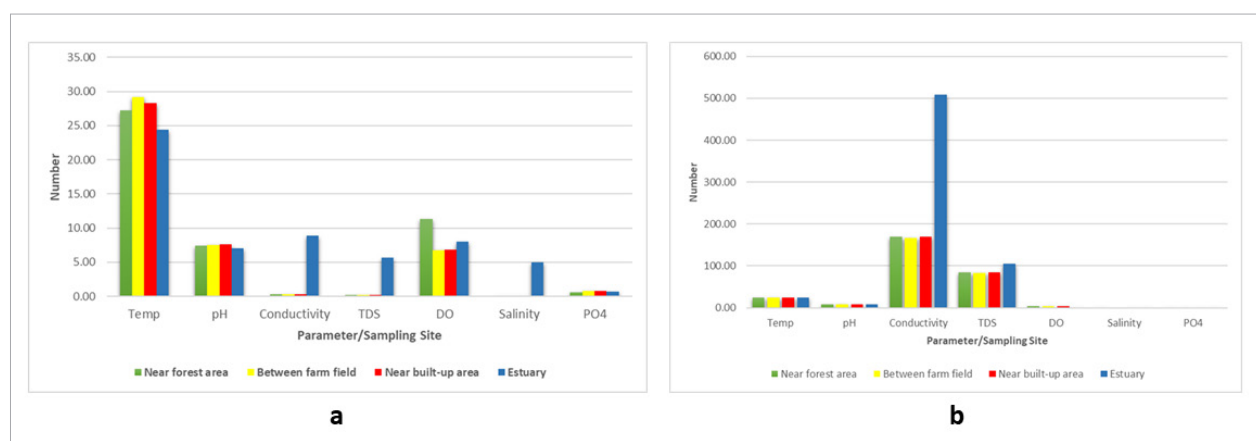


Figure 4. Water quality of Baroro River Watershed: (a) dry season (December 2014) and (b) rainy season (July 2015).

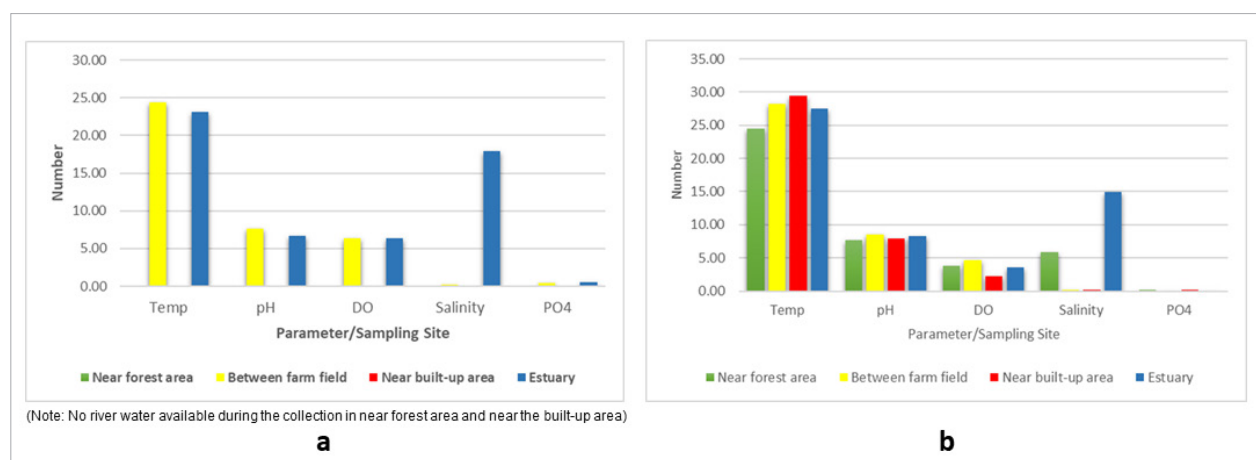


Figure 5. Water quality of Quiaoit River Watershed: (a) dry season (December 2014) and (b) the rainy season (July 2015).

Table 2. Physicochemical parameters of surface water in Baroro River Watershed.

Parameters/ Site	Unit	Standard level*	Near forested area		Between farm		Near built-up area		Estuary		Mean	
			DS	RS	DS	RS	DS	RS	DS	RS	DS	RS
Temperature	°C	25–31	27.28	24.28	29.15	24.52	28.27	24.87	24.44	23.96	27.29	24.41
pH		6.5–9.0	7.45	7.90	7.56	7.87	7.58	7.82	7.08	7.86	7.42	7.86
Conductivity	mg cm ⁻¹		0.27	170.00	0.27	167.00	0.30	169.00	8.93	509.00	2.44	253.79
Total dissolved solids (TDS)	mg L ⁻¹		0.17	85.00	0.18	83.00	0.20	84.00	5.63	105.00	1.55	89.25
Dissolved oxygen (DO)	mg L ⁻¹	5.0	11.29	3.80	6.76	3.94	6.84	4.21	8.03	1.24	8.23	3.30
Salinity	ppt		0.10	0.08	0.10	0.00	0.10	0.08	5.00	0.10	1.33	0.07
Depth	meter		0.67	0.33	0.15	0.25	0.15	0.60	2.60	1.20	0.89	0.60
Phosphate (PO ₄)	mg L ⁻¹	0.5	0.64	0.28	0.78	0.26	0.76	0.25	0.73	0.43	0.73	0.31

* Based on DENR No. 2016-08 (Water Quality Guidelines and General Effluent Standards of 2016).

Table 3. Physicochemical parameters of surface water in Quiaoit River Watershed.

Parameters/ Site	Unit	Standard level*	Near forested area		Between farm		Near built-up area		Estuary		Mean	
			DS	RS	DS	RS	DS	RS	DS	RS	DS	RS
Temperature	°C	25–31	No water collected	24.43	24.34	28.18	No water collected	29.39	23.10	27.49	23.72	27.37
pH		6.5–9.0	(river water used by the farmers for their farm lots)	7.71	7.61	8.58	(river water used by the farmers for their farm lots)	7.87	6.71	8.26	7.16	8.11
Conductivity	mg cm ⁻¹			10.35	0.46	410.00		315.00	29.00	24.62	14.73	189.99
Total dissolved solids (TDS)	ppm			517.50	0.30	205.00		158.00	18.00	12,320.00	9.15	3,300.13
Dissolved oxygen (DO)	mg L ⁻¹	5.0		3.75	6.36	4.66		2.25	6.40	3.52	6.38	3.55
Salinity	ppt			5.81	0.20	0.19		0.15	17.90	14.90	9.05	5.26
Depth	m			5.00	0.20	0.65		0.28	0.15	0.35	0.18	1.57
Phosphate (PO ₄)	mg L ⁻¹	0.5		0.15	0.44	0.03		0.22	0.58	0.06	0.51	0.12

* Based on DENR No. 2016-08 (Water Quality Guidelines and General Effluent Standards of 2016).

Soil texture characteristics

The soil textural characteristics in all study areas were dominated by sand and sandy loam. The soil samples were collected from near forest area > between farm > near the built-up area to the estuary in dry and rainy season (**Tables 4 and 5**). The soil's organic carbon showed a similar mean values trend from the dry to the rainy season. In Baroro River, with a mean value of 0.36%, the lowest OC was collected at near settlement/built-up area (0.08%) and the highest percentage from estuary (1.14%). The organic matter varied from 0.07% to 1.95% (near the forested area was the lowest and the estuary site with the highest portion, respectively).

In Quiaoit River, the mean OC mean value in the dry season was 0.23% while 0.42% in the rainy season. The highest values were acquired from the sampling sites in estuaries

near the built-up area and farm. While OM has a mean value of 0.40% and 0.72% in dry and rainy seasons, highest at the estuary and between farm lot sites.

Species composition and distribution of benthic macroinvertebrates

A total of 187 macroinvertebrates were collected and identified during the dry and rainy season from the middle stream and estuary of Baroro River (**Table 6**). During the dry season, 77 macroinvertebrates were collected from the middle stream and estuary. These species belong to 2 phyla, 2 classes, and 5 families, including 21 species of Mollusca (1 class, 1 family, and 3 genera) in the middle stream (near forest area), accounting for 27% of the total number of species; 23 species of Mollusca and 1 species of Arthropoda (3 classes, 2 families, and 3 genera) in sampling station near farm lots,

Table 4. Physical properties of soil in Baroro River Watershed.

Parameters/Site	Unit	Near forest area		Between farm		Near settlement		Estuary	
		DS	RS	DS	RS	DS	RS	DS	RS
Sand	%	90	100	94	92	90	92	60	96
Silt	%	2	0	2	0	2	0	26	0
Clay	%	6	0	6	8	6	8	14	4
Soil texture		Sandy	Sandy	Sandy	Sandy	Sandy	Sandy	Sandy loam	Sandy
Organic carbon	%	0.09	0.18	0.16	0.50	0.08	0.14	1.14	0.53
Organic matter	%	0.07	0.30	0.27	0.85	0.13	0.24	1.95	0.91

Table 5. Physical properties of soil in Quiaoit River Watershed.

Parameters/Site	Unit	Near forest area		Between farm		Near settlement		Estuary	
		DS	RS	DS	RS	DS	RS	DS	RS
Sand	%	No data	100	94	100	No data	70	96	100
Silt	%		0	4	0		16	2	0
Clay	%		0	2	0		14	2	0
Soil texture			Sandy	Sandy	Sandy		Sandy loam	Sandy	Sandy
Organic carbon	%		0.21	0.35	1.06		0.43	0.12	0.21
Organic matter	%		0.37	0.61	1.83		0.74	0.20	0.37

31% of the total number of species; 18 species of Mollusca and 1 species of Arthropoda (3 classes, 4 families, and 6 genera), accounting for 25%; 13 species of Mollusca (1 class, 1 family, and 2 genera) in the estuary, accounting of 27%. Overall, class Gastropod is the absolute dominant group of macrobenthos during the dry season with 97.92. Macrobenthos were most abundant in the middle stream (near forest area), comprising 33% of the total number of the said species collected. The macrobenthos Shannon-Weiner diversity index (H') and abundance did show much variation, with the highest diversity (H') recorded at the near built-up area (1.41) and the lowest was at estuary (0.69). Meanwhile, the maximum evenness value was found at the estuary (1.00), and the minimum was between farm lots (Table 6).

During the rainy season, 110 macrobenthos were identified in the Baroro River, of which 32 species were collected near forest areas, 19 in between farm lots, 11 near built-up areas, and 48 at the estuary sampling point. Similar to the dry season, Gastropods were recorded at all sites. However, other than Mollusca that dominated all sampling points during the dry season, Arthropoda, Chordata, and Annelida were also collected during the rainy season with a mean value of 68.64, 18.28, 5.47, and 7.61, respectively. *Melanoides* species (82%) were abundant near forest areas, while *Thiara* species (64%) were dominant at estuary during this season. The highest species richness was found in this season, especially at stations near forest areas and estuary where 9 and 8 were recorded, while the stations in between farms and near built-up areas

had the lowest number of species. The mean values of H' in the near forest area, between farm lot, near the built-up area, and estuary were 1.52, 1.69, 0.60, and 1.81; and the mean values of Evenness (E') were 0.69, 0.87, 0.55, 0.87 (Table 6). In the Quiaoit River, 176 macroinvertebrates were collected during the dry season in two stations only, namely, near the forest area and estuary (Table 7). None was collected in the other stations since the river flow was dry at that time of sampling due to drought aggravated by the heavy use of river flow for irrigation of farms. The specimens collected during the dry season comprised 3 phyla, 4 classes, and 9 families, of which the most frequent taxon was the Mollusks (77.78%), followed by Arthropods (16.67%), and Annelids (5.56%) found near forest area. From the station in the estuary, the specimens collected comprised only two taxa: Mollusks (72.21%) and Arthropods (26.79%). The most abundant mollusk was the gastropod *Melanoides* species (9 and 17 individuals near forest area and estuary) and amphipods *Gammarus fasciatus* (15 individuals at estuary).

During the rainy season, 102 specimens were collected from all four sampling stations. The species composition and distribution of the specimen were more diverse than during the dry season. Specimens comprised 5 phyla, 5 classes, and 19 families; the greatest abundance was recorded at stations near forest area (40%), followed by the estuary (30%), near the built-up area (22%), and station in between farms (8%). In relation to the dominant species per station: three taxa were found near forest area, mollusks (75.61%), arthropods

Table 6. Diversity indices, composition, and distribution of macrobenthos in Baroro River Watershed.

Diversity index	Near forested area		Between farm		Near built-up/ Settlement		Estuary		Mean	
	DS	RS	DS	RS	DS	RS	DS	RS	DS	RS
Species richness	3	9	3	7	6	3	2	8	4	7
Evenness	0.76	0.69	0.74	0.87	0.79	0.55	1.00	0.87	0.82	0.74
Shannon Weiner (H')	0.83	1.52	0.81	1.69	1.41	0.60	0.69	1.81	0.94	1.41
<i>Dominant species/taxa</i>										
No. of individual per station	13	32	19	19	24	11	21	48	19	28
Mollusca (% of the total number of specimens)	100.00	68.75	95.83	57.89	95.83	100.00	100.00	47.92	97.92	68.64
Arthropoda (% of the total number of specimens)	0.00	12.50	4.17	21.05	4.17	0.00	0.00	39.58	2.08	18.28
Chordata (% of the total number of specimens)	0.00	9.38	0.00	0.00	0.00	0.00	0.00	12.50	0.00	5.47
Annelida (% of the total number of specimens)	0.00	9.38	0.00	21.05	0.00	0.00	0.00	0.00	0.00	7.61

Table 7. Diversity indices, composition, and distribution of macrobenthos in Quiaoit River Watershed.

Diversity index	Near forested area		Between farm		Near built-up area		Estuary		Mean	
	DS	RS	DS	RS	DS	RS	DS	RS	DS	RS
Species richness	6	7	-	5	-	6	8	7	7	6
Evenness	0.81	0.78	-	0.93	-	0.90	0.79	0.80	0.80	0.85
Shannon Weiner (H')	1.45	1.51	-	1.49	-	1.62	1.65	1.56	1.55	1.55
<i>Dominant species/taxa</i>										
No. of individual per station	18	41	-	8	-	22	56	31	37	26
Mollusca (% of the total number of specimens)	77.78	75.61	-	25.00	-	54.55	73.21	83.87	75.50	59.76
Arthropoda (% of the total number of specimens)	5.56	19.51	-	75.00	-	13.64	26.79	6.45	16.17	28.65
Annelida (% of the total number of specimens)	16.67	0.00	-	0.00	-	13.64	0.00	0.00	8.33	3.41
Chordata (% of the total number of specimens)	0.00	0.00	-	0.00	-	18.18	0.00	9.68	0.00	6.96
Nematoda (% of the total number of specimens)	0.00	6.45	-	0.00	-	0.00	0.00	0.00	0.00	1.61

(19.51%), and annelids (6.45%); two taxa in station between farms where arthropods were dominant at 75%, and 25% of Mollusca. In a nearby built-up area, mollusks also dominated (54.55%), followed by chordates (18.18%), arthropods (13.64%), and annelids (13.64%). Pelecypods and Gastropods were dominant near forest areas (21 individuals of *Martesia* species) and *Melanoides* species at sites near the built-up area (8 individuals) and estuary (14 individuals).

The greatest total abundance was found in near forest areas and estuary, and the lowest was documented along farm lot

sampling sites. The highest H' were recorded near the built-up area, estuary, and forest area, and the lowest was near the farm lot. Conversely, macrobenthos evenness showed less variation near forest area and highest at the station in between farms.

The presence of *Melanoides* species in the sampling sites was likely due to the prevailing water quality conditions in Baroro and Quiaoit Rivers. Hutchinson (1993) explained that Class Gastropods like *Melanoides* could breed and thrive in various substrates rich in food materials and with chemical and physical properties that allow them to thrive even

under harsh conditions. In the dry season, this species was abundantly found near forest areas along Baroro River, where large piggery farms are draining their wastewater upstream of the river. Similarly, this snail was also observed in several sampling stations at Quiaoit estuary in the rainy season. *Melanoides* species are viviparous and parthenogenetic snails that occur in many places worldwide. This species is a successful invasive species recognized by its ability to colonize human-impacted areas (Pointier *et al.* 1993; De Marco 1999; Martins-Silva & Barros 2001).

Several environmental conditions influenced macrobenthos community structure and diversity, which demonstrated geographic divergence (Liu *et al.* 2016). Macrobenthos mainly inhabit river water–soil interface layers or sediments, and the physical, chemical, and biological factors of the water and sediment environments jointly affect the community distribution (Tews *et al.* 2004; Yan *et al.* 2005; Cooper *et al.* 2007; Schneider & Sager 2007). This study revealed that most macroinvertebrate species were found in the sampling stations and near forest areas and estuaries (Figure 6). The least number was observed in the stations between farms and near built-up areas along Baroro and Quiaoit Rivers. The estuarine environment is exposed to a diverse change in physicochemical variables due to the continuous mixing of freshwater with marine water (George *et al.* 2012). The high amount of organic material found in the sediment of the Baroro River is due to its semi-closed condition in the dry season and a large amount of nutrients from fish pens and agricultural runoff from adjacent towns (Peña-Cortés *et al.* 2006a;b). The different levels in organic material between the stations may be due to biological interactions, although the effects of anthropogenic activities near the river cannot be discounted. The agricultural activities near the river of the watershed result in excessive nutrient load inputs, where the PO₄ in between field/farm lots were exhibited with the highest value in the dry season, specifically in Baroro River, which would consequently cause eutrophication and even episodic crises of anoxia (Castel *et al.* 1996). H' represents the impact of environmental variables on the distribution of macrobenthic communities, and the disappearance of environmentally sensitive groups will lead to a decline in the complexity and stability of macrobenthic community structure (Gao & Song 2005). Evenness measures the uniformity of the individual distribution of macrobenthic species (Sun & Liu 2004). Considering the importance of these two rivers in Region 1 for propagation and growth of fish and other aquatic resources; agriculture, irrigation, and livestock watering, the results showed that according to the Shannon-Weiner Index from 1.0–2.0 in the dry season and the rainy season is an indication of probable moderate pollution of water (Table 8). Martins-Silva & Barros (2001) also found the same distribution patterns in Lake Paranoa and Riacho Fundo Creek, mainly in organically polluted areas.



Figure 6. Macrobenthic invertebrates sample found in sampling sites.

Table 8. Relations between Shannon Diversity Index and pollution level.

Diversity level	Shannon diversity index	Pollution level
High	3.0 – 4.5	Slight
Moderate	2.0 – 3.0	Light
Less	1.0 – 2.0	Moderate
Very Less	0.0 – 1.0	Heavy pollution

Source: Kumar & Sharma (2014)

Diagnostic taxa

The distribution characteristics of macrobenthos with different tolerance degrees are shown in Figure 7. The spatial variation of the pollution-tolerant species in Baroro river during the dry season was as follows: between farm field (1 species); moderately pollution-tolerant species along the way: near the built-up area (1 species); and the sensitive species to pollution were found: near forest area (21 species) > near the built-up area (16 species) > between farm field (14 species) > estuary (13 species). During the rainy season, these pollution tolerant species were also found: near forest area (3 species) > between farm field (4 species) > estuary (1 species); moderately pollution-tolerant species: near forest area (3 species) > between farm field (1 species) > estuary (19 species); and sensitive species: near forest area (1 species).

During the collection in Quiaoit River, the tolerance degree to pollution of specimens in the dry season were as follows: pollution tolerant in near forest area (4 species); moderately tolerant to pollution were mostly found at estuary (15 species); and the sensitive species: near forest area (14 species) > estuary (21 species). In the rainy season, 3 pollution-tolerant species at the estuary, 4 moderately pollution-tolerant species near forest area, and 3 species at estuary were identified (Figure 8).

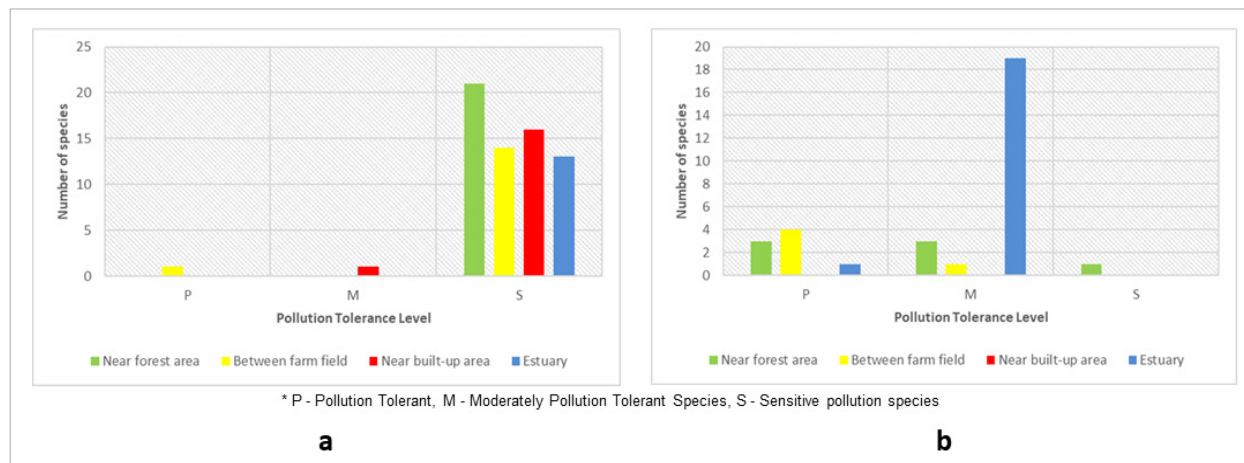


Figure 7. Distribution characteristics of macroinvertebrate communities with different tolerance levels in Baroro River Watershed: (a) December 2014 and (b) July 2015.

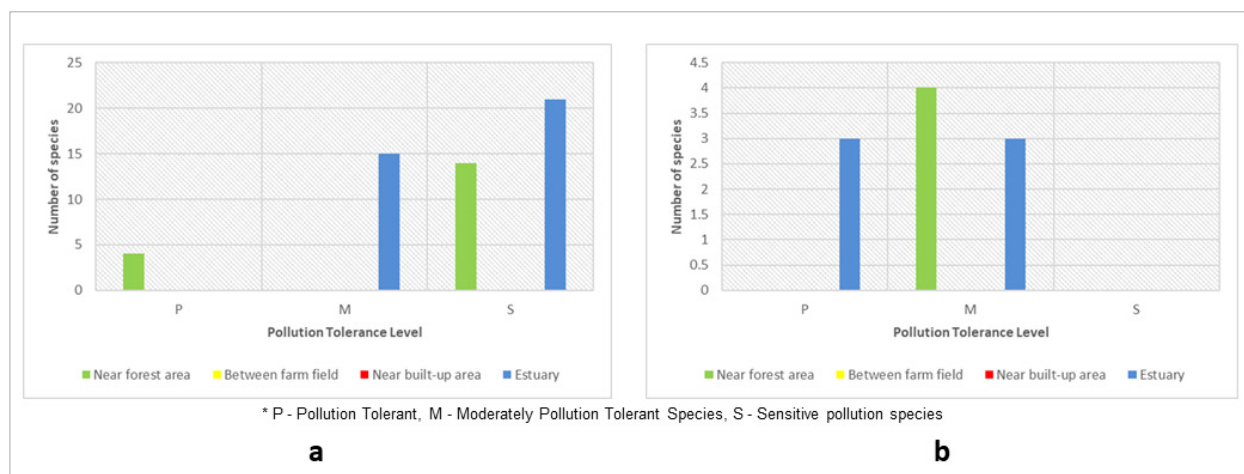


Figure 8. Distribution characteristics of macroinvertebrate communities with different tolerance levels in Quiaoit River Watershed: (a) December 2014 and (b) July 2015.

The presence of diagnostic taxa or biological indicators for pollution was observed in both study areas in dry and rainy seasons. *Limnodrilus hofmeisteri* and *Chironomus* species were collected along the Quiaoit River, specifically in the sampling station near the forested area in the dry season. These two aquatic organisms are classified as pollution-tolerant organisms that can survive in areas with poor water quality. They can live in water with low dissolved oxygen, turbid waters, or nutrient-enriched waters (Virginia Department of Environmental Quality 2003).

Meanwhile, with the typhoon *Egay* during the collection period last July 2015 (rainy season), Oligochaeta and Chironomidae were dominantly observed near forest area, between field/farm lot and estuary of Baroro River. Pollution-sensitive taxa like *Togoperla* species (Order Plecoptera) were collected at the site near the forested area of Baroro River. This organism requires good water quality to survive, such as high dissolved oxygen levels and non-turbid waters. The

flow rate and water temperature have a strong influence on the survival and reproduction of macrobenthos that is suitable for the survival of species that require flowing water and cold temperatures, providing habitats for predators like Plecoptera, which adapted to riparian habitats (Allen *et al.* 2002; Peng *et al.* 2013; Chen *et al.* 2019). The water flow in a river system is regulated by rainfall (Oliveira *et al.* 2015). Extreme rainfall event produces nonpoint source pollution that generally results from excessive surface runoff in many areas vulnerable to the force of the surface flow. As the surface runoff moves, it picks up and carries away natural and human-made pollutants, finally depositing them into lakes, rivers, coastal, and groundwaters. Oligochaeta and Chironomidae are macroinvertebrates belonging to pollution tolerant taxa that can survive in poor water quality (e.g. with low dissolved oxygen, turbid waters, or nutrient-enriched waters).

Benthic macroinvertebrates are considered good indicators of local-scale conditions (Metcalf 1989; Freund & Petty 2007).

According to Thorne & Williams (1997), there is a wide range of tolerance taxa which can be observed depending on the families that composed the diagnostic orders and taxa. These groups are rather more effective where pollution gradients are higher. The presence of diagnostic taxa in both study sites can be related to the increase of built-up areas and agricultural lands that contributed to the pollution loading of the water system from fertilizers, sewage, heavy metals or pesticides. According to Beasley & Kneale (2003), increasing urbanization and industrialization generate different non-point sources of contamination, causing impairment of water quality of rivers. Many studies have shown the negative impacts of different pollutants on aquatic biota, which resulted in biodiversity loss and poor water quality (Beasley & Kneale 2003, 2004; Benetti & Garrido 2010; Fernández-Díaz *et al.* 2008; Garrido *et al.* 1998; Harper & Peckarsky 2005; Hirst *et al.* 2002; Lytle & Peckarsky 2001; Smolders *et al.* 2003; Song *et al.* 2009).

SUMMARY AND CONCLUSION

This paper characterized the distribution characteristics of macrobenthic organisms from the middle stream to estuaries (near forest area > between farm lots > near built-up area > estuaries) in the main rivers of Quiaoit Watershed and Baroro Watershed and the apparent response of these organisms to streamflow quality as influenced by land cover and land use activities. The reduction in species richness, abundance, biological indices, and changes in faunal composition appear to be associated with pollution of the streamflow in Baroro River and Quiaoit River (Oscoz *et al.* (2006). In general, the results of this study indicate that forests tend to have enhanced impacts on the population of pollution-sensitive macrobenthos. Moreover, built-up areas tend to negatively impact water quality and the assemblage of macrobenthic communities that is more pronounced during the dry season than in the rainy season. The agricultural land cover also appears to have affected water quality, particularly in the Baroro River Watershed during the dry season.

The results in this study tend to affirm the importance of proper management of land use activities and forest cover in the watershed. Further, this study points to future research that may shed more light on the interconnection of hydrological processes and terrestrial and river ecosystems with land use and cover. Particularly, in-depth studies on the dominance of certain taxa (*e.g.* Oligochaeta and Chironomidae) and the absence of others (*e.g.* Tellinidae at some sites) concerning land use activities in the watershed will be useful.

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