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Diversity and distribution of freshwater fish in mineralized watersheds of the Agno River Basin, northern Philippines

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A R T I C L E I N F O

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A B S T R A C T

The Agno River Basin in the northern Philippines is a region of significant ecological and economic value; however, baseline data on its fish diversity and distribution are poorly documented, limiting effective river basin management. This study provides the first baseline assessment of water quality and fish assemblages (July 2021 and January 2022) across eight sample stations representing diverse land use in the upper and lower Agno River Basin. Diversity indices and spatio-temporal analyses were applied to characterize patterns in both water quality and fish communities. While most physicochemical parameters complied with national and international water quality standards, elevated electrical conductivity was detected near mining zones, and agricultural areas exhibited increased temperatures and reduced dissolved oxygen levels. Most water quality parameters showed significant variability across stations, seasons and interactions effects ($p < 0.001$). A total of 23 fish species, representing 13 families were recorded, with Gobiidae (84%) and Cichlidae (11%) accounting for the highest abundance. *Pseudogobius javanicus* and *Rhinogobius bucculentus* were the most abundant taxa. Notably, no fish specimens were found at the Baloy station, located downstream of intensive mining activity. Species diversity ranged from low to moderate (Shannon index $H' = 0.29$–1.62), with low evenness and high dominance, indicating habitat specialization and uneven resource distribution. Non-metric multidimensional scaling (NMDS) ($p > 0.05$) and species clustering analysis showed similar species composition across sites. Multivariate analyses, including canonical correspondence analysis (CCA) and redundancy analysis, revealed that temperature showed affinities with fish composition and abundance. However, patterns must be interpreted cautiously due to the lack of statistical support ($p > 0.05$). The findings provide valuable insights into the current ecological condition of the Agno River Basin and highlight the importance of continuous monitoring and comprehensive evaluation of land-use impacts and aquaculture pressures to inform evidence-based, ecosystem-based river basin management.

1. Introduction

Freshwater ecosystems in the Philippines are under increasing pressure from anthropogenic activities, including deforestation, agriculture, urbanization, mining, and river confinement[1–3]. These pressures contribute to habitat degradation, pollution, and hydrological changes, all of which can significantly impact fish community composition and distribution[4]. Whilst river systems play a crucial role in supporting biodiversity and local livelihoods, they remain vulnerable to environmental stressors.

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The Philippines possesses an abundant supply of freshwater resources, comprising 18 major river basins and 421 principal rivers that cover one-third of the country's total land area[5]. Major river basins in the country typically have large drainage basins and are critical for various economic activities, including agricultural, commercial, and domestic needs[6]. Among the 18 major river basins in the Philippines, the Agno River Basin is one of the largest river systems in the country[7]. The Department of Environment and Natural Resources in the Philippines classified the Agno River Basin as Class C[8], indicating that the water can be used for agriculture, aquaculture, and recreational services such as boating, fishing, and similar activities[9]. The Agno River Basin has been considered a lifeblood, providing various ecological services to communities in the northwestern part of Luzon, including support for endemic and economically important fish species [10]. However, the multitude of anthropogenic activities, such as mining, upland agriculture, and urbanization[11], have altered natural processes that support diverse flora and fauna[12]. This places the river basin at the intersection of conservation and resource extraction interests.

In particular, the presence of fish species has been used in numerous studies to assess the ecological condition of water bodies, given their inherent sensitivity to disturbance[13]. Fish assemblages reflect the integrative interactions among multiple environmental factors, including ecosystem structure, productivity, and the nutrient cycle, as well as the impacts of anthropogenic activities[14]. In the Agno River Basin, only a few studies with limited research designs have identified freshwater fish species. These studies are mainly fragmented and focused only on specific geographical areas, such as aquatic macrofauna assessment of Dantis and Lacap [8] in Pangasinan, fish and shell assessment [15], and macrofauna assessment on the Amburayan River in Benguet[10]. There have been countless studies on freshwater fish ecology conducted in the Philippines[16], but studies have dwelled only on isolated habitats[17], or short-term surveys[18]. Despite the critical ecological and socio-economic importance of the Agno River Basin, significant knowledge gaps remain in understanding the impacts of mining activities, where the effects of land use and water quality on fish assemblage is poorly documented. Including mining-impacted sub-catchments also enables preliminary exploration of anthropogenic influences on fish assemblages, an area overlooked in previous studies in the basin. Given the mix of land uses and the limited research documenting freshwater fish species in the basin, this baseline inventory of freshwater fish assemblages in the Agno River Basin was conducted alongside spatial patterns of water quality and land use. The holistic and exploratory nature of the study presents integrative ecological observations and considers anthropogenic contexts, thereby contributing to a broader body of knowledge on freshwater ecology in the Philippines by addressing gaps in documenting fish community composition and distribution in these ecosystems. Explicitly, the study aims to (1) characterize water quality across seasons and different land-use zones of the Agno River Basin, (2) assess freshwater fish diversity and distribution, and (3) examine relationships between fish assemblages and environmental variables. Ultimately, the study will provide a foundation for future, more detailed assessments and management efforts for the Agno River basin.

2. Methods

2.1. Study area

The study was carried out in the Agno River Basin, located in northwest Luzon, Philippines. It covers a land area of 6179 km^2 [19]and is considered the fifth-largest basin in the country (DENR, 2015). The upper section of the Agno is underlain by metamorphosed volcanic rocks (Cretaceous-Paleogene), which are intruded by batholithic bodies (large masses of intrusive igneous rock) (Oligocene to Miocene). Overlying these rocks are volcaniclastic rocks (Eocene to Miocene), with limestones capping them. The older rocks have been intruded by younger diorites and andesites (Pleistocene), which caused mineralization, including copper and gold, in the region. The lower Agno is characterized by recent deposits (Quaternary alluvium). Four fault systems traverse the basin, encompassing 13 volcanoes that possess rich metallic and non-metallic mineral resources (RBCO, 2014). In terms of land cover, the Agno River Basin is significantly dominated by tree vegetation (48%), followed by cropland (31%), grassland (16%), built-up areas (2%), and water bodies (1%) (FAO, 2023). The river basin is classified as Type 1 under the Modified Coronas Classification System, which experiences pronounced dry and wet seasons. The annual rainfall in the river basin averages 3111 mm per year, and the annual temperature ranges from 22°C to 28°C across the basin.

There were eight (8) sampling stations established based on the specific land use activities present in the river basin (Fig. 1): ARB1 was established in Kabayan, Benguet; ARB2 in Bokod, Benguet; ARB3 in Baloy Bridge, Benguet; ARB4 in Dalupirip, Benguet; ARB5 in San Roque, Pangasinan; ARB6 in Viray, Natividad, Pangasinan; ARB7 in Paniqui, Tarlac; and ARB8 in Bocboc, San Carlos, Pangasinan. These sample stations were strategically located to represent different land uses and anthropogenic activities (Table 1). Necessary clearances were obtained from the Department of Environment and Natural Resources – Protected Area Management Board (DENR–PAMB), and courtesy calls were made to Local Government Units (LGUs) prior to the collection. Moreover, sampling activities were accompanied by representatives from the respective LGUs in the Agno River Basin (Table 1).

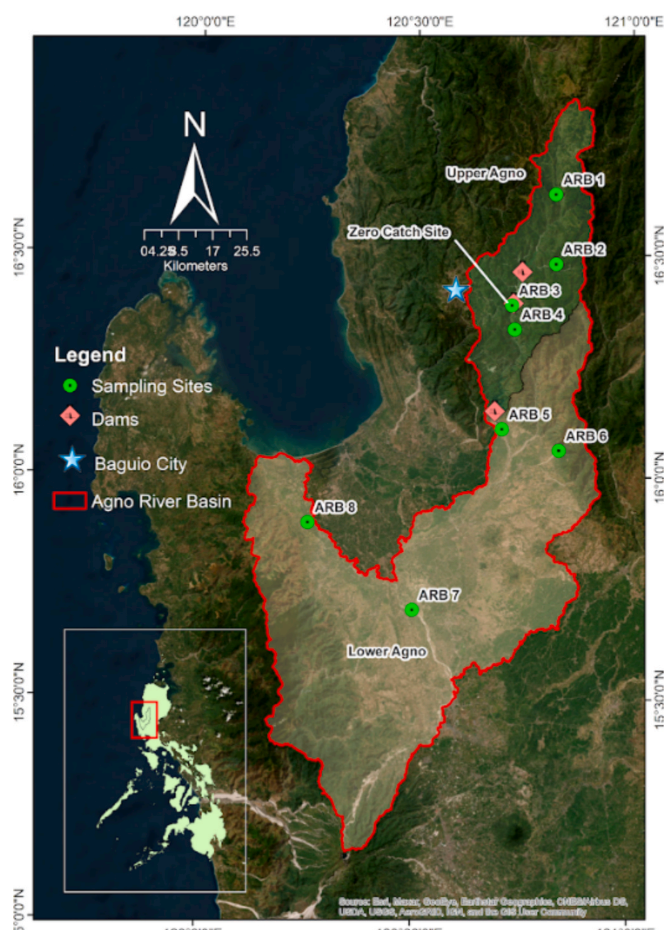

Fig. 1. Study sites for fish fauna assessment in the Agno River Basin, Philippines.

Table 1
Geographic coordinates, elevation, and dominant land use characteristics of the sampling sites for fish fauna assessment in the Agno River Basin, Philippines.

SamplingStations	Site	Location		Elevation(masl)	Land Uses Upstream of Station
		N	E		
Upper Agno					
ARB1	Kabayan, Benguet	16.6350	120.8225	1,063	Upland agriculture
ARB2	Bokod, Benguet	16.4781	120.8245	841	Upland agriculture and forest vegetation
ARB3	Baloy, Benguet	16.3846	120.7224	488	Active mining area
ARB4	Dalapurip, Benguet	16.3303	120.7295	383	Upland agriculture and forest vegetation
Lower Agno					
ARB5	San Roque, San Manuel, Pangasinan	16.1056	120.7019	79	San Roque Dam outflow
ARB6	Viray, Natividad, Pangasinan	16.0585	120.8345	168	Mineralized subwatershed without mining activities
ARB7	Paniqui, Tarlac	15.6974	120.4977	12	Lowland agriculture
ARB8	Bocboc, San Carlos, Pangasinan	15.8917	120.2536	0	Outlet of the Agno River Basin

2.2. Sampling design

Water quality assessment and fish sampling were carried out at eight (8) stations representing different land uses in the river basin in July and January, respectively, during the wet and dry seasons. A measuring tape was used to lay a 100-m transect at each sampling station. A 30–35 m run survey was conducted along the established transect, with three replicates at each station and daily data collection to ensure data accuracy and consistency. The standard protocol for water quality sampling followed the Water Quality Manual of the Philippine Department of Environment and Natural Resources – Environmental Management Bureau (DENR-EMB). The assessment lasted for 10 consecutive days at each station in both seasons. Three spatial replicates were collected along each transect per day as pseudo-replicates reflecting microhabitat variability. While this approach enables estimation of mean water quality for each station and season, the 10-day sampling window does not represent broader seasonal variability. An in situ multi-parameter water analyzer (In Situ Aquatroll 500) was used to measure water quality parameters directly at each site, specifically temperature, pH, dissolved oxygen (DO), electric conductivity (EC), and total dissolved solids (TDS). The device probe was submerged in the centroid of river flow, and an average measurement was taken over more than 60 s. River discharge was measured using acoustic Doppler current profilers (aDcp), with the Xylem SonTek-M9 used at sites where water depth exceeded 6 m and the SonTek RS5 used at sites with depths less than 6 m.

2.3. Fish sampling collection, preservation, and identification

Fish samples were collected from eight sites in the basin during the wet season (July) and the dry season (January). The collection was conducted once, simultaneously at all stations, as part of a water quality assessment that lasted for at least 10 days in both months. Fish sampling was performed once per season at each site, with all stations sampled within a short time window. This approach provides a comparative assessment across seasons but is limited in its ability to capture temporal dynamics, especially for mobile fish assemblages. This method was employed due to financial and logistical constraints, given the distance between sampling stations. The sampling employed active gear, a combination of electrofishing and seine netting. Each method was used based on its applicability in different river gradients. The electric fishing method was intentionally used in parts of the river where seine netting is inapplicable[20,21]. Fish samples were collected along a 100-m transect line laid parallel to the riverbank of each sampling station. The fish sampling effort lasted up to 2 h per station. The absence of fish at certain sampling stations should be interpreted with caution, as it may reflect low detectability rather than a true absence, and sampling effort equivalence is acknowledged as a potential limitation. The fish samples caught were segregated, grouped, counted, and recorded based on morphological features. Samples were initially identified at the lowest possible taxonomic level using the University of the Philippines Los Baños Limnological Station's handbook on Freshwater Fishes of Southern Luzon, Philippines [22]. Representative samples of each species were selected for measurement and photograph documentation using a digital camera. Each representative sample was preserved in a container with 75% ethanol. Identified and unidentified fish samples were sent to the Museum of Natural History (MNH) at the University of the Philippines Los Baños, for validation. Replication for fish data refers to spatial sampling across stations within each season, whereas the lack of temporal replication within seasons is a recognized limitation.

2.4. Data analysis

Mean values of the physicochemical parameters across the stations for spatial and seasonal variations were analyzed using two-way analysis of variance (ANOVA) with season and stations as fixed factors for the analysis. Tukey's HSD test was performed for post hoc comparisons of means. Temporal replicates were considered as pseudo-replicates. The following equations were used to determine the relative abundance, diversity, evenness and dominance:

Relative Abundance:

$$RA_i = \frac{ni}{N}x100$$

where

RA_i = Relative abundance of species i.

ni = no. of collected in the ith species.

N = total number of species collected in a sample are.

$x\ 100$ = converts the value to a percentage.

Shannon diversity index:

$$H' = -\sum_{i=1}^{s} p_i * \ln(p_i)$$

where

H' = Shannon diversity index.

S = total number of species.

Pi= proportion of individuals of species to the total number of individuals found ($\frac{ni}{N}$).

In (Pi) = the natural logarithm of Pi.

Pielou's Evenness:

$J' = \frac{H'}{\ln(S)}$where

J' = Peilou's eveness.

$H' = H' = -\sum_{i=1}^{s} Pi*\ln(Pi)$ or Shannon Diversity Index.

S = total number of species.

In (S) = the natural logarithm of total species.

Simpson's Dominance Index:

$$D = \sum_{i=1}^{s} \frac{[n_i(n_i - 1)]}{[N(N - 2)]}$$

where

S = number of species.

n_i = the number of species in the *ith* species.
N = total no. of species.

2.5. Species-environment relationship

Fish assemblage and water-quality data from sampling sites were analyzed to investigate species–environment relationships. Species abundance data were separated from environmental predictors, and all environmental variables were standardized using z-scores prior to analysis to ensure comparability across differing units and scales. Stations with no environmental data were excluded from the analysis. Multicollinearity among predictors was assessed using Variance Inflation Factors (VIFs), which revealed substantial collinearity in the full model, particularly for electrical conductivity (EC; VIF $\approx$ 25.81), which was strongly correlated with temperature and pH. Consequently, EC was excluded, and VIFs were recalculated for the remaining predictors (temperature, pH, dissolved oxygen, total dissolved solids, and discharge), all of which exhibited acceptable VIF values below 4 after model reduction.

To determine the appropriate ordination framework, gradient-length was assessed using Detrended Correspondence Analysis (DCA). The first DCA axis measured approximately 6.39 SD units, exceeding the commonly used 4-SD threshold for unimodal responses; thus, Canonical Correspondence Analysis (CCA) was selected as the primary constrained ordination method. In CCA, species data were left in their original form consistent with unimodal responses assumptions. Permutation tests were applied to assess global, term-wise, and axis-wise significance.

In addition to CCA, a Helinger-transformed Redundancy Analysis (RDA) was performed to provide a linear robustness check. The Helinger transformation is commonly recommended for community data because it reduces the influence of double zeroes and prevents linear methods from being dominated by rare species. This tranformation allows RDA to approximate species-environment relationships in a metric space appropriate for Euclidean-based ordination. RDA was applied using the same reduced predictor set to compare unimodal and linear results under a consistent predictor strcuture.

Finally, to visualize unconstrained differences in fish assembalge composition that may not be captured by the measured environmental variables, Non-metric Multidimensional Scaling (NMDS) ordination using Bray–Curtis dissimilarity was conducted. NMDS provided ordinaton based solely on community dissimilarities, independed of environmental predictors, and complements constrained methods by revealing patterns driven by unmeasured habitat or spatial factors. Water quality and ecological data were analyzed using RStudio (version 2025.09).

3. Results

3.1. Physicochemical characteristics of water quality

The water temperature between the dry and wet seasons indicated a significant spatial difference across sampling stations ($F(7, 144) = 106.20$, $p < 0.001$), with a significant station and season interaction ($F(7, 144) = 40.03$, $p < 0.001$). A gradual increase in temperature was observed from the Upper to the Lower Agno stations in both the wet and dry seasons. Measured temperatures ranged from 21.2°C to 31.6°C during the wet season and from 16.9°C to 27.9°C during the dry season (Table 2). The lowest temperature values were observed in ARB1, while the highest were in ARB7. Regarding DO, the river basin showed significant variation among stations ($F(5, 108) = 38.12$, $p < 0.001$). It showed a decreasing trend in DO concentration from the Upper Agno to the Lower Agno stations. The highest DO values were observed in ARB1 during the wet (8.8 mg/L) and dry (8.4 mg/L) seasons. The lowest values were observed in ARB8, with 4.0 mg/L and 5.2 mg/L in the wet and dry seasons, respectively. The pH showed significant spatial variability ($F(7, 144) = 17.68$, $p < 0.001$), as well as significant seasonal variation (F =

Table 2
Seasonal variation in river discharge and physicochemical water quality parameters across stations in the Agno River Basin.

Parameters	DAO 2016 – 08	ARB1 Wet Season	ARB1 Dry Season	ARB2 Wet Season	ARB2 Dry Season	ARB3 Wet Season	ARB3 Dry Season	ARB4 Wet Season	ARB4 Dry Season	ARB5 Wet Season	ARB5 Dry Season	ARB6 Wet Season	ARB6 Dry Season	ARB7 Wet Season	ARB7 Dry Season	ARB8 Wet Season	ARB8 Dry Season
Temperature(°C)	25 – 31	21.3	16.8	24.2	19.1	26.7	22.2	25.9	23.4	25	28.9	20.9	20.9	28.3	31.82	26	30.38
pH	6.5–9	8.4	8.3	8.4	8.3	8.3	8.2	8.1	7.9	8.1	7.5	8.45	8.0	7.6	8.1	8.4	7.8
Dissolved Oxygen (mg/L)	5	8.4	8.8	8.65	8.25	7	7.53	7.1	7.5	n.d.	n.d.	n.d.	n.d.	7.4	7	4	5.2
Total Dissolved Solids (mg/L)	1000*	221.9	0.18	101.9	0.12	637.8	633.7	203.2	184.5	221.9	207.1	81.3	92.2	205.8	0.29	168.6	0.54
Electrical Conductivity(μm/cm)	1000*	271.7	265.5	211.9	192.2	1425.5	1266.4	396.1	367.7	444.4	416.4	161.9	176.8	377.1	490.9	337.4	873.7
River Discharge (m^3/sec)	–	6.57	4	43.5	18.9	3.2	2	13.77	7.3	15.8	2.75	1.72	1.32	7.5	0.59	116.4	51.5

Note. The means assigned with the same letter group are not statistically different at a 5% level of significance, n.d – no data, * Interim Water Quality Standards for Malaysia (DOE, 2005).

11.71, $p < 0.001$) and interaction effect ($F = 16.66$, $p < 0.001$). Upper Agno stations had higher values, leaning towards more alkaline waters, during both wet (7.6 to 8.4) and dry seasons (7.5 to 8.3), while values in the lower Agno tended to be circum-neutral. More importantly, the average pH values across all stations were within the Philippine standard limits. Notably, average EC values were elevated in ARB3 for both seasons, exceeding the standard limit of 1000 μm/cm set by the National Water Quality Standard for Malaysia (DOE, 2005), followed by ARB7 and ARB8 in the Lower Agno for both seasons. Except for the ARB3 values, EC values at the other sample sites were within the standard limits. Electrical conductivity showed significant variation among stations ($F(7, 144) = 216.98$, $p < 0.001$), as well as significant seasonal ($F = 8.51$, $p = 0.004$) and interaction effects ($F = 16.61$, $p < 0.001$). Most TDS measurements were higher in the river basin during the wet season than during the dry season. Significant variation at a 0.1% significance level was also observed within stations ($F(7, 144) = 192.04$, $p < 0.001$), with significant seasonal ($F = 74.94$, $p < 0.001$) and interaction effects ($F = 10.25$, $p < 0.001$), with the highest readings in ARB3 for Upper Agno during the wet (717.9 mg/L) and dry season (633.7 mg/L). Based on the National Water Quality Standards for Malaysia, most results fell within acceptable limits. For river discharge, significant spatial variation ($F(7, 144) = 67.29$, $p < 0.001$) exists across stations, with significant seasonal ($F = 38.46$, $p < 0.001$) and interaction effects ($F = 10.02$, $p < 0.001$). The measurements were highest at ARB8 (Bocboc, San Carlos) of the Lower Agno, with values of 116.4 m^3/s during the wet season and 51.5 m^3/s during the dry season. This was followed by ARB2 in the Upper Agno, with a value of 43 m^3/s during the wet season and 18.9 m^3/s in the dry season.

3.2. Fish composition and abundance

A total of 13 families and 23 species of fish comprised the 2599 individuals recorded during the wet and dry season sampling in the Agno River Basin (Table 4, Fig. 2). Among all the stations, only at station ARB3 were no fish samples caught during sampling. Fish species collected belong to the following families: Ariidae, Gobiidae, Cichlidae, Carangidae, Channidae, Clariidae, Cyprinidae, Loricariidae, Poeciliidae, Scatophagidae, Terapontidae, and Zenarchopteridae. *Arius manillensis, Caranx ignobilis, Channa striata, Clarias batrachus, Cyprinus carpio, Pterygoplichthys disjunctivus, Scatophagus argus,* and *Zenarchopterus philippinus* were the lone species found from the families Carangidae, Channidae, Clariidae, Cyprinidae, Loricariidae, Scatophagidae, and Zenarchopteridae, respectively. Similarly, *Leiopotherapon plumbeus* was the only species of the Family Terapontidae endemic to the country and listed as vulnerable by the International Union for Conservation of Nature (IUCN). Three species belonging to the Family Cichlidae were recorded. These were *Oreochromis niloticus*, *Oreochromis mossambicus*, and *Sarotherodon melanotheron*. *Poecilla reticulata* and *Poecilla sphenops* were the two species belonging to the Poeciliidae family. In the family with the highest number of individuals, seven species were recorded under Gobiidae. These were *Awaous sp, Glossogobius aureus, Glossogobius celebius, Glossogobius giuris, Pseudogobius javanicus, Rhinogobius* sp., and *Rhinogobius bucculentus*.

In terms of overall relative abundance (Fig. 3), Gobiidae (84%) and Cichlidae (11%) account for the highest abundance among the species. While in terms of endemicity, 87% (n = 2256) of fish samples collected are native to the Philippines, while only 13% (n = 343) are introduced species. Native species belong to eight families, with Gobiidae accounting for 97% (n = 2184) of the total population of 14 native species. The most abundant species are *Pseudogobius javanicus*, which comprises 30%, followed by *Rhinogobius bucculentus* (16%) and *Glossogobius celebius* (13%). Introduced species belong to five families, with Cichlidae accounting for 85% (n = 291) of the total population of the nine introduced species. The most abundant species are *Oreochromis mossambicus* (47%), followed by *Oreochromis niloticus* (24%), and *Sarotherodon melanotheron* (13%). Interestingly, native species dominated in the upper Agno, while the increase in introduced species began at stations downstream of hydropower dams with aquaculture activities towards the lower Agno.

San Roque, Pangasinan (ARB5) and Paniqui, Tarlac (ARB7) showed the highest species richness across all the stations (Table 5), followed by Dalupirip (ARB4) with a value of 9, Bocboc (ARB8) with 6, Kabayan (ARB1) with 4, Bokod (ARB2), and Viray (ARB6) with a value of 3. Shannon-Weiner diversity index values were high only in San Roque (ARB5) and Paniqui, Tarlac (ARB7), with values of 1.60 and 1.70, respectively. This is followed by Dalupirip (ARB4) with a diversity index value of 1.40, Bokod with 0.99, Viray with 0.76, Bocboc with 0.74, and Kabayan with 0.41. Species evenness ranged from 0.38 to 0.89. ARB1, with the lowest diversity index, exhibited the highest dominance value across the river basin. The lowest dominance values were observed in

Table 3
Two-way ANOVA results showing the effects of season, station, and their interaction with water quality parameters in Agno River Basin.

Parameters	Source of Variation	df	SS	MS	F	*p*-value
Temperature	Stations	7	1803.84	257.69	106.20	< 0.001***
	Seasons	1	0.70	0.70	0.29	0.591
	Stations x Season	7	679.94	97.13	40.03	< 0.001***
	Error	144	349.42	2.43	–	–
Dissolved Oxygen	Stations	5	209.54	41.91	38.12	< 0.001***
	Seasons	1	2.32	2.32	2.11	0.15
	Stations x Season	5	8.64	1.73	1.57	0.174
	Error	108	118.75	1.10	–	–
pH	Stations	7	16.13	2.30	17.68	< 0.001***
	Seasons	1	1.53	1.53	11.71	< 0.001***
	Stations x Season	7	15.21	2.17	16.66	< 0.001***
	Error	144	18.77	0.13	–	–
Electrical Conductivity	Stations	7	19964543.44	2852077.63	216.98	< 0.001***
	Seasons	1	111904.74	111904.74	8.51	0.004
	Stations x Season	7	1528134.15	218304.88	16.61	< 0.001***
	Error	144	1892828.70	13144.64	–	–
Total Dissolved Solids	Stations	7	5157108.92	736729.85	192.04	< 0.001***
	Seasons	1	287486.39	287486.39	74.94	< 0.001***
	Stations x Season	7	275282.99	39326.14	10.25	< 0.001***
	Error	144	552424.52	3836.28	–	–
Discharge	Stations	7	110304.86	15757.84	67.29	< 0.001***
	Seasons	1	9007.63	9007.63	38.46	< 0.001***
	Stations x Season	7	16428.14	2346.88	10.02	< 0.001***
	Error	144	33722.92	234.19	–	–

Note. p < 0.05 (*), p < 0.01 (**), p < 0.001 (***).

Table 4
Taxonomic composition and fish species observed at sampling stations in the Agno River Basin.

Family	Species name	Common name	Local Name	IUCN Status	Status	Site
Ariidae	*Arius manillensis (Valenciennes, 1840)*	Manila Sea Catfish	Kanduli	Data Deficient	Native	ARB8
Gobiidae	*Awaous* sp.		Biya	Not Found	Native	ARB1, ARB6
	Glossogobius aureus (Akihito & Meguro, 1975)	Golden Tank Goby	Biya	Least Concern	Native	ARB1, ARB5
	Glossogobius celebius (Valenciennes, 1837)	Celebes Goby	Biya	Least Concern	Native	ARB1, ARB2, ARB4, ARB7
	Glossogobius giuris (Hamilton, 1822)	Tank Goby	Biya	Least Concern	Native	ARB1, ARB4, ARB5, ARB7
	Pseudogobius javanicus (Bleeker, 1856)	Spotfin Snouted Goby	Wading	Least Concern	Native	ARB2, ARB6
	Rhinogobius sp.		Biya		Native	ARB2, ARB4
	Rhinogobius bucculentus (Herre, 1927)		Biya	Vulnerable	Native	ARB6
Cichlidae	*Oreochromis mossambicus (Peters, 1852)*	Mozambique Tilapia	Tilapia	Least Concern	Introduced	ARB5, ARB7, ARB8
	Oreochromis niloticus (Linnaeus, 1758)	Nile Tilapia	Tilapia	Least Concern	Introduced	ARB4, ARB5, ARB7, ARB8
	Sarotherodon melanotheron (Rüppell, 1852)	Black-chinned Tilapia	Arroyo	Least Concern	Introduced	ARB5, ARB7, ARB8
Carangidae	*Caranx ignobilis (Forsskal, 1775)*	Giant Trevally	Maliputo	Least Concern	Native	ARB7
Channidae	*Channa striata (Bloch, 1793)*	Snakehead Murrel	Dalag	Least Concern	Introduced	ARB5
Clariidae	*Clarias batrachus (Linnaeus, 1758)*	Catfish	Hito	Least Concern	Native	ARB5
Cyprinidae	*Cyprinus carpio (Linnaues, 1975)*	Common Carp	Karpa	Least Concern	Introduced	ARB5, ARB7
	Barbodes sp.		Taiwan		Introduced	ARB7
Loricariidae	*Pterygoplichthys disjunctivus (Weber, 1991)*	Vermiculated sailfin catfish	Janitor Fish	Least Concern	Introduced	ARB5, ARB7
Mugiliidae	*Mugil cephalus*	Flathead grey mullet	Banak	Least Concern	Native	ARB8
Poeciliidae	*Poecilia reticulata (Peters, 1859)*	Guppy		Least Concern	Introduced	ARB4
	Poecilla sphenops (Valenciennes, 1864)	Common Molly		Least Concern	Introduced	ARB4
Scatophagidae	*Scatophagus argus (Linnaeus, 1766)*	Spotted Scat	Kitang	Least Concern	Native	ARB8
Terapontidae	*Leiopotherapon plumbeus (Kner, 1864)*	Silver Perch	Ayungin	Vulnerable	Native	ARB4, ARB5, ARB7
Zenarchopteridae	*Zenarchopterus philippinus (Peters, 1868)*	Needlefish	Baroy	Least Concern	Native	ARB6

Note: ARB1- Kabayan, Benguet; ARB2- Bokod, Benguet; ARB3- Bokod, Benguet (No fish samples found); ARB4- Dalupirip, Benguet; ARB5- San Roque; ARB6- Viray, Natividad; ARB7 – Paniqui, Tarlac; and ARB8 – Bocboc, San Carlos.

ARB7 and ARB5, at 0.22 and 0.23, respectively.

3.3. Spatial pattern of freshwater fishes

The non-metric multidimensional scaling (nMDS) analysis using the Bray-Curtis similarity index was performed (Fig. 4) and yielded a good ordination (stress = 0.18). The analysis of similarity (ANOSIM) produced an R value of 0.009 and a p-value of 0.40, indicating no statistically significant difference in fish species between the Upper and Lower Agno stations. In other words, the data suggest that, based on these analyses, fish communities across the river basin are more alike than different. Additionally, species composition was assessed using UPGMA to look into similarity patterns in fish communities across the basin. The result showed clustering among seven sites: ARB1, ARB5, ARB7, and ARB8 (Fig. 5). While ARB2 and ARB6 deviated from the other stations, with 45% similarity, these observations should be interpreted cautiously, as ANOSIM tests did not indicate significant differences among stations. *R. bucculentus* was observed at both stations (ARB2 and ARB6) with a high relative abundance. Tank goby (*Glossogobius giuris*) and Mozambique tilapia (*Oreochromis mossambicus*) were both found in San Roque and Bocboc. Celebes goby (*Glossogobius celebius*), silver perch (*Leiopotherapon plumbeus*), tank goby (*Glossogobius giuris*), and Nile tilapia (*Oreochromis niloticus*) were observed in Dalupirip and Paniqui, Tarlac.

3.4. Fish assemblage patterns and environmental associations

Multicollinearity screening of the full environmental predictor set revealed substantially elevated variance inflation factors (VIF) values, particularly for electrical conductivity (EC; VIF = 25.81), temperature (VIF = 13.25), and pH (VIF = 10.97), indicating strong redundancy among predictors. Removal of EC markedly improved model stability, reducing VIFs to acceptable levels (< 4) for all retained variables: temperature (2.19), pH (2.81), dissolved oxygen (2.43), total dissolved solids (1.54), and discharge (2.25). These values are presented in Table 6. Detrended Correspondence Analysis (DCA) showed a long primary gradient (Axis 1 = 6.39 SD), indicating unimodal species responses and supporting the use of unimodal constrained ordination via CCA. The CCA fitted using the reduced predictor set explained a modest amount of constrained variation but was not statistically significant (global $p > 0.05$). Term–wise and axis–wise permutation tests similarly indicated that none of the predictors significantly structured fish assemblages within the CCA framework. These outcomes correspond visually to the CCA biplot (Fig. 6a), where environmental vectors are short, and species scores cluster near the origin, reflecting weakly constrained structure in the averaged dataset (see Fig. 7).

To complement the unimodal analysis, a Hellinger–transformed RDA was performed using the same reduced predictor set (Table 7). Although the global RDA model was not significant, the ordination revealed that temperature exhibited the strongest linear relationship with species

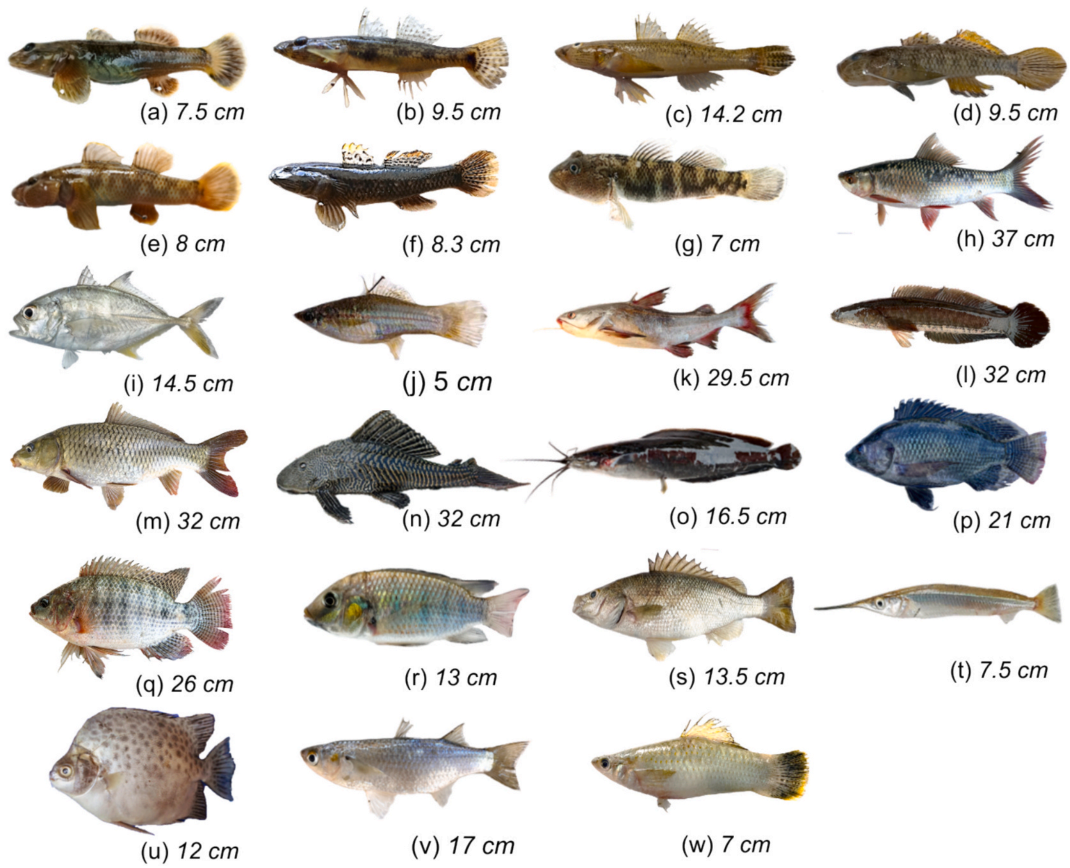

Fig. 2. Fish species sampled in the Agno River Basin: (a) *Awaous* sp.; (b) *Glossogobius aureus*; (c) *Glossogobius giuris*; (d) *Glossogobius celebius*; (e) *Pseudogobius javanicus*; (f) *Rhinogobius sp.*; (g) *Rhinogobius bucculentus*; (h) *Barbodes* sp.; (i) *Caranx ignobilis*; (j) *Poecilia reticulata*; (k) *Arius manillensis*; (l) *Channa striata*; (m) *Cyprinus carpio*; (n) *Pterygoplichthys disjunctivus*; (o) *Clarias batrachus;* (p) *Oreochromis mossambicus*; (q) *Oreochromis niloticus*; (r) *Sarotherodon melanotheron*; (s) *Leiopotherapon plumbeus*; (t) *Zenarchopterus philippinus*; (u) *Scatophagus argus*; (v) *Mugil cephalus*; (w) *Poecilia sphenops.*

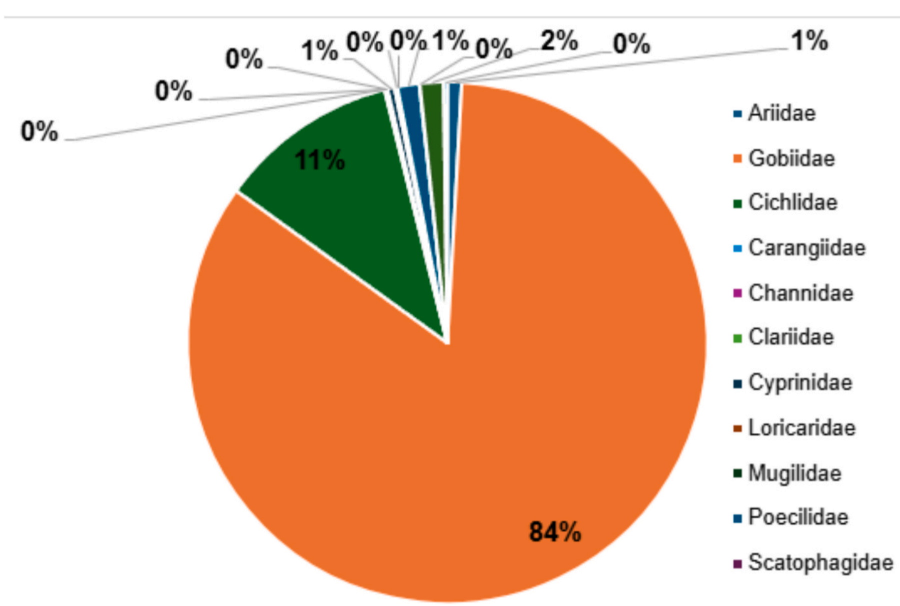

Fig. 3. Percent distribution of freshwater fish in the Agno River Basin.

composition. Other predictors (pH, dissolved oxygen, TDS, and discharge) had comparatively weaker loadings. This pattern is clearly evident in the Hellinger–RDA biplot (Fig. 6b), where temperature aligns with the dominant gradient in species distribution. Together, these multivariate results indicate that while several environmental variables covary among sites, temperature emerges as the most consistent predictor, and overall community structure likely reflects a combination of thermal gradients, site–level heterogeneity, and unmeasured habitat

Table 5
Summary of diversity indices of freshwater fish communities across sampling stations in the Agno River Basin.

Sites	Richness	Abundance	Dominance	Shannon	Evenness
Upper Agno					
ARB1	4	277	0.81	0.41	0.37
ARB2	3	720	0.41	0.98	0.89
ARB3	n.d	n.d.	n.d.	n.d.	n.d.
ARB4	9	416	0.33	1.41	0.45
Lower Agno					
ARB5	10	245	0.23	1.61	0.50
ARB6	3	659	0.49	0.76	0.71
ARB7	10	137	0.22	1.74	0.57
ARB8	6	145	0.62	0.74	0.34

Note: n.d. – not determined; No fish samples were found in ARB3.

factors.

4. Discussion

4.1. Spatio-temporal patterns in river physicochemistry

The majority of the physicochemical parameters measured in the study were within the permissible limits set by the National Water Quality Guidelines and General Effluent Standards (DAO 2016–08). Significant variations ($p < 0.001$) in the physicochemical parameters measured between stations in the river basin were observed (Table 3). The temperature showed an increasing trend as the river descends from the upper to the lower part of the river basin. Several factors contribute to this observation. One reason is the reduced riparian vegetation, crucial in regulating water temperature[23]. In addition, the elevation of the stations[24] affects temperature. Stations in the upper Agno River Basin experience lower temperatures, while those in the lower portion experience relatively warmer temperatures. It is important to note that the January data, collected during the dry season, had lower temperatures than the July data, collected during the wet season, due to the Northeast monsoon. Most values were within standard limits, except at ARB7 during the wet season, where they slightly exceeded the upper limits. The observed significant station and season interaction suggests that the influence of season on temperature varies depending on the sampling location. On the other hand, the DO concentration, which explicitly provides information on the rate of photosynthesis, nutrient availability, and bacterial activity, among others [25], exhibited a decreasing trend from the upper to lower portion of the river basin, which coincides with the findings of Ojao et al. [26] where lower DO was observed in relatively slower river discharge. This pattern is consistent with the significant spatial variation observed among stations. Water temperature increases as the river proceeds to lower elevations in the river basin, and DO follows its inverse proportional relationship with increasing temperature [27]. Oxygen dissolves more readily in cooler waters and reaches higher concentrations than in warmer waters[28,29]. The pH was found to be within the alkaline range during the wet season, indicating high concentrations of carbonate, bicarbonate, chloride, and other substances that raise the water's alkalinity[30]. During the dry season, the pH became more neutral, which can be attributed to the leaching of certain ions and waste materials, and to the decomposition of organic matter from the channel and riparian vegetation[31]. This seasonal shift supports the significant variation observed between wet and dry seasons. Overall, the significant spatial variability indicates that pH varies across sampling stations within the river basin. Furthermore, the significant interaction effect suggests that seasonal changes in pH vary depending on the location along the river, supporting the findings of the study where pH values in the upper Agno differ from those in the Lower Agno River Basin indicating that the influence of wet and dry seasons varies across stations. For EC, values were the highest in ARB3. The Philippine water quality guidelines and general effluent standards (DAO 2016–08) do not have standard values for EC and TDS, nor standalone standard values specific to mining areas; thus, the Interim National Water Quality Standard for Malaysia (NWQS) [32]was used, 1000 μS/cm and 500 to 1000 mg/L, respectively. The majority of the values were within the standard limits set by the INWQS, except for ARB3, which could be due to mining and/or geothermal activity in the area. This observation is consistent with the significant spatial variation in EC across stations. This was followed by stations in ARB7 and ARB8, located in relatively intense lowland agricultural activities in Paniqui, Tarlac, and Bocboc, San Carlos, Pangasinan. The significant seasonal and interaction effects further indicate that EC levels vary not only between seasons but also depending on the location within the river basin. Regarding TDS, measured values were the highest in ARB3, similar to those of EC, but did not exceed the standard limits. Varying TDS values can be linked to different influences from urban and agricultural landscapes [33], which are reflected in the river basin. These results support the significant spatial, seasonal, and

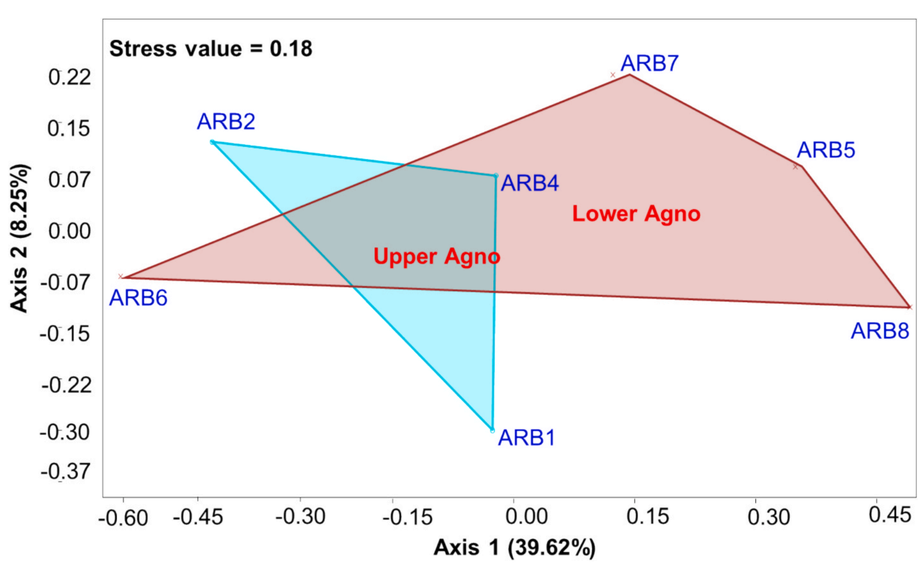

Fig. 4. Non-metric multidimensional scaling (nMDS) of freshwater fish assemblages in the Agno River Basin. Abbreviations – DS1: ARB1 Dry season; DS2: ARB2 Dry season; DS4: ARB4 Dry season; DS5: ARB5 Dry season; DS6: ARB6 Dry season; DS7: ARB7 Dry season; DS8: ARB8 Dry season; WS1: ARB1 Wet season; WS2: ARB2 Wet season; WS4: ARB4 Wet season; WS5: ARB5 Wet season; WS6: ARB6 Wet season; WS7: ARB7 Wet season; WS8: ARB8 Wet season.

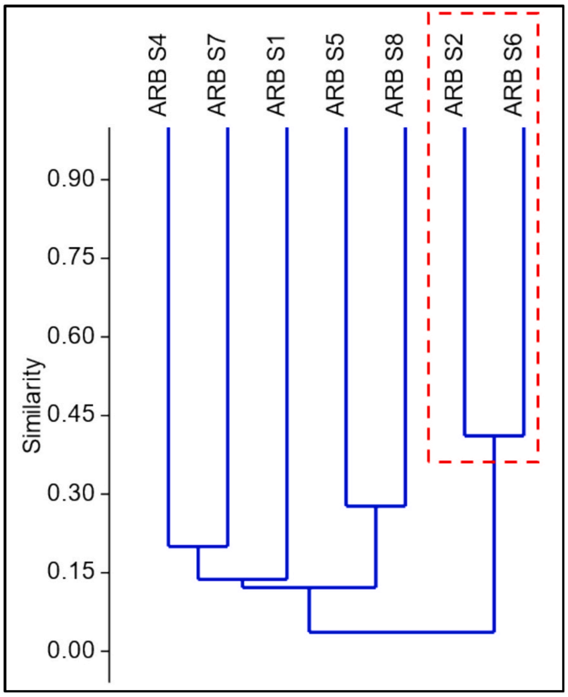

Fig. 5. Cluster analysis of freshwater species using the unweighted pair group method with arithmetic mean (UPGMA), illustrating the relationships among study sites based on species composition.

Table 6
Variance Inflation Factor (VIF) values for environmental variables.

Predictor	VIF (Full Model)	VIF (Reduced Model)
Temperature (°C)	13.25	2.19
pH	10.97	2.81
Dissolved Oxygen (mg/L)	2.91	2.43
Electrical Conductivity (EC, μS/cm)	25.81	—
Total Dissolved Solids (TDS)	2.99	1.54
Discharge (m^3/s)	2.32	2.25

Note: EC exhibited extreme multicollinearity in the full model and was removed before refitting. Final predictor set used for modeling: Temperature, pH, Dissolved Oxygen, TDS, Discharge.

interaction effects observed, indicating that TDS concentrations are influenced by both temporal changes and location-specific factors. In terms of river discharge, higher levels were observed during the wet season, compared to the dry season, as expected [34]. Moreover, the river discharge was higher in the lower Agno than in the upper basin. This aligns with the significant spatial and seasonal variation observed, while the significant interaction effect suggests that the magnitude of seasonal changes in discharge differs across stations within the river basin.

4.2. *Fish assemblages and community health*

Gobies were the most common family, with seven species in the river basin. Specifically, the spotfin snout goby (*Pseudogobius javanicus)* (locally known as "*wading*"[35]), recorded the highest relative abundance. A study by Bestre et al. [15] reports that gobies, such as the tank goby and the spotfin snout goby, have been two of the most common fish species in the Agno River Basin in Benguet province. This finding aligns with the study's results, which suggest that these gobies dominate specific areas of the basin, particularly in Benguet. In a study by Jamandre [16], a total of 375 freshwater fish species is recorded in the Philippines, with gobiiformes having the most diverse order with 114 species across

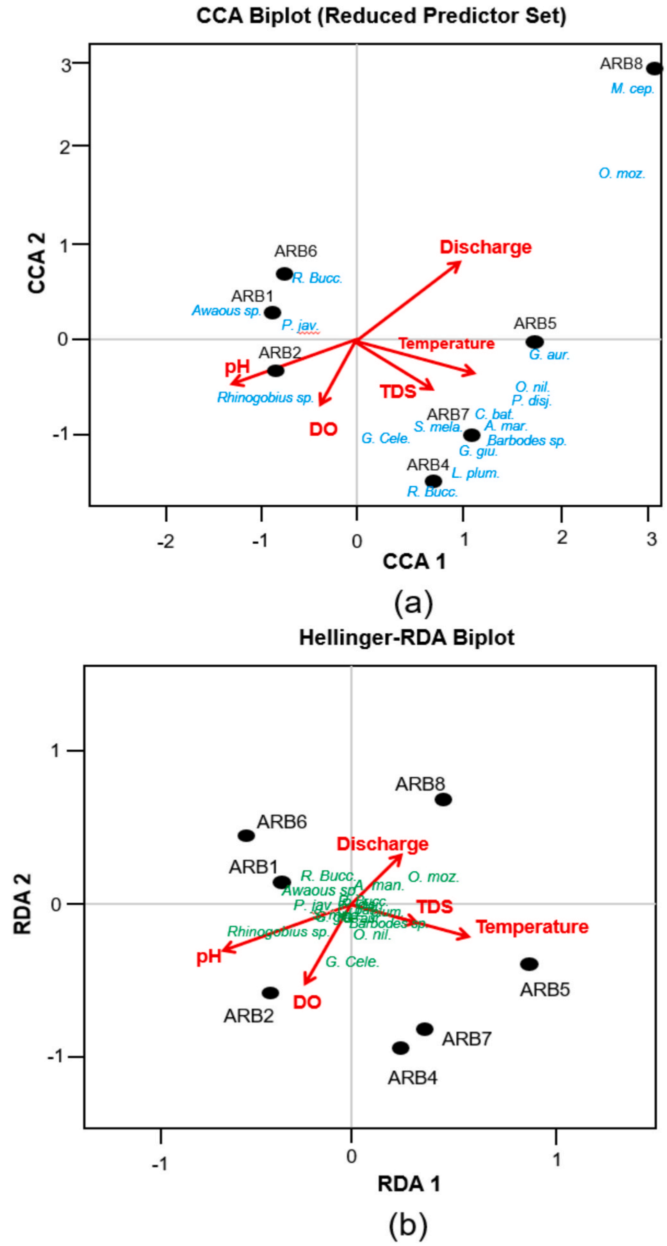

Fig. 6. Canonical Correspondence Analysis (CCA) plot (a) using the reduced predictor set (temperature, pH, dissolved oxygen, total dissolved solids, and discharge) and Hellinger-transformed species data (b) constrained by the reduced predictor set. Site scores (filled circles) are labeled by station (ARB1–ARB8).

five families, which undoubtedly explains the natural distribution of gobids observed in the river basin. Additionally, the study of Dantis & Lacap [8] reported several freshwater species that were also found during the sampling in the study, such as manila sea catfish (*Arius manillensis*), snakehead murrel (*Channa striata*), Nile tilapia (*Oreochromis niloticus*), black-chinned tilapia (*Sarotherodon melanotheron*), catfish (*Clarias batrachus*), asian carp (*Cyprinus carpio*), tank goby (*Glossogobius giuris*), spotted scat (*Scatophagus argus*), and silver perch (*Leipotherapon plumbeus*). No fish samples, even bivalves and gastropods, were collected during wet and dry season sampling activities in ARB3. The absence of these freshwater species may be associated with elevated EC readings exceeding acceptable limits, or linked to potential leachate from large- and small-scale mining activities in the headwaters of this sub-catchment. This pattern is similarly observed in other river systems, where water-quality degradation driven by anthropogenic activities,

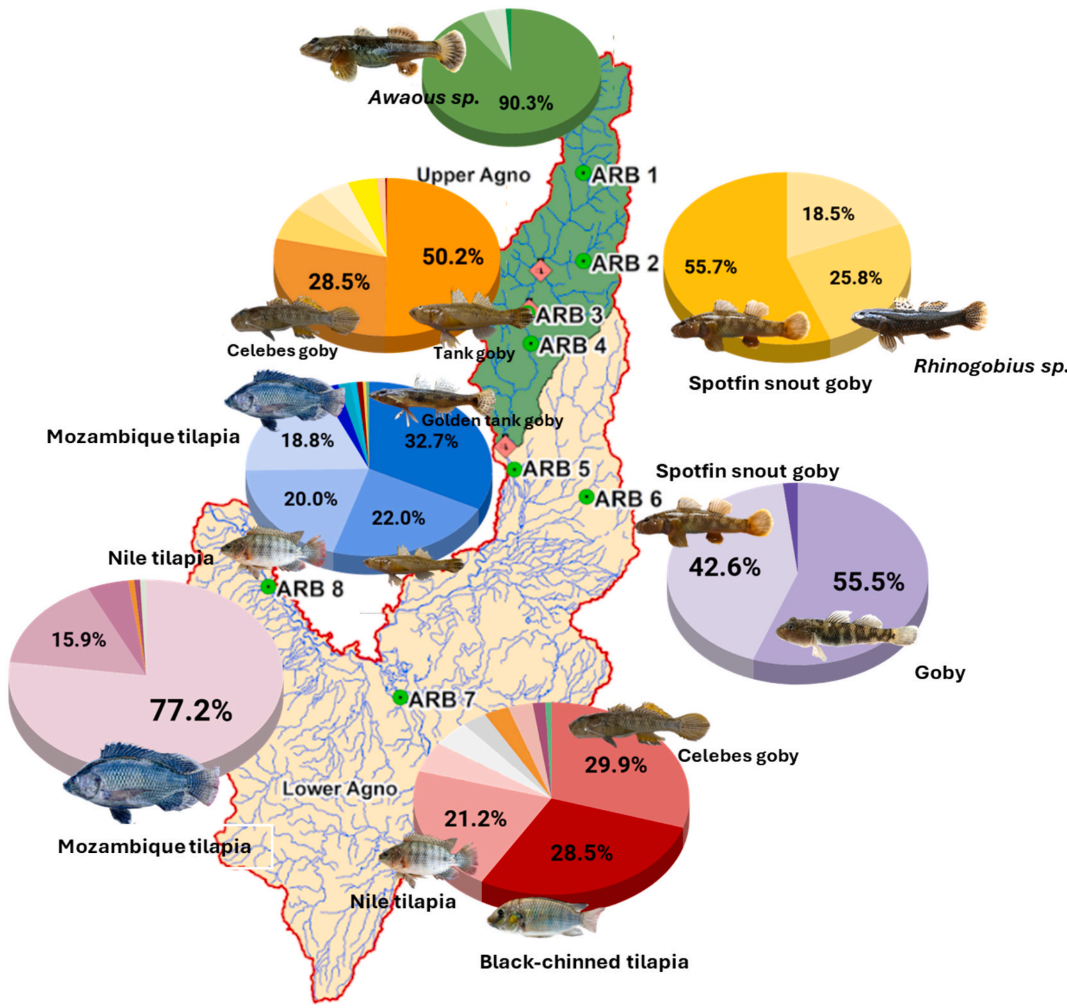

Fig. 7. Fish community distribution in the Agno River Basin.

Table 7
Permutation Test Results for Canonical Correspondence Analysis (CCA) and Redundancy Analysis (RDA).

Analysis	Test Component	Test Statistic	*p-value*
CCA (Temperature)	Global model	F = 1.4638	0.032*
	Temperature (°C)	F = 1.4638	0.038*
	Axis 1	F = 1.4638	0.032*
RDA (Temperature)	Global model	F = 1.8272	0.048*
	Temperature (°C)	F = 1.8272	0.032*
	Axis 1	F = 1.8272	0.047*
RDA (Temperature, Discharge)	Global model	F = 1.3522	0.120
	Temperature (°C)	F = 1.7944	0.039*
	Discharge (m^3/s)	F = 0.9101	0.590
	Axis 1	F = 1.7946	0.128
	Axis 2	F = 1.1373	0.367

Note. $p < 0.05$ (*). Species data were Hellinger-transformed for RDA; predictors were z-score standardized. Compact models were used to increase power at 7 sites.

including but not limited to mining, can significantly influence fish assemblage and lead to a decrease in species diversity[36]. In comparison to a Southeast Asian river, although it did not exceed Malaysian standards, the electrical conductivity was one of the parameters linked to disturbance in a specific section of the Bengawan Solo River in Indonesia, significantly reducing the diversity of freshwater fish species compared to other sections of the river[37]. High levels of EC can disrupt osmoregulation in fish, leading to stress or mortality, and may also degrade habitat quality, making the area unsuitable for fish survival [38]. However, EC measurements are surrogate indicators that do not identify individual pollutants; however, they provide a useful basis to complement targeted chemical analyses (e.g., nutrients, metals, organic contaminants) to pinpoint precise pollutant sources affecting species in a particular environment[39]. In addition, given the limited sampling frequency of the study, which accounts for seasonal variations, the impact of mining activities on water quality and the absence of fish species, warrants targeted follow-up sampling and additional parameters to collect further evidence that will link the impact of mining activities to the absence of freshwater species in the study area.

Species from the families Cichlidae, Channidae, Cyprinidae, Loricaridae, and Poeciliidae were observed as introduced species in the river basin. Species from the families Cichlidae, Cyprinidae, and Channidae began to be observed in ARB4 after Binga and Ambuklao Dam, or in ARB5 at San Roque Dam in Lower Agno. Although these species were observed at other stations, such as ARB7, their presence was primarily observed at ARB5, San Roque Dam. This observation can be linked to aquaculture activities[40]and the continuous introduction of tilapia fingerlings by the Bureau of Fisheries and Aquatic Resources – Department of Agriculture (BFAR–DA) in Ambuklao Dam[15]and Binga Dam [41], located upstream of San Roque Dam. A study by Petr [42] mentioned that *"Tilapia"*, *Cyprinus carpio* (Common carp), and even *Mugil* sp. (Mullet) were among the fish species found to dominate in the river basin through experimental fishing by BFAR. The Nile tilapia is the most commonly cultivated fish in the river basin. A study by Dantis and Lacap [8] found that it dominates the Lower Agno River Basin. This concern was also documented in a study by Batani et al. [35], in which locals reported that the extinction of certain native fish in Ambuklao Dam was attributed to the introduction of Nile tilapia. The widespread distribution of introduced species often destabilizes aquatic ecosystems by competing with or preying on native fishes, leading to declines in native fish populations[40]. The abundance of Nile tilapia demonstrates the effects of aquaculture activities, as its rapid increase can result in escapes from fish cages or pens and even intentional seeding into open fisheries[43]. Nile Tilapia originated in Africa and was introduced in the Philippines in 1972[44,45]. Nile tilapia is being cultured in different lakes, rivers, and other freshwater bodies throughout the country. This freshwater fish has played a crucial role throughout the decades, enhancing the condition of fisheries in the Philippines[40,43]. Species from the Family Poeciliidae were also observed in ARB4, specifically *Poecilia reticulata* and *Poecilia sphenops. P. reticulata* was introduced in the country [46] as a biocontrol agent against mosquitoes to combat malaria cases in 1905, while *Poecilia sphenops* was also investigated as a possible mosquito control by a study of Syifa et al. [47].

A study conducted along the Agno River Basin in Pangasinan found that macrofaunal diversity was very low (H' = 1.6)[8] according to the Fernando et al. (2000) classification. Flores and Zafaralla [48] similarly noted that diversity index values below 2.5 are considered relatively low. Consistent with these findings, the Agno River Basin exhibited persistently low diversity indices, ranging from 0.41 to 1.74 across all stations. In a protected freshwater fish sanctuary within the Cagayan River, Perez [49] also reported similarly low diversity values (H' = 1.66–1.91), with introduced species like Nile tilapia dominating. Compared to other large Southeast Asian river basins, these values indicate a simpler fish assemblage in the Agno River Basin. The study's results were lower than those documented for the Koto Panjang Reservoir system in Indonesia (H' = 2.1), where major anthropogenic activities, such as dams, aquaculture, and invasive species, were identified as pressures [50], similar to those in the Agno River Basin. In contrast, larger systems like the Mekong and Red Rivers, which support more structured fish communities, exhibit greater habitat heterogeneity and longitudinal connectivity, resulting in higher diversity[51,52].

The apparent dominance of the spotfin snout goby and other gobioids[15]in the river basin, as reported in previous studies and in this study, may reflect natural ecological specialization and morphofunctional adaptations to flowing-water habitats. Interestingly, native species were abundant in the upper Agno, whereas the relative abundance of introduced species increased in the lower Agno (Fig. 6). However, based on the similarity analysis, no significant species differentiation ($p > 0.05$) was found between the upper and lower Agno. The persistence of native species, especially gobids, may be due to their adaptations, including fused pelvic fins that serve as adhesive suckers, allowing them to attach to substrates in strong currents and enhancing their competitiveness and dominance in riffle and run habitats[53]. This functional trait of gobies is commonly reported in tropical rivers[16]and even in Southeast Asian goboid fish, which report high gobiid abundances structured by environmental filters, such as flow, depth, and substrate [54].

In terms of the abundance of introduced species in the lower Agno, Liao et al. [55] claimed that the construction and operation of hydropower dams are capable of changing habitat structure, flow, and connectivity, creating conditions for the expansion of introduced species [55]. These conditions contribute to the establishment of new niches, where flowing environments are converted to still waters, allowing introduced species to occupy them. Similar studies also align with the finding that habitat fragmentation and flow changes, as influenced by dam construction, favor increases in the number of introduced species, such as Nile tilapia[56]. However, despite the increasing population of introduced species, native species adapted to upstream riverine environments, with less modification, can remain abundant where the flow regime and habitat complexity remain the same [57]. In addition, native species can still have high abundance when upstream conditions continue to support native niches, and habitats in downstream areas, such as in lower Agno, can provide habitat that introduced species can exploit[55,57]. Even studies of tropical Asian rivers have shown that diversity patterns often vary along the upstream, midstream and downstream gradients, with localized dominance of certain species emerging as a natural outcome of geomorphology, flow regime, and habitat availability rather than solely as a signal of ecosystem degradation[58,59]. Although the dominance of some species is apparent, reflecting the potential inequitable distribution of niche space[60], it does not automatically reflect the result of disturbances in the basin.

4.4. Species-environment relationships

The exploratory multivariate analysis demonstrated parameters associated with both the stations and the fish assemblage. The findings showed that the majority of the introduced species, such as Nile tilapia, were present in areas with relatively warm temperatures. Non-native species, with their generalist traits, can withstand warmer water[61]. These species are adaptable to a wider range of environmental conditions and are efficient resource users, enabling them to thrive in specific areas[62]. The triplot diagram illustrates the parameter patterns characterizing ARB1, ARB2, and ARB6, and shows native species, such as the spotfin snout goby and *Awaous* sp. Based on the observed patterns, these species may inhabit environments with relatively cool temperatures, high DO levels, and alkaline water. Similarly, Golden tank goby (*G. aureus*), Silver perch (*L. plumbeus*), Catfish (*C. batrachus*), and Celebes goby (*G. celebius*), native to the country, showed strong structure to temperature and TDS.

Based on the constrained (CCA) and unconstrained (Hellinger-RDA) analyses (Fig. 6a and 6b), temperature appeared to be the most consistent parameter associated with assemblage composition, revealing a detectable relationship in both linear and unimodal analyses, compared to pH, dissolved oxygen, TDS, and discharge. However, the statistical insignificance in our CCA analysis underscores the need for careful interpretation, as biotic interactions and selected environmental drivers are often complex and context-dependent, particulary in tropical river systems where stochastic and deterministic processes may interact[63]. Freshwater fishes such as manila sea catfish (*Arius manillensis*), snakehead murrel (*Channa striata*), asian carp (*Cyprinus carpio*), *Rhinogobius bucculentus*, Black-chinned tilapia (*Sarotherodon melanotheron*), Flathead grey mullet (*Mugil cephalus*), *Barbodes sp*., needlefish (*Zenarchopterus philippinus),* and guppy *(Poecilla reticulata),* were only found in a single station. Hence, association with the physicochemical parameters cannot be established. On the other hand, the similarity analysis showed similar fish composition between the Upper and Lower Agno stations. This similarity is often observed in fish communities, which exhibit resilience to spatial variation despite differences in environmental gradients [64]. Studies of tropical rivers showed that local environmental variables can play only a limited role in shaping assemblages, with hydrological connectivity and landscape context typically exerting greater influence [65]. The lack of significant environmental variables explaining variation in fish distribution in this study suggests that unmeasured factors, such as habitat structure, seasonal hydrology, and anthropogenic pressures, may be more influential, as demonstrated in other tropical river basins[66]. This underscores the need to integrate more ecological variables, geomorphological and temporal data to explain the composition of fish communities in the Agno River basin and similar tropical systems.

5. Conclusion

The majority of the water quality parameters in the Agno River Basin were within the acceptable limits of the Philippine water quality guidelines and general effluent standards (DAO 2016–08), as well as the National Water Quality Guidelines of Malaysia. However, elevated EC readings near mining areas in Baloy, along with slightly elevated temperatures, and low DO levels in low-altitude areas such as in Paniqui and Bocboc, indicate localized environmental stress. While the results are consistent with impairment at ARB3 (Baloy), causality cannot be established due to the study's limited design. Future studies should include targeted sampling for trace and toxic metal(loids)s in water and sediment as well as consideration of hydraulic or geomorphic factors, such as substrate instability or channelization, as potential additional stressors at this site and elsewhere in the basin. Overall, the significant spatial and seasonal variations driven by land use, elevation and climatic factors strongly influence the physicochemical parameters and river discharge in the basin.

The ichthyofaunal assessment exhibited low to moderate species diversity, dominated by gobioid assemblage reflecting their adapatation to the riverine conditions in the basin. The presence of introduced cichlids is likely associated with the aquaculture activities in major dams, which may have influenced the fish diversity downstream. Although multivariate analyses indicated temperature as a potential factor influencing fish distribution, these relationships were not statistically significant, and results should therefore be interpreted with caution. Overall, the exploratory nature of these findings highlights the need to improve the study's design and inclusion of additional environmental variables. Nevertheless, the study provides the first basin-wide baseline assessment of fish and water quality in the Agno River Basin. The findings of the study not only contribute to the existing literature on fish composition and abundance under anthropogenic pressures in the Agno River basin but also across the major river basins in the Philippines. It underscores the crucial role of effective, holistic management in tropical river basins facing similar pressures.

CRediT authorship contribution statement

Kit Felian C. Tenio: . **Loucel E. Cui:** . **Decibel V. Faustino-Eslava:** Writing – review & editing, Investigation, Funding acquisition. **Juan Miguel R. Guotana:** Writing – review & editing, Investigation. **Jenielyn T. Padrones:** Writing – review & editing, Investigation. **Kennethjer G. Alejo:** Writing – review & editing, Investigation. **Manilyn Casa:** Conceptualization. **Francis Ian P. Gonzalvo:** Investigation. **Earvin Jon Guevarra:** Investigation. **Rosemarie Laila D. Areglado:** . **Maria Regina V. Regalado:** Investigation. **Patrick Byrne:** Writing – review & editing. **Richard Williams:** Writing – review & editing. **Emma Biles:** Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Data access

The dataset used to generate the results presented in this article are available from https://doi.org/10.5525/gla.researchdata.2287.

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