Research Article

Universal Journal of Life and Environmental Sciences **2025, Vol 7, Pages 68-93 Serie 1**

Submission (30 July 2025) Accepted and Published (30 October 2025) www.ijarme.org

Evaluation of chemical Water Quality and Macro Invertebrates Biodiversity in the Obili Aquaculture Unit –Yaounde (Cameroon)

TANGEM LUCAS LEKU (+237674930502, tangemlucasleku@gmail.com)

Professional Master of Engineering in Fisheries and Aquatic Sciences, Option Aquaculture and Master of Science in HYDROBIOLOGY AND ENVIRONMENT, LABORATORY OF HYDROBIOLOGY AND ENVIRONMENT,

DEPARTMENT OF ANIMAL BIOLOGY AND PHYSIOLOGY, FACULTY OF SCIENCE, UNIVERSITY OF YAOUNDE I.

TANGEM LUCAS LEKU, OMGBA MARIE THÉRÈSE VIVIANE, MPOMEZOK CHILLY VANESSA GABY, NYAMA JOSEPH, TAMPONO IDEDOU CHRISTELLE.

MINISTRY OF LIVESTOCK, FISHERIES AND ANIMAL INDUSTRIES

YAOUNDE, CAMEROON.

Abstract

The study evaluated water quality and macroinvertebrate biodiversity in four (04) fish ponds at the Obili Aquaculture Unit, Centre Region of Cameroon, from June 2022 to November 2022. Monthly sampling was carried out, measuring physico-chemical parameters according to Rodier's guidelines and collecting benthic macroinvertebrates using a multihabitat approach. Results indicated poorly oxygenated, slightly acidic water conditions, which are unfavorable for aquatic species production, along with low levels of organic pollution indicators such as nitrates, orthophosphates, and nitrites. A total of 532 macroinvertebrates were identified, spanning two phyla, two classes, six orders, and ten families. Insects dominated the community, comprising 51.7% relative abundance across four orders and eight families, followed by Gastropoda, which accounted for 48.3% relative abundance across two orders and two families. Spatial-temporal analysis revealed the presence of pollution-tolerant taxa, including Lestidae, Thiaridae, and Lymnaeidae, indicating excessive organic pollution. Diversity indices (Shannon-Weaver and Pielou's equitability) reflected low taxa diversity, caused by unfavorable conditions for pollution-sensitive species. Hilsenhoff's Biotic Index confirmed significant organic pollution across all ponds. The Global Biotic Numeric Index (GBNI) indicated poor water quality in the fish ponds, while Sörensen's similarity coefficient (>50%) showed high similarity among ponds.

. Finally, the study suggests promoting macroinvertebrate cultivation as a viable alternative to fishmeal in aquaculture feed.

Key words: Biodiversity, Benthic Macroinvertebrates, Water quality, Fish ponds, Obili.

Résumé

L'étude a évalué la qualité de l'eau et la biodiversité des macroinvertébrés dans quatre (04) étangs de l'unité d'aquaculture d'Obili, dans la région du Centre, Cameroun, de juin 2022 à novembre 2022. Des échantillonnages mensuels ont été effectués, avec des paramètres physico-chimiques mesurés selon les directives de Rodier et des macroinvertébrés benthiques collectés en utilisant une approche multihabitat. Les résultats ont révélé une eau faiblement oxygénée et légèrement acide, défavorable à la production d'espèces aquatiques, ainsi que des niveaux faibles d'indicateurs de pollution organique (nitrates, orthophosphates et nitrites). De plus, un total de 532 macroinvertébrés ont été identifiés, représentant deux phylums, deux classes, six ordres et dix familles. Les insectes dominaient (abondance relative de 51,7 %, quatre ordres, huit familles), suivis par les Gastropoda (abondance relative de 48,3 %, deux ordres, deux familles). L'analyse spatio-temporelle a montré une prévalence de taxons polluants comme Lestidae, Thiaridae et Lymnaeidae, indiquant une pollution organique excessive. Les indices de diversité (Shannon & Weaver et équitabilité de Pielou) ont mis en évidence une faible diversité des taxons en raison de conditions défavorables pour les espèces sensibles à la pollution. L'indice biotique de Hilsenhoff a confirmé une pollution organique substantielle dans tous les étangs. Le calcul du GBNI a indiqué une mauvaise qualité de l'eau dans les différents étangs, tandis que le coefficient de similarité de Sörensen (>50 %) a montré une bonne similarité entre les étangs. Enfin, l'étude suggère de se concentrer sur la culture de macroinvertébrés comme substitut potentiel au farine de poisson dans l'alimentation des poissons

Mots-clés : Biodiversité, macro-invertébrés benthiques, qualité de l'eau, étangs à poissons, Obili.

INTRODUCTION

Water is a basic and primary need of all vital processes and it is now well established that the life first arose in aquatic environment. It is one of the most important compounds that profoundly influence life (Jekayinfa *et al*, 2022). Rapid industrialization and indiscriminate use of chemical fertilizers and pesticides in agriculture are causing heavy and varied pollution in aquatic environment leading to deterioration of water quality and depletion of aquatic biota." Poorly managed resources can cause water scarcity or pollution, which may lead to health, social and economic crisis. Water quality includes all physical, chemical and biological factors of water that influence the beneficial use of the water (Alley, 2007).

Physical parameters include colour, odour, temperature, transparency, turbidity, total solid wastes etc. Chemical characteristics involve parameters such as pH, dissolved oxygen, free carbon dioxide, alkalinity, total hardness, presence of ammonia, phosphate, chlorine, calcium, magnesium etc. Likewise, biological indicators of water quality include fishes, macroinvertebrates, macrophytes and phytoplankton. Selection of parameters for testing of water solely depends upon for what purpose we are going to use that water and what extent we need its quality and purity (Patil *et al.,* 2012). Water is a natural resource and fundamental need of all organisms, plants, animals and humans; it is also the most necessary solvent for agriculture, industry, tourism and aquaculture (Aydin, 2018, Partyka *et al,* 2022)

Aquaculture depends predominantly on water and regular monitoring of water quality is a necessity. Fish cultivation also known as aquaculture consists of natural and artificial fish farming carried out in ponds (Akpotayire *et al.,* 2018). Fish and other organisms with aquacultural potential live in water, thus, it is no surprise that professional fish culturists state that "Water quality determines to a great extent the success or failure of a fish cultural operation" (Piper *et al.,* 1982). Environmental pollution is a primary burden of aquaculture as poor water quality in fish ponds will result to deteriorated fish health and eventually low production. The status of various water parameters like turbidity, pH, alkalinity, hardness, ammonia, nitrite, nitrate, biochemical oxygen demand (BOD) etc. cannot be overlooked for maintaining a healthy aquatic environment (Bhatnagar and Pooja, 2013. This is a key concern for this study especially as the result will offer valuable information to fish farmers in raising fishes efficiently. If culturists are properly guided and aware about water quality management practices, they can get maximum fish yield in their ponds to a greater extent (Bhatnagar and Pooja, 2013). This also demand the necessity for this study.

The physicochemical properties of water could be influenced by the culture systems (Mustapha, 2017). Beyond filling the gap in dearth of scope of inquiry into fish pond water quality, this study also aims to bring awareness to fish culturists about the vital water quality parameters that needs constant monitoring as a result of their impact on the health of fishes.

Macroinvertebrates are animals that have no backbone and can be seen with the naked eyes. They generally include insects, crustaceans, molluscs, arachnids, and annelids. These organisms are important link in the food chain of freshwater ecosystems (Hussain and Pandit, 2012). Some aquatic macroinvertebrates can be quite large, such as freshwater crayfish, however, most are very small. Invertebrates that are retained on a 0.25mm mesh net are generally termed macroinvertebrates. These animals live in the water for all or part of their lives, so their survival is related to the water quality. They are significant within the food chain as larger animals such as fish and birds rely on them as a food source. Macroinvertebrates are sensitive to different chemical and physical conditions. If there is a change in the water quality, perhaps because of a pollutant entering the water, or a change in the flow downstream of a dam, then the macroinvertebrate community may also change. Therefore, the richness of macroinvertebrate community composition in a waterbody can be used to provide an estimate of waterbody health. Macroinvertebrate communities vary across the State and different waterbodies often have their own characteristic communities (Huang *et al,* 2023). The chemical parameters mostly used in the characterization of water bodies are as follows: potential of Hydrogen, electrical conductivity, forms of nitrogen, orthophosphates, dissolved oxygen, dissolved carbon dioxide, alkalinity, calcium hardness and oxidizability (Rodier *et al.,* 2009). The Hydrogen potential (pH) determines the acidic, neutral or basic feature of water. It depends on the nature of the field studied (Nola *et al.,* 2003) and influences most of the chemical and biological mechanisms of waters. Electrical conductivity is a numerical expression of the ability of water to conduct electrical current. It accounts for the degree of mineralization and gives an idea of the quantity of mobile ions present in the water (Bazin, 1996). Dissolved oxygen (DO) is one of the most important indicators of water quality. It is essential for the survival of fish and other aquatic organisms. Oxygen is also introduced into the water as a byproduct of aquatic plant via photosynthesis (Zébazé, 2000; Nziéleu, 2006). Oxygen is used in water for the respiration of organisms and for the breakdown of organic matter. The carbon dioxide dissolved in water comes from the air, rainwater, respiration of organisms, decomposition of organic matter in sludge, mud and from groundwater. Carbon dioxide can contribute significantly to the distribution of aquatic organisms (Angelier, 2000). The major source of ammonia in a water of a heavily stocked culture pond or in the effluent of a raceway is from excretion of fish, mostly via their gills. Ammonia is produced by animals as a byproduct of protein metabolism. When it is measured by chemical analysis (Nessler method) for ammonia is called total ammonia nitrogen (TAN) because it includes two forms of ammonia: ammonia (NH3), the unionized form, and the ammonium ion (NH4+). The temperature and pH of water affects the ratio of (NH4+): (NH3) in water. At lower temperatures and lower pH, the reaction (3) shifts from left to right, decreasing the percent of unionized (toxic) form (NH3) of ammonia (Thurston *et al.* 1979).

Toxicity from high TAN is more likely at high pH and high temperatures, conditions that occur in mid-summer in ponds with high standing crop of fish, which are also likely to have a heavy algal bloom, and mid-afternoon pH values close to 9. The unionized ammonia (UIA) is toxic to fish. According to the CEAEQ (2007), the NH4+ content is very high in waters rich in organic matter. Nitrifying bacteria, nitrosomonas, convert ammonia into nitrite, which is then converted by another bacterium, nitrobactor, into nitrate. Nitrite is more harmful and should be kept at 0 ppm. Once nitrite is converted to nitrate, nitrate is viewed as plant food and is usually of no concern to pond keepers regarding fish. However, nitrate can be a key contributor to green water algae. Phosphorus is an essential element for the growth of aquatic plants. It is involved in the synthesis of new tissues in algae, ahead of carbon and nitrogen (Rodier *et al.,* 2009). Phosphorus and nitrogen are present in water systems in the form of PO_4^{3-} and nitrate, respectively.

Nitrogen and phosphorus are both extremely important nutrients that are necessary in the right amounts in water that feeds plant and animal ecosystems. Too much phosphate and nitrate in any water-based ecosystem can produce eutrophic and or hypoxic condition. It is found in water in inorganic (H_2PO^{4-}, $HPO_4^{2-,}$ PO_4^{3-}) and dissolved or particulate organic form; the latter form being generally trapped in the sediments and returned to the water column on demand or by mixing the water. Phosphorus is needed for the growth, maintenance, and repair of all tissues and cells, and for the production of the genetic building blocks, DNA and RNA. It is the basic element of photosynthesis and perhaps it is 'limiting nutrient' in aquatic ecosystems. It becomes limiting for algal growth when the N/P mass ratio is greater than 7 (Reynolds, 1984). Of all the existing forms, only the inorganic form of phosphorus is used by plants for photosynthesis. The enrichment of the water with phosphorus leads to the increase in the productivity of the pond and the acceleration of the eutrophication process. Thus, to ensure good fish productivity without destroying the pond, Schlumberger (2002) suggests phosphate ion contents should be between 0.2 and 0.5 mg/L in the water column. The CTA is one of the chemical variables of the waters of a fish farming pond. It reflects the ability of water to absorb protons. In natural waters, alkalinity generally results from the presence of hydrogen carbonates and hydroxides (Rodier et al., 2009). The TAC varies in the same direction as the calcium hardness of the water and increases with the degree of mineralization (Verneaux, 1973).

In natural waters, alkalinity generally results from the presence of hydrogen carbonates and hydroxides (Rodier *et al.,* 2009). The waters coming from limestone soils and especially from gypsum soils have very high hardnesses. While those flowing on crystalline, metamorphic or schistose grounds display very low hardness (Rodier *et al.,* 2009). Oxidability corresponds to the overall estimate of the concentration of biodegradable organic matter (Derwich *et al.,* 2010). Its value provides information on the level of organic matter present in the environment and therefore makes it possible to assess the degree of water pollution. To this end, Zébazé, (2000) points out that the variation in the oxygen content of the environment is inversely proportional to that of biodegradable organic matter. The physico-chemical parameters are decisive for maintaining good water quality in the ponds.

Benthic macroinvertebrates are animal organisms that do not only lack a backbone but are also visible to the naked eye. (Moisan, 2010). They are found particularly in sediments at shallow depths, in organic debris, on macrophytes (Boissonneautl, 2010). The macroinvertebrates commonly used as bioindicators are aquatic insects, worms, molluscs and crustaceans (Boissonneautl, 2010). They are established as good indicators because of their rapid and different reaction to toxic substances, their sedentary lifestyle, their varied life cycle, their great diversity, their variable tolerance to pollution and habitat degradation (Moisan ., 2010; Boissonneault, 2010).

They are primary food sources for several species of fish, amphibians and birds. Moreover, they have a fairly well-known ecology, a ubiquitous character and a large size that facilitate their collection, manipulation and recognition (Neveu *et al.,* 2001). Macroinvertebrates are also essential for the transformation of organic matter by shredding and recycling a large part of the plant and/or animal matter found in hydrosystems (Olivier *et al.,* 2004). They also intervene in the biological cycle of certain parasites, by serving them as intermediate and/or definitive hosts.

Aquatic insects are found within the interfaces of terrestrial and mainly freshwater ecosystems such as lentic systems, e.g., lakes, ponds, wetlands, bogs, as well as lotic systems, e.g., springs, streams, and rivers, while only a few occur in truly marine habitats. According Henry and Dellapé (2010), the insects are essentially terrestrial for certain orders at the adult stage and develop at the larval stage in fresh water for the most part. Other orders, however, are entirely aquatic. Aquatic insects are often used as surrogates to assess water quality and pollution impacts in freshwater environments. For example, the EPT (Ephemeroptera, Trichoptera, and Plecoptera) richness index is one example of surrogacy that is widely used in many aquatic studies. We distinguish a group with gradual metamorphosis (Hemimetaboles) made up of Hemiptera, Odonata, Plecoptera and Ephemeroptera whose wing sheaths gradually develop with each molt and a group with complete metamorphosis (Holometaboles) made up of Diptera, Trichoptera, Megaloptera, Coleoptera and Lepidoptera (Pyralidae). The body of an insect basically consists of three parts; a head bearing a pair of antennae, the eyes (compound eye and ocelli in larvae and adults of heterometaboles and in hemimetaboles), a thorax made up of three segments each bearing basically a pair of articulated legs and in the adult normally two wings and an abdomen of 11 segments bearing no articulated appendages (except a pair of extensions such as the cerci). Their diet is diversified, so their habitat and their mode of reproduction is specific to each family (figure 2).

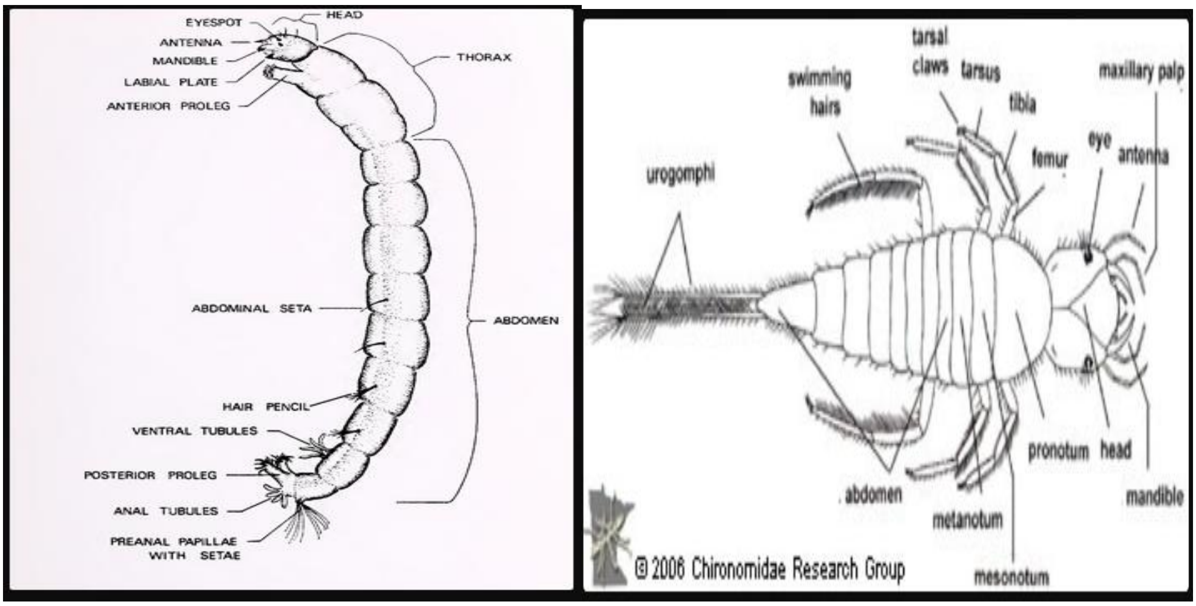


Figure 1: Lateral view of dipteran larvae and dorsal view of ephemeropteran larvae, respectively (Chironomidae Research Group, 2006).

Gastropods

Most diverse molluscan class with 80,000 known species and Only molluscan class to colonize land. Gastropods are a class of molluscs characterized by the presence of a single shell usually spiral like that of snails. Some have a horny or calcareous plate called an operculum which closes the opening of the shell when the animal is inside. Only one group has a really different shape, a shape of a small hat (Nathalie M, 2000). They are herbivorous or scavengers in fresh water. Some are substrate scrapers ingest microinvertebrate algae at the same time. Gastropods are also an intermediate host for several species of Trematodes such as Fasciola hepatica. In the prosobranchs, the sexes are separate except in Valvata and reproduction for some is oviparous, some viviparous and others ovoviparous like the Thiaridae which are also parthenogenesis (Henri *et al.,* 2010). In pulmonates there is hermaphroditism. Gastropods with an operculum (prosobranchs) have an average pollution tolerance, and those without an operculum (pulmonate) are considered tolerant (figure 2).

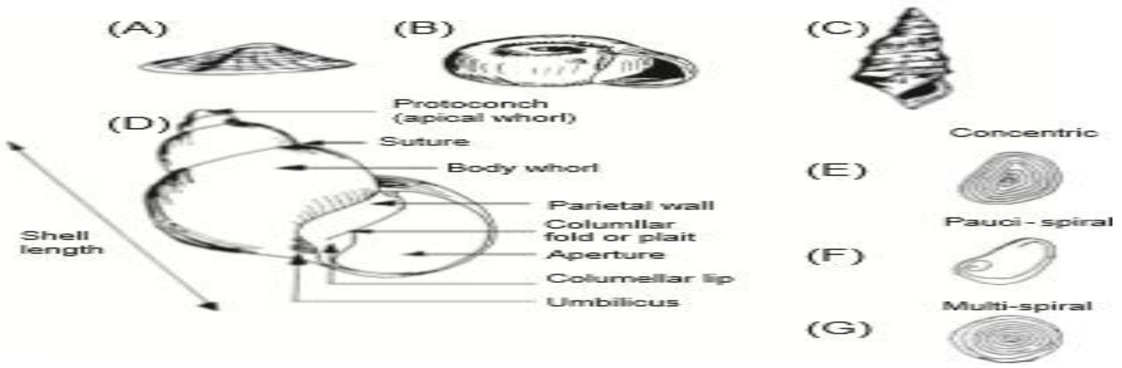


Figure 1: Basic anatomy of the shell, including shell architecture (conical, A; planospiral, B; spiral C, D), major features of the shell (D), and three types of opercula: (E) = concentric; (F) = paucispiral; and (G) = multispiral. (Sherman and Sherman, 1976).

Population dynamics is the study of spatio-temporal variations in the numerical strength of a population or its biomass (Lebrun, 1973). In other words, it is the study of the population as a functional system. Any spatio-temporal study involves the observation of the causes of numerical changes, migrations and antagonistic factors that contribute to maintaining a certain level of density at a given time. This dynamic integrates changes at the individual level, at the community level and at the ecosystem level.

In Africa, few studies have been carried out on the importance of macroinvertebrates on the diet of fish in a fish pond (Diguingue, 2001) and the evolution of the population of macroinvertebrates in a production pond in a natural environment (Serge, 1999). Other studies have been carried out on the use of macroinvertebrates to assess the biological quality of ponds and streams (Mbiye, 1997). In Cameroon, studies carried out in ponds focused mostly on zooplankton biodiversity and the variability of low-input fish farming (Dakwen, 2020) and other studies focused on the complementary supply of exogenous feed (Edwards, 1993; Pouomogne, 1994). The main objective of this study is to assess the biodiversity of macroinvertebrates in four fish ponds at the Obili Aquaculture Unit. The specific objectives are to measure the physico-chemical parameters of the fish ponds water, to identify the macroinvertebrates at the Obili Aquaculture unit, and bring out the correlation between the physicochemical parameters of the water and the distribution of macroinvertebrates in the ponds.

II.1 Materials and methods

II.1.1.1 Presentation of the study zone

This study was carried out at the Obili Aquaculture Unit in Obili, a locality within the Yaounde 6 Municipality, Mfoundi Division of the Centre Region in Cameroon. The geographical coordinates are 3°51’23.1’’N and 11°29’43.5’’E, with a mean depth of 750 meters. The Obili Aquaculture Unit was established by the Ministry of Livestock, Fisheries, and Animal Industries and is managed by the ministry's staff. The climate of the area corresponds to that of Yaounde, characterized by a tropical wet and dry climate: a long dry season from November to February; a long rainy season from March to October, with the heaviest rains typically occurring between August and September.

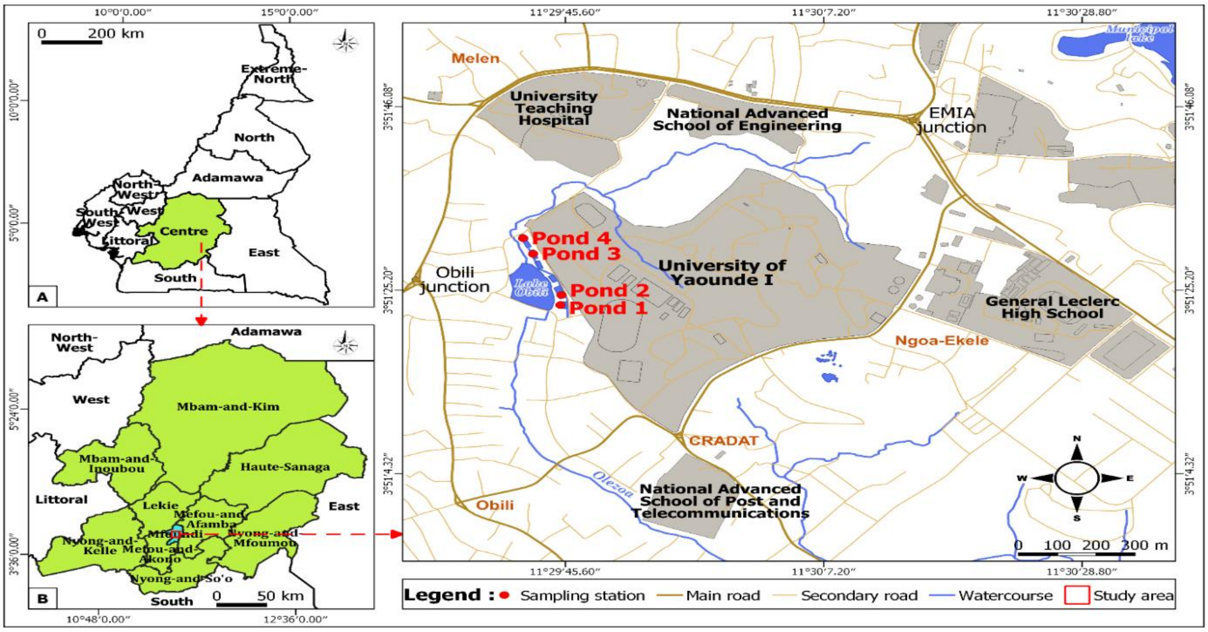


Figure 2: Location of the study area and site

II.1.2 Presentation of study site

The four fish ponds studied are located at the Obili Aquaculture Unit, adjacent to Lake Obili, one of the most well-known lakes in the city of Yaounde. Studies conducted on this lake have shown that it is hyper-eutrophic, which poses significant risks because the lake is used for aquaculture, tourism, and serves as a useful site for hydro-biological engineering research. The ponds are situated near the campus of the University of Yaounde 1, hospitals, farmlands, and are surrounded by residential houses. The water sources for Lake Obili and the ponds come from the Olezoa River and Lake Atemengue. These ponds are diversion ponds fed directly by gravity through a diversion canal, which serves as the main water feeder. Each pond has an inlet and an outlet. Only one pond among them was fully stocked. Each pond represents a station, making up four stations (Station 1, 2, 3, and 4).

II.1.3 Description of study stations

Pond 1, or Station 1, has a surface area of 150 m² and an average depth of 70 cm, located at geographical coordinates 03°51.394'N and 11°29.745'E, with an altitude of 705 meters. An extensive fish farming system, which is the least intensive and least managed type, is practiced here. This system involves large ponds with stocking densities limited to less than 5,000 fish per hectare. No supplemental feeding or fertilization is provided, and the fish depend solely on natural food sources. During the research period, this pond was partially drained and cleared once in August. Its surface was partially covered with macrophytes such as Cyperaceae and Nympheaceae. Fish species in the pond include tilapia (*Oreochromis niloticus*) and African catfish (*Clarias gariepinus*), with tilapia outnumbering catfish by approximately four to one. The ponds in the unit are connected in parallel (Figure 4).

Figure 3 : Station 1 before(A) and after(B) cleaning

Pond 2, or Station 2, has a surface area of 140 m² and an average depth of 100 cm, located at geographical coordinates 3°51.408'N and 11°29.752'E, with an altitude of 702 meters. Similar to Station 1, an extensive fish farming system is practiced here, which is the least managed form of fish farming, involving minimal care. This system includes large ponds with a stocking density limited to less than 5,000 fish per hectare. No supplemental feeding or fertilization is provided; fish depend solely on natural food sources. During the research period, this pond was partially drained and cleared once in August. The pond's surface was partially covered with macrophytes such as those from the Cyperaceae and Nympheaceae families. Fish species present include tilapia (*Oreochromis niloticus*) and African catfish (*Clarias gariepinus*), with tilapia outnumbering catfish by approximately four to one. At the unit, the ponds are connected in parallel (Figure 5).

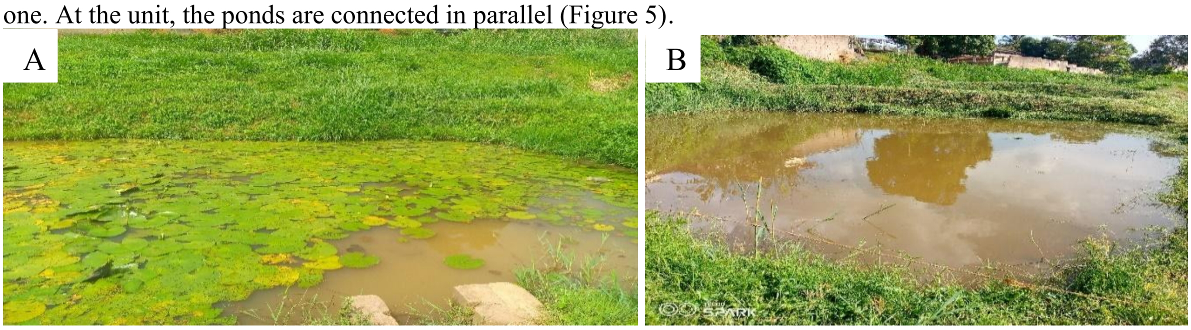


Figure 4 : Station 2 before(A) and after(B) cleaning

Pond 3, or Station 3, has a surface area of 300 m² and an average depth of 100 cm, located at geographical coordinates 3°51.489'N and 11°29.715'E, with an altitude of 697 meters. Unlike Stations 1 and 2, a semi-intensive fish farming system is practiced at this station. This system involves fertilizing the pond with organic fertilizers in varying proportions to enhance natural productivity. Exogenous feeding with cereal bran and other locally available feeds is also applied to supplement pond productivity. Therefore, fish here do not rely solely on natural food sources. During the research period, this pond was partially drained and cleared twice, both times in August.

The pond surface was partially covered with macrophytes such as those from the Cyperaceae and Nympheaceae families. Fish species present include tilapia (*Oreochromis niloticus*) and African catfish (*Clarias gariepinus*), with tilapia outnumbering catfish by approximately four to one. At the aquaculture unit, the ponds are connected in parallel. Pond 3 is approximately 300 meters from Stations 1 and 2 but only about two meters from Station 4 (Figure 6).

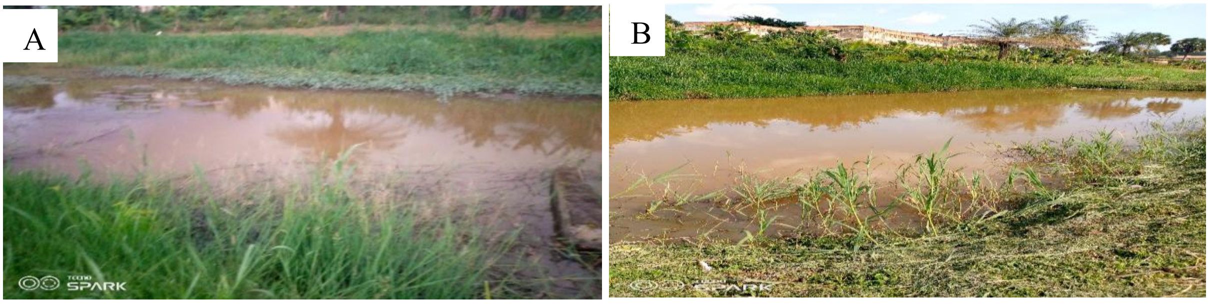


Figure 5 : Station 3 before(A) and after(B) cleaning

Pond 4, or Station 4, has a surface area of 400 m² and an average depth of 100 cm, located at geographical coordinates 3°51.523'N and 11°29.699'E, with an altitude of 689 meters. Similar to Station 3, a semi-intensive fish farming system is practiced here, where the pond is fertilized with organic fertilizers in varying amounts to enhance natural productivity. Exogenous feeding with cereal bran and other locally available feeds is regularly applied to supplement pond productivity. In this station, African catfish (*Clarias gariepinus*) is the only stocked species, stocked at a density of 20 fingerlings per square meter. Catfish are primarily omnivorous bottom feeders that feed mainly at night. Their diet includes aquatic plants and seeds, fish, mollusks, insects and their larvae, and crustaceans. During the research period, several fish deaths were recorded, attributed to over-fertilization. The pond was consistently kept clean and surrounded by iron rods to prevent predators and theft (Figure 7).

Figure 6 : Station 4 before(A) and after(B) cleaning

The required materials used are shown in the table 3 below:

Table 1: Materials for sampling of macroinvertebrates in the ponds.

Field Sampling Equipment		Lab Equipment	
	Aquatic D-frame net		Sieve to rinse sample
	Waders		Sorting pans
	Preservative		Petri dish
	Dishpan for sorting		2 Wash bottles: 1 water,1with 80% alcohol
	Sample bottles for storage		Data sheets
	Data sheets		Tweezers
	Labels for sample bottles		Glass vials to store samples
	Clip boards		Labels for vials written in pencil
	Tape measure		Taxonomic keys
	Wash bottle with water for rinsing		
	Tweezers		

II.2 Methodology

II.2.1 Study period

This study was conducted from May 2022 to November 2022 and consisted of two phases. The first phase, lasting one month in May 2022, involved prospecting the site to gain a better understanding of the ponds and to select appropriate sampling stations. The second phase, from June 2022 to November 2022, involved monthly sampling over six months for the collection of physico-chemical and biological data from the four fish ponds.

II.2.2 chemical analyses

Water samples for chemical analysis were collected using 250 ml and 1000 ml double-capped polyethylene bottles. Care was taken to avoid introducing air bubbles by filling the bottles to the brim. The samples were then stored in a cooler with dry ice and transported to the laboratory. The chemical parameters analyzed in this study were selected based on their direct influence on the development of cultured fish or their impact on the pond's food web. These parameters were measured using standard analytical methods as described by Rodier et al. (2009).

II.2.3.5. Dissolved Oxygen and Oxidizability

Dissolved oxygen (DO) in the water was measured in situ using a Lutron DO-5509 oxygen meter, with results expressed in mg/L. Oxidizability was determined by volumetric analysis. In this procedure, 2 ml of monosodium carbonate was added to 200 ml of the water sample in an Erlenmeyer flask, then boiled on a hot plate for 20 minutes. At the onset of boiling, 20 ml of N/80 potassium permanganate (KMnO4) was added. After boiling, the solution was cooled with tap water. Following cooling, 5 ml of 25% sulfuric acid and 20 ml of Mohr's salt were added.. The resulting colorless solution was titrated with N/80 KMnO4 until a persistent pink color appeared. A control test was performed using distilled water instead of the sample. Oxidizability (mg/L of O2) was calculated using the formula:

Oxidizability (mg/L of O_2) = [(Control burette reading drop– Sample burette reading)/2]×3.95

II.2.3.6 Forms of nitrogen and orthophosphates

Concentrations of orthophosphate, nitrate, and nitrite were analyzed in the laboratory using a DR/2010 HACH LANGE spectrophotometer. Concentrations were measured using the Nessler method on 10 ml water samples, with absorbance readings taken at a wavelength of 425 nm. Reagents Nitraver III and Phosver were used by adding 10 ml of each to the samples. Nitrite concentrations (mg/L NO2-), nitrate concentrations (mg/L NO3-), and orthophosphate concentrations (mg/L PO4^3-) were determined at wavelengths of 507 nm, 500 nm, and 430 nm respectively.

II.2.3.7 Alkali Metric Titration (AMT)

Alkalinity was determined volumetrically in the laboratory. A 50 ml water sample was placed in a beaker, followed by the addition of 2 to 3 drops of methyl bromocresol green-red indicator. The blue solution was titrated with N/50 sulfuric acid (H2SO4) until the endpoint was reached. Alkalinity (mg/L HCO3-) was calculated using the formula: Alkalinity (in mg/L of HCO_3^-) = burette reading x 20

II.2.3.8 Dissolved Carbon Dioxide (CO_2)

The concentration of dissolved CO2 was determined volumetrically. On-site, 180 ml of the water sample was placed into a 200 ml volumetric flask, to which 20 ml of N/20 sodium hydroxide

(NaOH) and 2 to 3 drops of phenolphthalein indicator were added. The resulting pink-colored mixture was transferred to a double-capped 250 ml polyethylene bottle. A 50 ml aliquot of this fixed sample was then titrated with N/10 hydrochloric acid (HCl) until the pink color disappeared. A control titration was performed using distilled water instead of the sample. The dissolved CO2 concentration (mg/L) was calculated using the formula:

Dissolved CO_2 (mg/L) = (first burette reading – second burette reading) × 17.6

II.2.3.9 Sampling of biological specimens

Benthic macroinvertebrates were collected monthly using a D-net. The D-net was first held in the air to allow it to fully unfold before sampling. Sampling followed a multi-habitat approach as described by Stark et al. (2001). During each sampling event, the net was submerged in the water and moved into vegetated banks or around submerged objects such as snags, logs, or roots, heading towards the bottom. The net was then bounced into the sediments ten times before being slowly lifted through the water to the surface, ensuring no organisms escaped. The contents at the bottom of the net were carefully overturned into a bucket. Organisms caught in the mesh were collected using forceps and fixed in 10% formalin on site. In the laboratory, samples were transferred to 70% ethanol and identified with the aid of an optical microscope and identification keys from Nathalie (2000), Henri et al. (2010), and Moisan (2010).

II.3 Data analysis and statistical tests

II.3.1 Kruskal-Wallis and Mann-Whitney H-test

Kruskal-Wallis H test was used to assess significant differences in data across ponds and months, while the Mann-Whitney test allowed pairwise comparison of densities, both performed using SPSS version 16.0.

II.3.2 Spearman rank correlation coefficient

This correlation has the formula: $r = 1 - \frac{6 \times \sum \left(Y_i' - X_i'\right)}{n\left(n^2 - 1\right)}$ where

X'= rank of x; Y'= rank of y; n = number of values of x with n < 10; r = Spearman correlation.

II.3.3 Sörensen's similarity coefficient

The Sörensen similarity coefficient make it possible to establish the degrees of resemblance of the different families of invertebrates between the sampling ponds, according to the following formula:$\boldsymbol{S} = \frac{\boldsymbol{2c}}{\boldsymbol{a+b}} \times \boldsymbol{100}$ where

S: similarity coefficient; n, a: number of taxa present in the first station; b: number of taxa present in the second station; c: number of taxa common to the two stations.

II.3.4 Biocenotic indices

II.3.5 Diversity index (H') of Shannon and Weaver

This index makes it possible to make an approximate comparison of the taxonomic diversity of the population of benthic invertebrates. It is independent of the size of the samples and takes into account both the specific richness and the relative abundance of each species, thus making it possible to characterize the balance of the population of an ecosystem. It is given by the formula:ilog2Pi$\boldsymbol{H'} = -\sum_{i=1}^{s} \boldsymbol{P}$,where *Pi*= proportional abundance or percentage of importance of species i; *pi = ni /N*; S = total number of species; *neither*= number of individuals of species i in the sample; N = total number of individuals of all species in the sample. The value of the index varies from 0 (a single species, or a species dominating over the others) to log2 S (when all the species have the same abundance).

II.3.6 Evenness index (J) of Piélou

The Piélou evenness index was developed to account for the relative abundance of each taxon. We can calculate the evenness from the maximum equal distribution or diversity (H'max) which corresponds to the case where all the species would be represented by the same number of individuals. It makes it possible to measure the distribution of individuals within species, independently of specific richness. It is obtained according to the formula: $\mathbf{J} = \frac{\mathbf{H'}}{\mathbf{log^2 S}}$where H'= Shannon index and Weaver; S = Specific richness; J = Pielou index. When J tends to 1, the population is made up of species with similar abundances. J tends to 0, a single species dominates the stand.

II.3.7 Hilsenhoff Index or Family Biotic Index (FBI)

It is calculated by multiplying the number in each family by the tolerance value for that family, summing the products, and dividing by the total arthropods in the sample (Hilsenhoff 1988): $\mathbf{FBI} = \sum \boldsymbol{XiTi/n}$ where Xi is the number of individuals of the i^e taxon; *Ti* the tolerance of the i^e taxon and n the number of individuals that made up the sample.

II.3.8 Global biological Normalized Index(GBNI)

This index is calculated in three stages. The first stage involves determining the "taxonomic variety class" (VT), which is based on the number of taxa collected from a sample. Out of the 152 taxa potentially present, the VT corresponds to the total taxa recorded, even those represented by a single individual. Fourteen variety classes are defined according to the taxa count. The second stage involves determining the Faunal Indicator Group (IBGN), which considers only indicator taxa represented by at least three individuals (or ten,

depending on the taxa). The IBGN is identified by examining the taxa list from highest to lowest pollutant sensitivity, selecting the taxon representing the greatest sensitivity in the entire sample from the station studied. Finally, the GBNI is calculated using the formula:
IBGN = Indicator faunal group + (variety class - 1), with IBGN ≤ 21.

GI = indicator group and faunal; VT = taxonomic variety of the sample.

II.3.9 Principal Component Analysis (PCA)

In this study, a PCA was carried out using the XLSTAT software to characterize the sampling ponds on the basis of all the physicochemical parameters measured as well as the biological affinities to different ponds throughout the study.

Results and Discussion

III.1.1.4. Total Dissolved Solids (TDS) and Alkalinity

Total Dissolved Solids (TDS) recorded a high value of 482 mg/L in pond 2 during September and a low value of 94 mg/L in both pond 1 and pond 3 in July, with an overall average of 429.20 ± 106.31 mg/L (Fig. 8A). The Kruskal-Wallis H-test indicated that spatio-temporal variations in TDS were not statistically significant ($P > 0.05$). Alkalinity levels ranged from 22 mg/L in pond 1 in November to 60 mg/L in pond 3 in June, with an average value of 33.95 ± 11.64 mg/L (Fig. 8B). Similarly, the Kruskal-Wallis H-test revealed no significant variation in alkalinity across ponds and sampling periods ($P > 0.05$) (Figs. 8A and 8B).

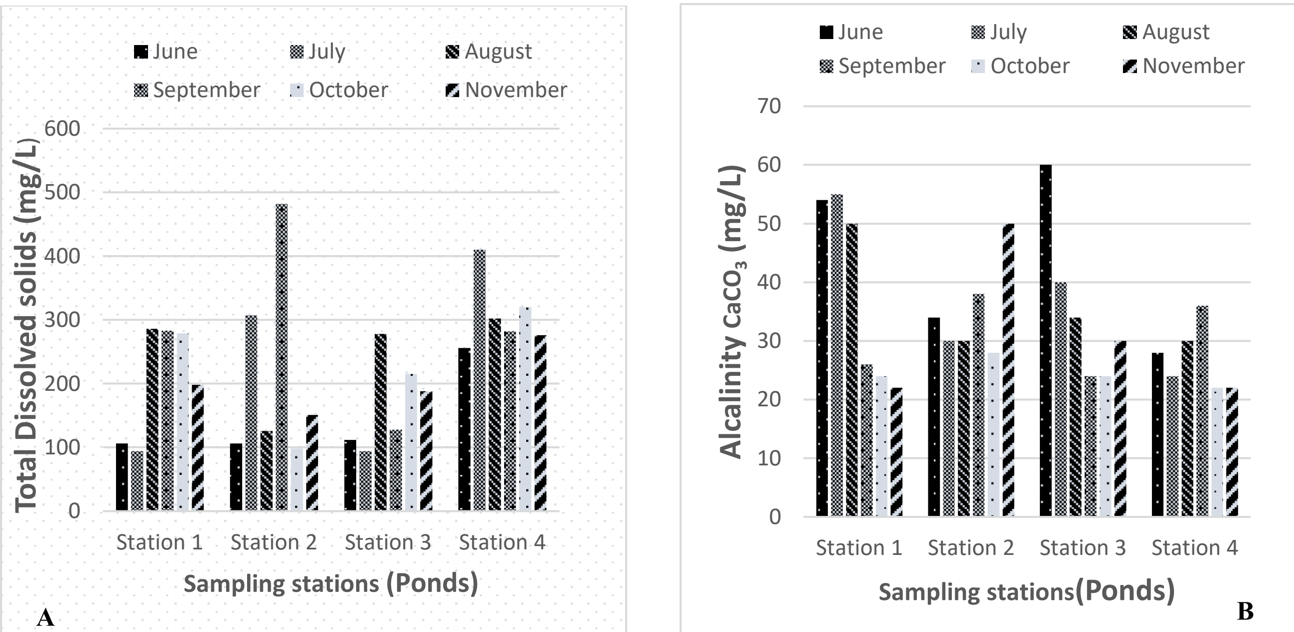


Figure 7 : Spatial and temporal variations of TDS (A), Alkalinity (B) in the studied ponds.

III.1.1.5. Dissolved Oxygen, Oxidizability and Dissolved CO_2

During the study, the lowest dissolved oxygen (DO) value of 25% was recorded in pond 4 in June, while the highest DO value of 49% was observed in pond 2 in October. The average dissolved oxygen concentration was 38.06 ± 6.52% (Fig. 9A). Spatial and temporal analysis using the Kruskal-Wallis H-test indicated no significant variations in dissolved oxygen ($p > 0.05$).

Oxidizability values ranged from a minimum of 3.5 mg/L in pond 3 in August to a maximum of 17.06 mg/L in pond 4 in June, with an average of 7.99 ± 3.24 mg/L (Fig. 9B). Spatial variation in oxidizability was significant ($P < 0.05$). The Mann-Whitney U test revealed similar oxidizability levels between ponds 3 and 4, although temporal variation was not significant.

Dissolved carbon dioxide (CO2) concentrations varied between 5.01 mg/L in pond 2 during July and 36.96 mg/L in ponds 1 and 2 during June and September, respectively (Fig. 9C), with an average of 25.55 ± 8.01 mg/L. The Kruskal-Wallis H-test showed no significant spatio-temporal variations in dissolved CO2 ($p > 0.05$) (Figs. 9A, 9B, and 9C).

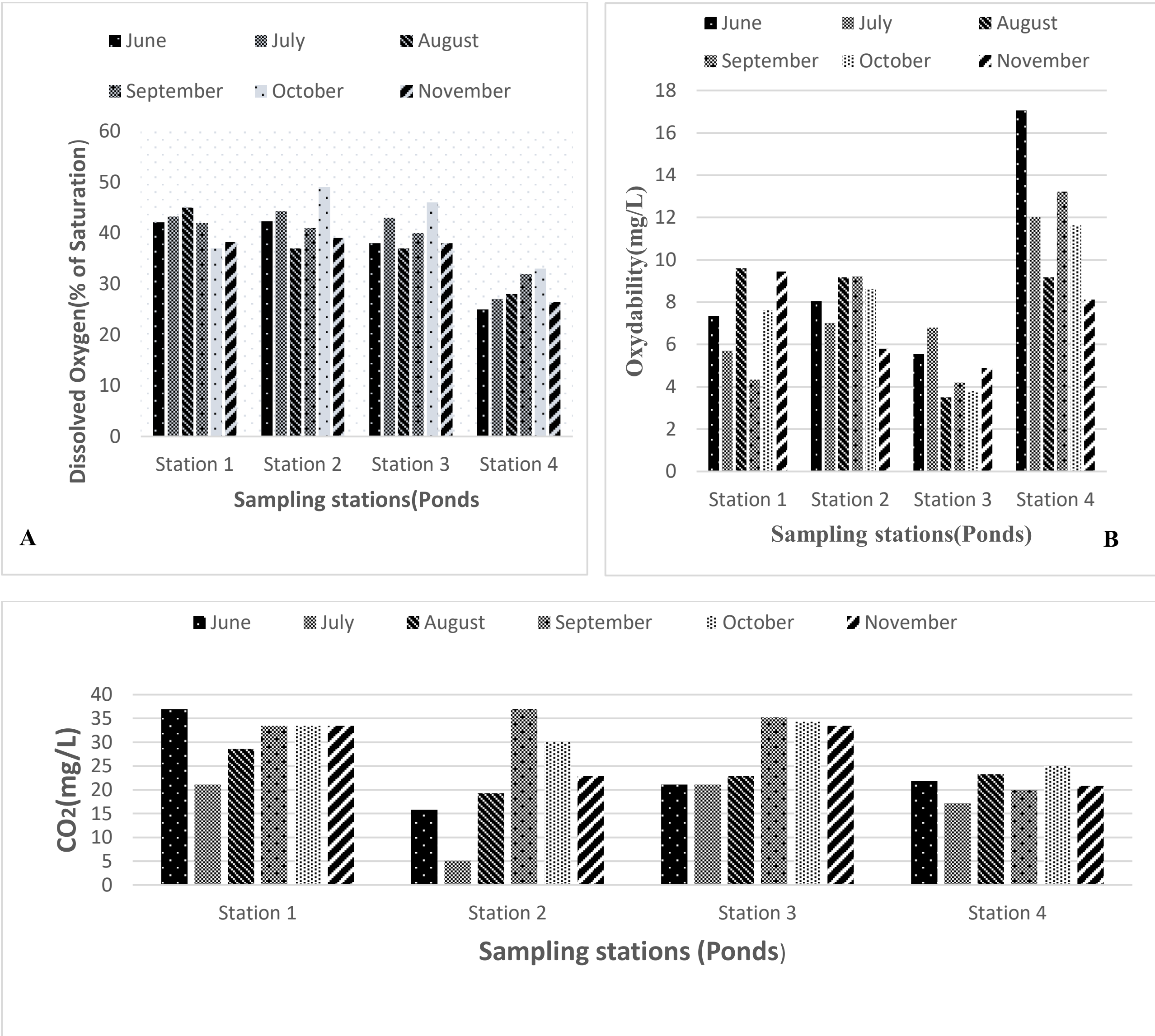


Figure 8 : Spatial and temporal variations of dissolved oxygen (A), oxidizability (B) and dissolved CO_2 (C) in the studied ponds.

III.1.1.6 Forms of Nitrogen

The lowest nitrite values (0 mg/L) were recorded in pond 1 during July, August, and September; pond 2 in June, August, and September; pond 3 in August; and pond 4 in August and September. The highest nitrite value of 0.04 mg/L was observed in October for both pond 1 and pond 4 (Fig. 10A). The mean nitrite concentration was 0.012 ± 0.013 mg/L. Spatial and temporal analyses using the Kruskal-Wallis H-test indicated no significant variations in nitrite levels ($p > 0.05$).

Regarding nitrate, the highest concentration of 0.48 mg/L was recorded in pond 1 in July, while the lowest concentration of 0 mg/L was noted in pond 1 (September, November), pond 2 (September), and pond 3 (July, September, November) (Fig. 10B). The average nitrate concentration was 0.18 ± 0.14 mg/L. Kruskal-Wallis H-test results showed no significant spatial or temporal variation in nitrate concentrations ($p > 0.05$) (Figs. 10A and 10B).

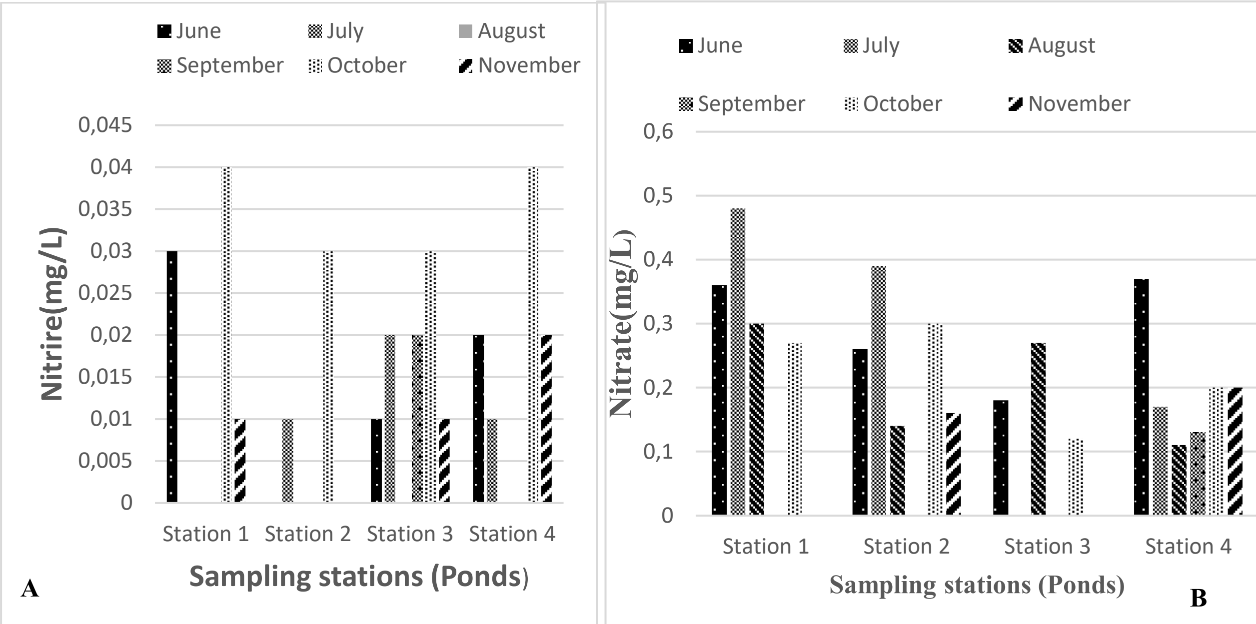


Figure 9 : Spatial and temporal variations of Nitrite (B) and Nitrate in the studied ponds.

III.1.1.7. Orthophosphates

The results obtained from the ponds indicate that a high phosphate ion concentration (1.4 mg/L PO4^3-) was recorded in pond 3 in July, while a concentration of zero (0 mg/L) was observed in pond 1 in August (Fig. 11). The average phosphate concentration across all ponds and sampling periods was 0.44 ± 0.34 mg/L. Spatial and temporal analysis using the Kruskal-Wallis H-test revealed no significant variations in orthophosphate concentrations ($p > 0.05$).

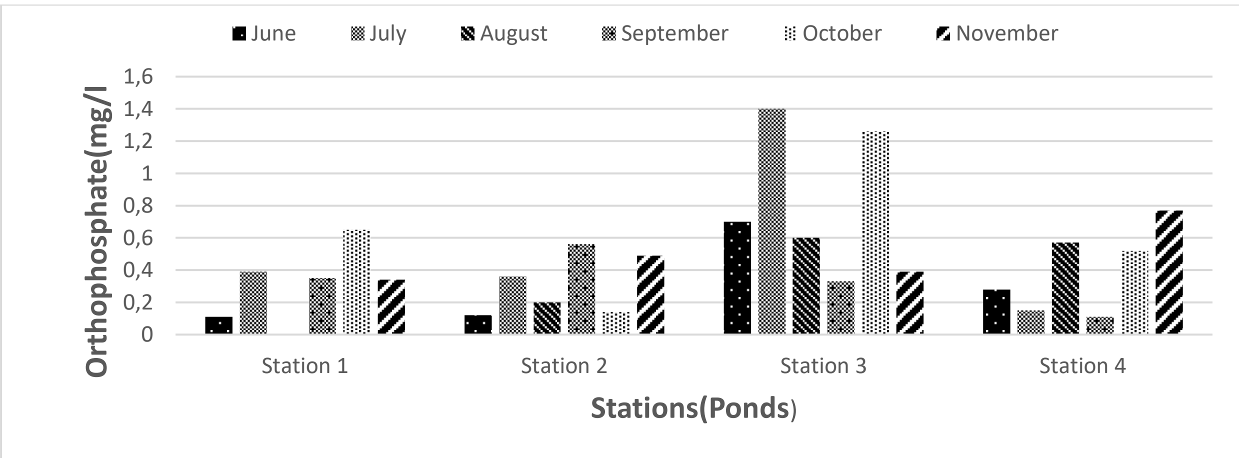


Figure 10 : Spatial and temporal variations of Orthophosphate in the studied fish ponds.

III.1.2. Macroinvertebrates

III.1.2.1. Taxonomic richness and relative abundance

During the study period, a total of 532 individuals were identified, divided into two phyla: Arthropods (51.7%) and Molluscs (48.3%). These organisms belonged to two classes, six orders, and ten families (Fig. 12). The class Insecta was predominantly represented, accounting for 51.7% relative abundance, comprising four orders and eight families. The class Gastropoda represented 48.3% relative abundance, with two orders and two families (Fig. 12A). Among the ten orders identified, Mesogastropoda was the most abundant, with a relative abundance of 44.73%, followed by Odonata at 33.57%. Hemiptera, Diptera, Basommatophora, and Coleoptera had relative abundances of 9.39%, 6.01%, 3.57%, and 2.63%, respectively. Of the ten families identified, four belonged to the order Odonata, two to Hemiptera, and one each to Basommatophora, Mesogastropoda, Coleoptera, and Diptera (Fig. 12).

family (Fig. 16).

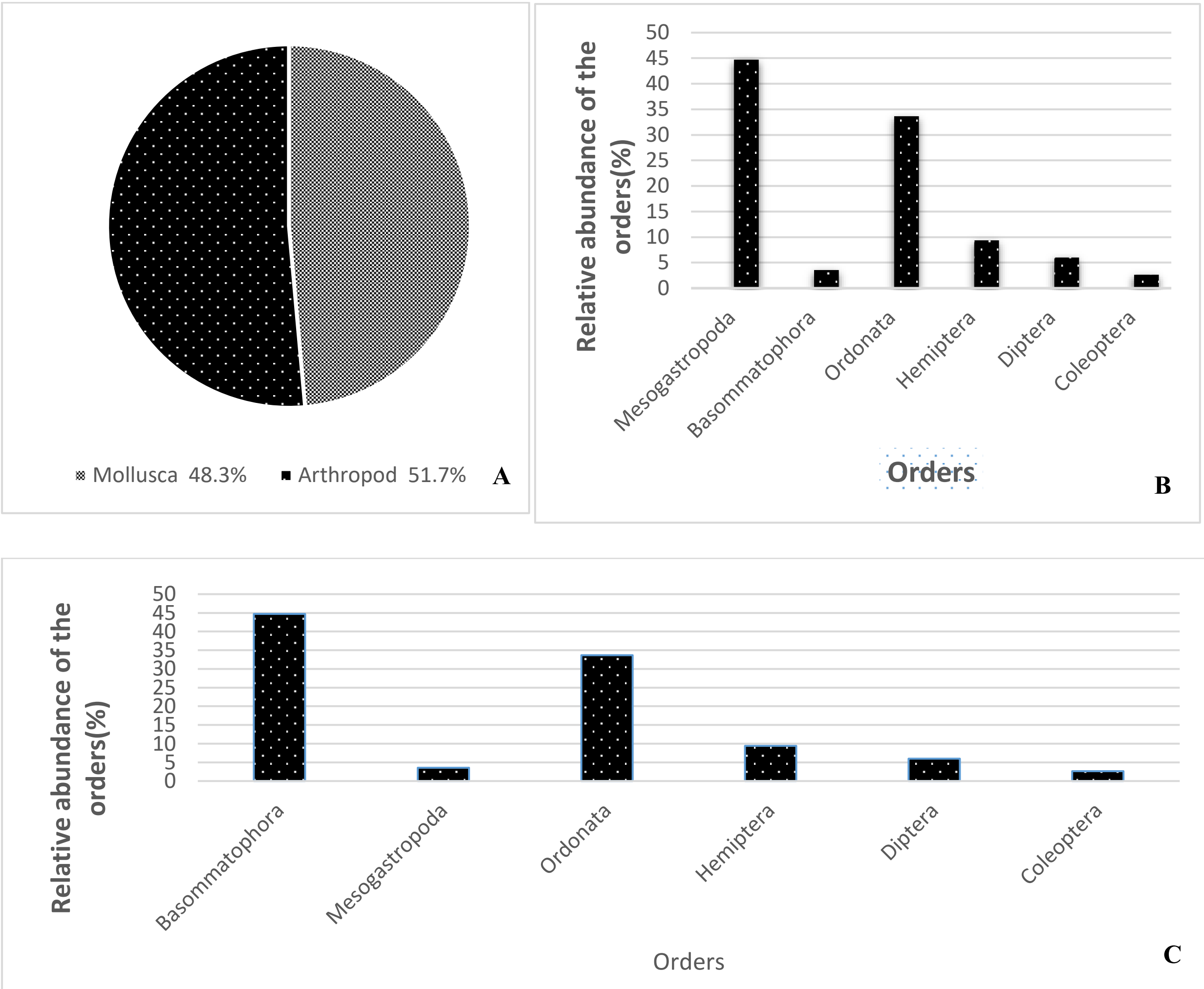


Figure 11 : Relative abundance of phyla (A), orders (B), and families by order (C) of benthic macroinvertebrates in the surveyed fish ponds.

III.1.2.2. Spatial and temporal variation in the total abundance of benthic macroinvertebrates

Figure 13(A) shows the total abundance profile of benthic macroinvertebrates collected from the ponds during the study period. A total of 230, 139, 100, and 63 individuals were identified in ponds 1, 2, 3, and 4, respectively (Table 2). The Kruskal-Wallis H-test indicates a significant spatial difference ($p < 0.05$) in abundance, while the Mann-Whitney U-test shows similarity in abundance among the families Calopterygidae, Chironomidae, Lymnaeidae, and Thiaridae.

Temporally, the total abundance of benthic macroinvertebrates declined sharply from the start of the study in June, with a peak of 163 individuals, to November, with a minimum of 36 individuals (6.7%). The monthly average abundance was 86.66 ± 47.12 individuals (Fig. 13B). However, no significant temporal variation was observed between the months ($p > 0.05$) (Figs. 13A and 13B).

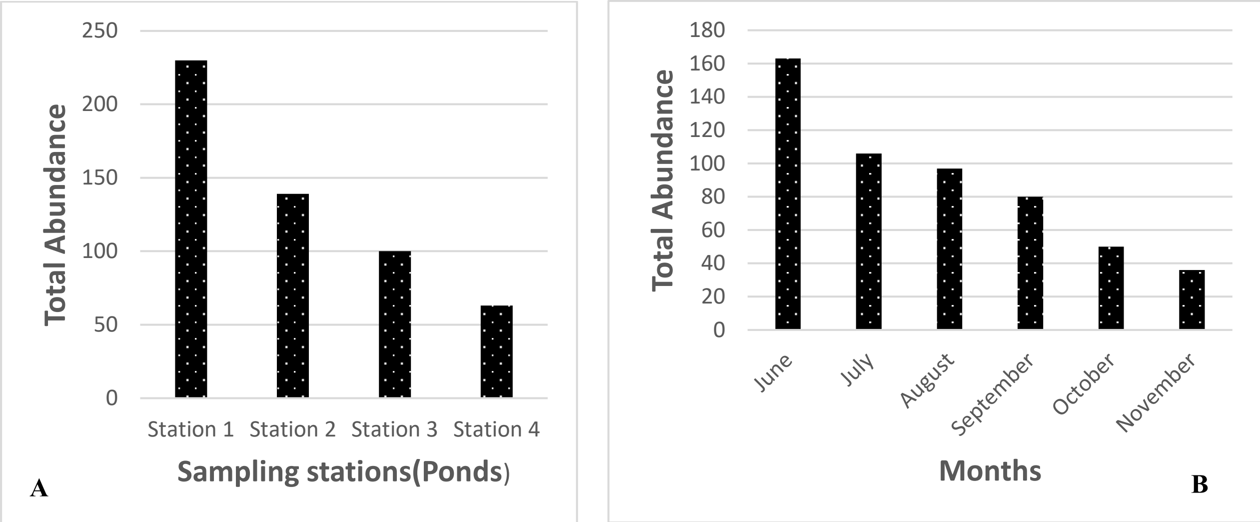


Figure 12 : Spatial (A) and temporal (B) variations in total BMI abundance in the studied ponds

Table 2: Abundance of the different benthic macroinvertebrate taxa collected in each fish pond studied.

Phyla	Classes	Orders	Families	Station 1	Station 2	Station 3	Station 4
Arthropods	Insects	Ordonata	Lestidae	57	43	32	16
			Cordulegasteridae	25	0	0	0
			Libellulidae	2	1	0	0
			Caloptrygidae	0	0	3	0
		Diptera	Chironomidae	11	10	4	7
		Hemiptera	Belostomatidae	15	9	3	3
			Nepidae	5	3	10	2
		Coleoptera	Dytiscidae	0	14	0	0
Molluscs	Gastropods	Basommatophora	Thiaridae	106	55	42	35
		Mesogastropoda	Lymnaidae	9	4	6	0
Total abundance of taxa per pond				230	139	100	63
Relative abundance of taxa per fish pond (%)				43.2	26.1	18.8	11.8
Total taxa abundance for the study period				532			

III.1.2.3. Spatio-temporal variation in taxonomic abundance

The total number of macroinvertebrate families identified across the ponds was ten. Stations 1 and 2 each harbored eight families, while Stations 3 and 4 had seven and five families respectively. Their relative abundances were 43.2%, 26.1%, 18.8%, and 11.8% correspondingly (Fig. 14A). The family Thiaridae was predominant with a relative abundance of 44.74%. This family, belonging to the class Gastropoda, is known for its adaptability and ability to survive in varied aquatic environments, often tolerating low oxygen levels due to lung-like organs. It was followed by Lestidae (27.81%), Chironomidae (6.01%), Belostomatidae (5.63%), Cordulegasteridae (4.70%), Nepidae (3.75%), Lymnaeidae (3.57%), Dytiscidae (2.63%), Libellulidae (0.56%), and Calopterygidae (0.56%). Temporally, the highest family richness was observed in July with nine families, while October recorded the lowest richness with five families. June and August had eight families each, and both September and November had six families (Figs. 14A and 14B).

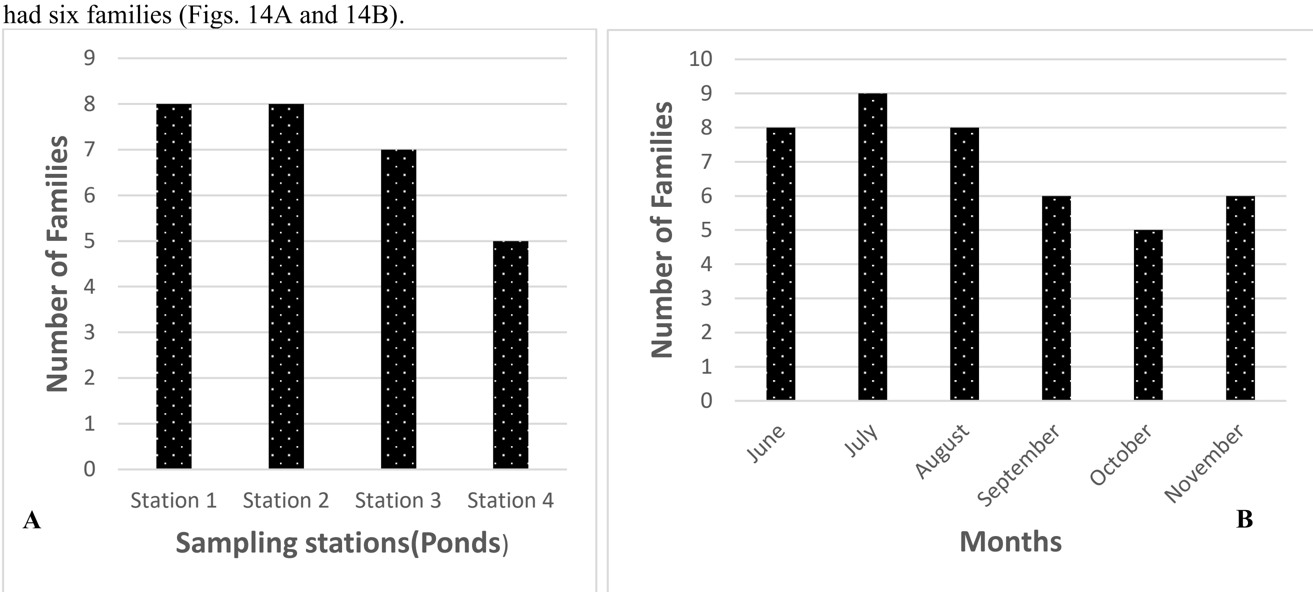


Figure 13 : Spatial (A) and temporal (B) variation in the number of families harvested in the sampled fish ponds

III.1.3 Biocenotic indices

III.1.3.1 Shannon and Weaver indices and Piélou equitability

Spatially, the Shannon-Wiener diversity index (***H*´** *(*ranged from 1.173 bits per individual in pond 4 to 1.467 bits per individual in pond 3. Similarly, Piélou's evenness index varied slightly, from 0.729 in pond 4 to 0.754 in pond 3 (Fig. 15A). Temporally, the highest values for these indices were observed in November (1.794 bits per individual for ***H*´** *(*and August (0.853 for evenness), while their lowest values occurred in August (1.774 bits per individual for ***H*´** *(*and November (0.443 for evenness), respectively (Fig. 15B). Both spatial and temporal analyses using the Kruskal-Wallis test indicated no significant differences in these indices ($p > 0.05$).

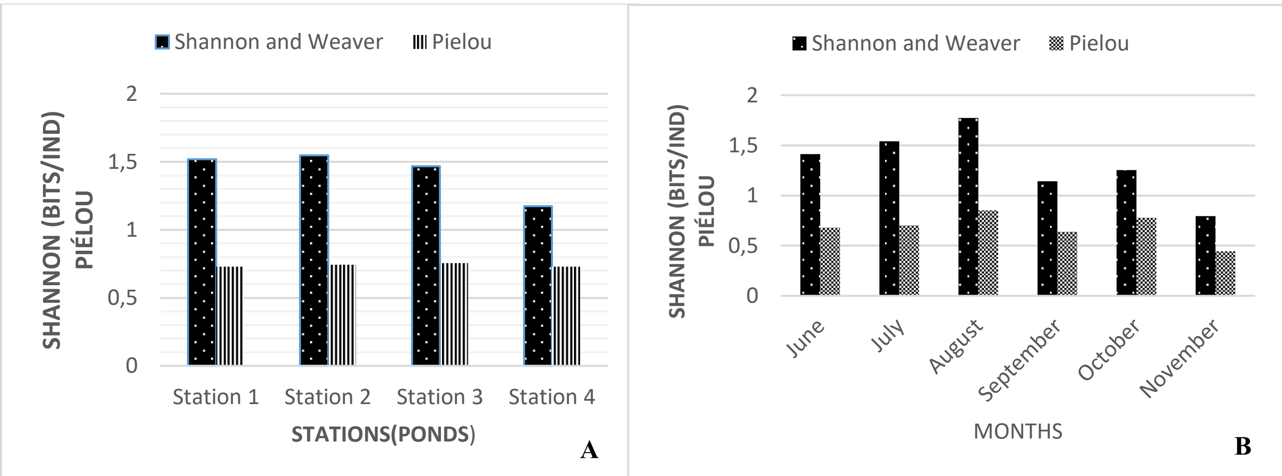


Figure 14 : Spatial (A) and temporal (B) variation of the Shannon and Weaver index and the Piélou equitability index

III.1.3.2 Sörensen similarity index

The calculation of Sørensen's similarity index indicates a high faunal similarity between the ponds. The greatest similarity was observed between pond 1 and pond 2, with an index value of 87.5% (Table 3).

Table 3: Sorensen's similarity index values between the different fish ponds studied.

Stations(S)	S1 and S2	S1 and S3	S1 and S4	S2 and S3	S2 and S4	S3 and S4
Sörensen's similarity index(%)	87.5	81.7	76.9	80.0	66.6	83.3

III.1.3.3. Hilsenhoff Index

The Hilsenhoff Biotic Index (HBI) values calculated for ponds 1, 2, 3, and 4 were 3.80, 4.02, 3.62, and 4.52 respectively (Table 4).

Table 4: Hilsenhoff Index values in the different fish ponds studied.

Stations	Pond 1	Pond 2	Pond 3	Pond 4
Hilsenhoff Index	6.49	6.80	7.00	7.00
Quality	Rather poor: Substantial organic pollution	Poor: Very substantial organic pollution	Poor: Very substantial organic pollution	Poor: Very substantial organic pollution

III.1.3.4 Global biological Normalized Index (GBNI)

The calculation of the Global Biological Normalized Index in ponds 1, 2, 3 and 4 (Table. 5) gave the respective values of 7, 5, 4 and 3 revealing poor water quality in the different fish ponds studied.

Table 5: GBNI values and their interpretation

Stations (Ponds)	Pond 1	Pond 3	Pond 3	Pond 4
Taxonomic Variety(TV)	9 to 7	9 to 7	9 to 7	6 to 4
Class Variety	3	3	3	2
Faunistic Indicator (GI)	5	3	2	2
GBNI Value	7	5	4	3
Colour	Orange	Orange	Red	Red
Quality	Bad	Bad	Very Bad	Very Bad

III.1.4 Affinities between physico-chemical and biological parameters

III.1.4.1 Principal Component Analysis (PCA)

The projection of the physico-chemical and biological data onto the factorial plane defined by the first two axes of the Principal Component Analysis (PCA) reveals relationships between the environmental parameters, macroinvertebrate families, and the fish ponds studied (Fig. 16). Together, these two principal components explain 75.73% of the total variance, with the first axis (F1) accounting for 42.79% and the second axis (F2) for 32.94%. The data were grouped into three clusters: Pond 1 was associated with high abundances of several characteristic families including Lestidae, Belostomatidae, Lymnaeidae, Thiaridae, Libellulidae, Cordulegasteridae, and Chironomidae, which correlated strongly with dissolved oxygen, pH, carbon dioxide, nitrate, and suspended particulate matter (MES). Cluster 2, comprising ponds 2 and 4, was linked to the Dytiscidae family, which showed affinities with color, oxidizability, turbidity, total dissolved solids (TDS), and conductivity. Finally, Cluster 3, representing pond 3, was characterized by high abundances of Nepidae and Calopterygidae families, associated with nitrite, temperature, and phosphate levels.

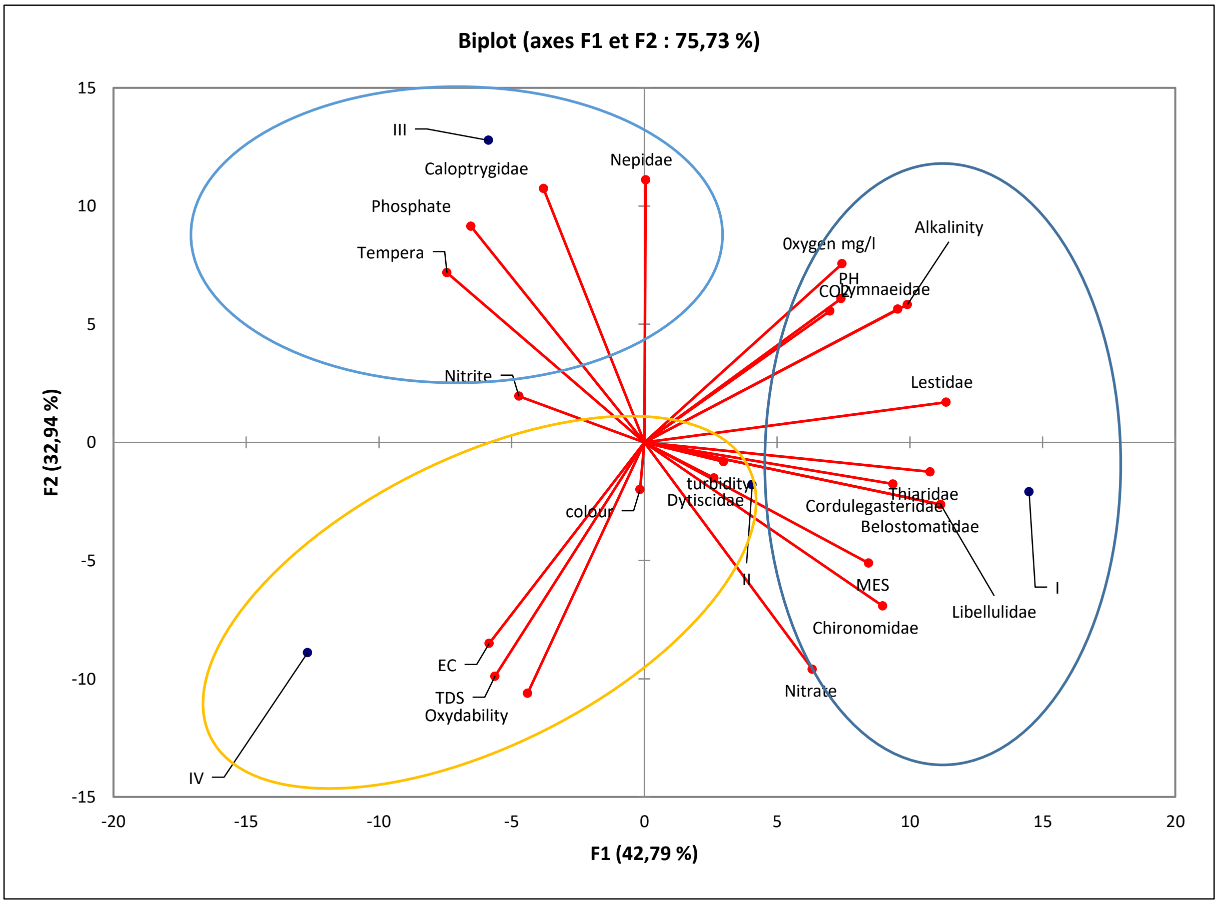


Figure 15 : PCA values grouping affinities between invertebrate families and physicochemical parameters in the studied fish ponds.

III.1.5 Correlations between the different parameters measured

III.1.5.1 Correlation between the physico-chemical data of the studied ponds

The Spearman rank "r" correlation test revealed correlations between pH and nitrite ($r=-0.415$; $p=0.044$), pH and turbidity ($r=-0.546$; $p=0.006$), pH and colour ($r=-0.509$; $p=0.011$), total dissolved solid and pH ($r=-0.554$; $p=0.005$), oxygen and oxydability ($r=-0.465$; $p=0.022$), alkalinity and nitrate ($r=-0.490$; $p=0.015$) and finally phosphate and oxydability ($r= -0.454$; $p=0.026$).

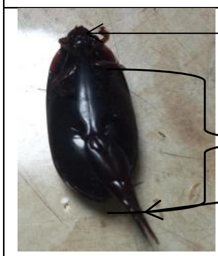
III.1.5.2. Influence of biotic and abiotic factors on the dynamics of invertebrates in the studied pond

The Spearman rank "r" correlation test revealed significant correlations between certain physico-chemical and biological parameters throughout the study period. The Lymnaeidae family was significantly and positively correlated with pH ($r = 0.440$; $p = 0.032$), oxygen ($r=0.519$; $p=0.009$), and alkalinity ($r=0.416$; $p=0.043$). Alkalinity was significantly and positively correlated with the family Belostomatidae ($r = 0.460$; $p = 0.024$). The Dytiscidae family was significant and negative correlated with carbon dioxide ($r = -0.479$; $p = 0.018$), Nepidae and oxydability ($r = -0.434$; $p = 0.034$), Lestidae and temperature ($r = -0.479$; $p = 0.018$). and finally the family Cordulgasteridae was also negatively correlated with temperature ($r= -0.473$; $p=0.020$).

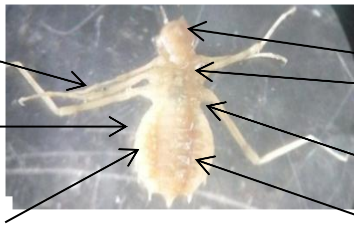
III.1.6 Some macroinvertebrates collected in the fish ponds studied

Dorsal view of a Nepidae

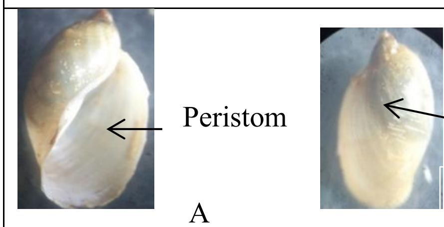
Dorsal view A, ventral view B of a Belostomatidae



Ventral view of a Dytiscidae

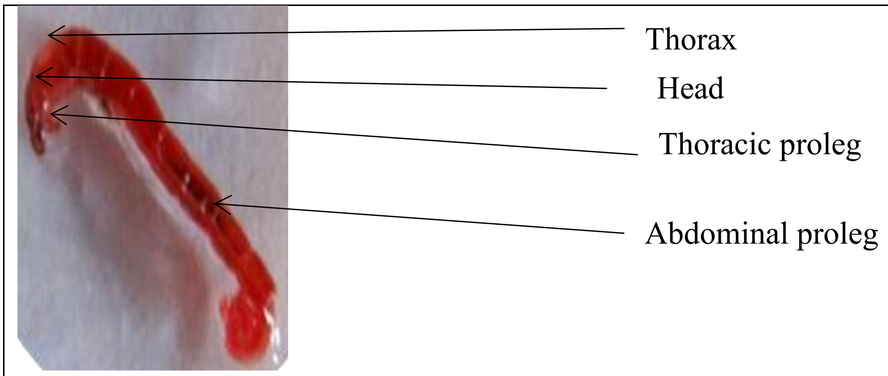


Dorsal view of a Libellulidae



Ventral view (A), dorsal view (B) of a Lymnaeidae

View of a Thiaridae



Dorsal view of a Chironomidae

Figure 16 : Some families of macroinvertebrates collected in the studied ponds

Table 6: Morphological characteristics of the identified macroinvertebrates

Macroinvertebrates	Characteristics
Calopterygidae	• Labium flat, lacking setae, median lobe deeply cleft, labial palps narrow with 3 sharp distal teeth, Pedicel of antenna enlarged, Abdomen usually slender, Gills elongated, median gill lamellate, and lateral gills triquetral and a tolerance value of 5 and are predators.
Lestidae	•Long-slender damselflies; all antennal segments similar; prementum with small triangular notch; prementum stalked and spoon shaped; 4-8 premental setae present; palpal lobes with 3-5 raptorial setae and trifid; gills of similar length; veins visible in gills and perpendicular to medial line and a tolerance value of 9 and are predators.
Libellulidae	They can be recognized by a notch on the posterior margin of the eyes and a foot-shaped anal loop in the hindwing. Many species have patterned wings and distinctive colours on the thorax and abdomen, , prementum and palpal lobes spoon-shaped, Palpal lobes with small rounded and regularly spaced teeth and a tolerance value of 9 and are predators.
Cordulegastridae	• Larvae often appear hairy; Prementum and Palpal lobes large covering face up to antennal bases; Palpal lobes triangular with large irregular teeth; Antennae with seven segments, tolerance value of 3 and are predators.
Chironimidae	• Head sclerotized, rounded and clearly separated from the thorax; body elongated and worm-like; mandibles moving against each other on a horizontal plane; two pairs of ventral prolegs(one on prothorax and one at the terminal end); prolegs terminate in a series of hooks. Tolerance Value of 6 (White) or 8 (Red) and are Collector-gatherer.
Dytiscidae	• Have a hard, smooth, oval body, without any ventral spine, having the hind legs flattened and with a fringe of hairs so that it can act like a paddle, and having long, thin antennae, either a single pair of wings or no wings, three body parts, single pair of compound eyes (some beetle species have additional simple eyes 'ocelli' on the back of the head, tolerance value of 5 and are predators. a
Belostomatidae	• Body flattened and oval, usually the legs are flattened; the head features two large compound eyes, but lacks ocelli contrasting with many hemipterans; antennae shorter than head, concealed below eye; beak cylindrical; fore legs raptorial; and a pair of strap-like appendages present at apex of abdomen.
Nepidae	• Body is cylindrical or flattened, with a siphon to pierce the water surface for air; antennae shorter than head, concealed below eye; their bodies resemble sticks and leaves; beak cylindrical; fore legs raptorial; adults have only one segmented tarsi, all other aquatic heteroptera have at least two tarsal segments on one or more legs.

Lymnaeidae	• Have flat, wide, triangular tentacles, their heads are divided into two flat lateral lobes, most lymnaeids have right-handed shells (when view from the opening, the shell spirals to the right) and are found in waters with moderate to high mineral content.
Thiaridae	• Fresh water snails with an operculum, the shell is elongated conic, turreted, or ovate-conoidal, and is solid with spiral ridges and/or axial ribs and microsculpture

Figure 18: Images of A- **Calopterygidae, B- Lestidae, C- Libellulida**e, D- **Cordulegastridae, E- Chironimidae, F- Dytiscidae, G- Belostomatidae, H- Nepidae, I- Lymnaeidae, J- Thiaridae**

III.2 Discussion

Water quality evaluation is an important part of environmental monitoring since it plays significant role for survival of aquatic organisms and other ecosystems process. When water quality is poor, it affects not only aquatic life but the surrounding ecosystem as well. These sections detail all of the parameters that affect the quality of water in the environment.

During the course of this study, water temperature values in the sampling stations were not high (25.4-26.5°C) and varied slightly from month to month and from station to station. These values are close to those recorded by Tuan *et al* (2021). According to Tuan *et al* (2021) it is caused by changes in weather conditions such as rainfall, wind, and cloud cover and according to Zhou et al. (2021), low dissolved oxygen levels can also affect water temperature in fish ponds by reducing the rate of oxygen consumption by aquatic organisms, which in turn can result in a decrease in heat production.

The suspended solids values are positively correlated with colour (r=0.688; p=0.002) and finally with turbidity (r= 0.622; p=0.001) which would be inputs through excretion, benthivorous species like common carp (Cyprinus Carpio) stir up the sediments while foraging, leading to increased turbidity and according to (Scheffer *et al,* 2003) it is due to the contamination of the water by poorly soluble organic waste coming from the clogging of the fish ponds with macrophytes. Rodier *et al* (2009) also emphasises that the higher the density of suspended particles, the more turbid and coloured the water. In this light, Arfi *et al*. (2003) state that, the main part of aquatic turbidity is linked to the presence of particles in suspension in the water. These values drop considerably after the cleaning of macrophytes in these fish ponds in September which would explain the role that weed control plays in eliminating undissolved pollutants contained in the water.

The average pH value (6.7 ± O.25 UC) shows that the pond waters are slightly acidic. The slightly acidic character of water would be, according to Zébazé (2000), influenced by the acid nature of the soils of the region because the pH of the waters depends on the nature of the substrate crossed. These values are similar to the result of Nziéleu (2006) obtained in two ponds in Yaoundé (6.83 CU). Nevertheless, this pH remains within the pH range (6.5 - 9.0) recommended by the MDDELCC (2014) for the protection of aquatic life. The presence of dissolved oxygen is essential to maintain the higher forms of biological life and to keep proper balance of various pollutions thus making the water bodies healthy. The chemical and biochemical process undergoing in water body are largely dependent upon the presence of oxygen. Estimation of dissolved oxygen is a key test in water pollution and waste treatment process control.

The permissible value recommended for DO is 5mg/L as per Indian standard. In the present investigation dissolved oxygen ranged from 2.0 – 4.0 mg/l. All of the ponds in the study area showed low DO. The average values of dissolved oxygen (38.06 ± 6.52%) observed in the sampling stations is not included in the range recommended by Schlumberger and Bouretz (2002) for fish farming waters (50 to 62.5%) but these values are similar to the result of Ezenwa *et al* 2018 which could be due to overstocking, excessive feeding, poor water circulation and Pollution of the ponds; CRE (2009) points out that at the air/water interface, oxygen molecules diffuse from air to water or from water to air, depending on the degree of oxygen saturation of the water. He also adds that during the day, plants, algae and certain bacteria use the sun's rays and carbon dioxide (CO_2) in order to make their food and release oxygen into the water through the phenomenon of photosynthesis.

The main parameters responsible for the acceleration of the degree of eutrophication (nitrite, nitrate and orthophosphate) were relatively low in the sampling stations which could result either from low anthropogenic activities around the ponds or from the fact that the sampling was carried out during the rainy period and the concentrations of nitrite, nitrate and orthophosphate were diluted. These results are similar to those obtained by Ajeagah and Mouncharou (2015) in the Abiergué, which is a tributary of the Mfoundi River.

Electrical Conductivity ranged from 188 – 796 µs/cm in the study area. The average values of electrical conductivity (429.20± 179.89 µS/cm) and TDS (429.20±106.31mg/L) were obtained in the sampling stations and according to Ajeagah et al. (2018) would be related to high mineralization of organic matter in the waters. Furthermore, it appears that electrical conductivity is positively and significantly correlated with TDS (r=0.939; p=0.000).

For a better pond fish farming, water should have a total alkalinity greater than 25 mg/L $CaCo_3$. Best fish production may be obtained in waters where the total alkalinity ranges from 75 to175mg/l $CaCo_3$ (FAO. 2017). The permissible value of alkalinity as recommended by the Indian standards is 250 mg/L as $CaCO_3$. The amount of alkalinity concentration of the water sample collected in the study area ranged from 22 to 60 mg/L. The low average values obtained in the studied ponds (33.95 ± 11.64 mg/L of HCO_3) are similar to those found by Serrano *et al* (2008). According to Nathalie Mary, 1999 this parameter is sensitive in the natural environment, to the amount of litter brought by the catchment, which oxidises and enriches the environment in hydroxide ions, carbonates, bicarbonates, phosphates, silicates and free ammonia. The analysis of the data also reveals an influence of meteorological factors, particularly the amount of precipitation through the dilution of the concentration of ions in solution.

The average CO_2 content (25.55 ± 8.01 mg/L) is higher than the 10 mg/L recommended by Rodier et al. According to Angelier (2000), the dissolved CO_2 in the ponds studied is due to the decomposition of organic matter present in the mud and the respiration of macroinvertebrates in these ponds which consume oxygen and release CO_2. In the water, the respiration of organisms decreases O_2 by increasing CO_2.

The high average oxidizability value (25.55±8.01 mg/L) obtained in the sampling stations indicate a high load of degradable organic matter in these ponds. Rodier et al (2009) point out that oxidizability values above 10 mg/l of O_2 indicate high organic pollution and very poor water quality.

From the high values of dissolved CO_2 and the very low mineralization of the waters, we can conclude according to the trophic states of ponds of Angeli (1980), that the waters of the ponds studied are eutrophic.

This study identified 10 families of benthic macroinvertebrates. The macroinvertebrate density profile shows a predominance of the pollutant-resistant family, which is characteristic of eutrophic environments (Tachet *et al.,* 2010). This high representativeness would therefore explain the richness of the water in organic compounds. Indeed, Moisan (2010) suggests that in polluted hydrosystems, the benthic macrofauna is largely dominated by pollutant taxa such as the Chironomidae, Lestidae, Thiaridae and Lymnaeidae. The absence of Ephemeroptera in these waters confirms these conclusions (Charvet, 1995). The presence of Arthropods, and Molluscs as well as their relative frequency which are similar to those observed in most of the anthropogenic rivers of the central region, notably the Ntsomo (Nyamsi 2004), and the Biyémé (Foto *et al.,* 2011). The high density of Lestidae, Thiaridae and Chironomidae with high tolerance values of 9,6 and 8 respectively in all the sampling stations during the study period could be explained by the fact that these organisms are pollution resistant and would adapt better to the eutrophication processes of these fish ponds (Whitehurst and Lindsey 1990). A high proportion of these macroinvertebrates in all the sampling stations studied shows that the ponds waters are of poor quality or eutrophic.

The low values of the Shannon and Weaver index and Pielou's equitability (J) observed in pond 3 and 4 respectively reflect a low diversity of MIBs due to a high abundance of Thiaridae which account for nearly 42% and 55.6% of relative abundance in pond 3 and 4 respectively. These results corresponded with those found by Levêque and Balian (2005) according to which the Shannon and Weaver diversity index decreases when a taxon has a very high relative abundance. These indices are higher in pond 1 and pond 2 because of the diversity of microhabitats. Dajoz (1985) emphasises that in a hydrosystem, the higher the diversity index, the better the environmental conditions for the establishment and maintenance of a balanced, integrated biological community capable of adapting to environmental variations. The relatively high values of the biotic index FBI (6,51 to 7,25) would indicate the abundance of pollution-tolerant macroinvertebrate taxa (families) in the ponds studied, since according to Hilsenhoff (1988) and Bode *et al.* (2002), shows organisms assigned with tolerance number from 0 to 10 pertaining to that group's known sensitive to organic pollutants; 0 being most sensitive, 10 being most tolerant. The FBI shows that the waters are of poor quality. The Hilsenhoff index shows poor quality (very substantial organic pollution) in pond EM1 and rather poor quality (substantial organic pollution) in ponds 3 and 4. The results of the indices indicate a very considerable level of organic pollution.

The Sörensen similarity indices of benthic macroinvertebrates reveal an overall stronger similarity between ponds 1 and 2 (S = 87.5%), ponds 1 and 3 (S = 85.7%), ponds 3 and 4 (S = 83.3%) and ponds 2 and 3 (S = 80.0%), However, relatively moderate similarities were found between ponds 1 and 4 (S = 76.9%), and ponds 2 and 4 (S = 66.6%). This could be explained by high water pollution at this point and its lentic faces, which would have considerably reduced the number of taxa compared to the other ponds. Thus the Sörensen index shows the degrees of similarity between the ponds studied.

The low GBNI values obtained in ponds 3 and 4 reflect a very poor water quality. The relatively high values obtained in ponds 1 and 2 characterise a poor ecological quality of the pond waters dominated by pollutant-tolerant species due to effluent inputs (MDDEFP, 2013). The Principal Component Analysis shows that the two axes group all the information (75.73%) discriminate or distinguish the studied ponds into three distinct nuclei. Core1 which represents Pond 1 shows waters rich in pollutant taxa such as Lymnaidae, Lestidae, Thiaridae, Libellulidae, Cordulegasteridae, Belostomatidae and Chironomidae. This predominance of pollutant-tolerant taxa could be justified by the low oxygen levels. Core 2, which involves ponds 2 and 4, shows affinities between certain pollutant-tolerant family (Dysticidae). This organism seems to prefer turbid and alkaline waters, thus indicating a deterioration in water quality. Finally, pond 3 shows a presence of pollutant-tolerant families (Nepidae and Caloptrygidae) which could be justified by the fact that these families are found in waters rich in suspended solids, nitrite and ammoniacal nitrogen contents, which reflects a deterioration in water qualit Conclusion

At the end of this study, which had as general objective to evaluate the water quality and macroinvertebrates biodiversity carried out in four (04) ponds or sampling stations at the Obili Aquaculture Unit, the physico-chemical parameters of the fish ponds were measured and was found out that the pond are poorly oxygenated and slightly acidic which are not favourable for the production of aquatic species. These ponds have low values of organic pollution indicators (nitrates, orthophosphates and nitrites) but have high levels of CO2 and oxidizability values indicating the eutrophic nature of these environments.

Secondly, it was noticed that pond 3 and 4 which had the highest number of fish species, had the lowest amount of macroinvertebrates unlike pond 1 and 2 which was due to the fact macroinvertebrates are an important food source for fish.

Furthermore, the macroinvertebrates in the ponds were identified and the faunistic analysis on a spatio-temporal level shows a dominance of Chironomidae, Lestidae, Thiaridae and Lymnaeidae which are pollutant taxa, thus reveals the excessive organic pollution of these ponds. The taxonomic diversity, physico-chemical parameters coupled with the Hilsenhoff index and the GBNI, show that the waters of these ponds are of poor quality. The Percentages above 50% of the Sörensen similarity coefficient show a good similarity between the studied ponds.

From the results obtained during the study period, and with the aim of improving and preserving the water quality and faunal diversity of the Obili Aquaculture Unit, the following recommendations were given:

The Ministry of Livestock, Fisheries and Animal Industries (MINEPIA) has to provide the unit and other decentralised services with sufficient means to enable the implementation of all the regulatory provisions for the protection of the ponds; ensures the strict application of the regulatory measures already adopted for the protection of the ponds, facilitates access to funds for fish farmers for the purchase of equipment for pond water analysis. The said ministry also has to supply manuals on pond water quality standards. Fish farmers should be trained on pond water quality management and how to manage water before it enters the ponds. We recommend that hydro biologists should take a greater interest in macroinvertebrate studies of peri-urban and rural fish ponds in order to build up a protein database for fish nutrition in extensive farming.

In view of the different microhabitats of benthic macroinvertebrates observed during this study, we plan to focus on the cultivation of macroinvertebrate which we intend to substitute fish meal in fish feed formulation.

References

Ajeagah G., Mbainaissem M., Njiawouo P., Ngakomo A (2018). Physicochemical characterization and biology of waters in peri-urban areas in equatorial Africa: the case of Ngoumou in central Cameroon. International Journal of Innovation and Applied Studies, 11: 33-43

Ajeagah G., Karie M (2015). Dynamics of the abundance of Isospora belli oocysts in an aquatic environment in the tropics (Cameroon). Journal of Microbiology Methods, 88: 61-155.

Alley E., (2007). Water quality control handbook, 2nd ed. 2007, McGraw-Hill; WEF Press: New York; Alexandria.

Angeli N. (1980). Interaction between water quality and the elements of its plankton. review In: Pollution of continental waters. Gauthier Villars (ed.), Paris 2, 97-146.

Angelier E. (2000): Running water ecology. Technique and Documentation, (edition) Paris, 199p.

Arfi R., N'gansoumana B., Bouvy M., Corbin D., Diop Y., KA Samba., Lebihan F., Mboup M., Ndour E., Pagano M., Sane S (2003). Environmental conditions and planktonic communities. 77p.

Aydin U (2018). Statistical Assessment of water quality parameters or pollution source identification in Bektas Pond (Sinop, Turkey). Global NEST Journal, 20, 151-160.

Bazin C (1996). Determination of the biological quality of fresh waters. Water analysis: natural waters, waste waters and sea waters, 8th edition, Paris Dunod, 1384 p.

Bhatnaga A., Pooja D (2013). Water quality guidelines for the management of pond fish culture.

Boissonneault Y (2010). Ecological monitoring of rivers in Quebec: comparison of bioindicators based on invertebrates and benthic diatoms. Master's thesis, University of Trois-Rivières, 137 p.

Bode R., Novak M., Abele L., Heitzman., Smith A (2002). Quality Assurance Work Plan for Biological Stream Monitoring in New York State, Albany, New York. Stream Monitoring Unit Bureau of Water Assessment and Management Division of Water, NYS Department of Environmental Conservation 41 p.

Bromage N., Hardiman P., Jones J., Springate J., Bye V (1990). Farming systems and husbandry practice. In: C. Shepherd and N. Bromage, intensive fish farming. BSP professional books, Oxford, 50-102p.

Celine C (2009). Evolutionary ecophysiology in underground aquatic environment: Influence of temperature variations on the distribution of Niphorgus rhenorhodamensis and Proasellus valdensis, Lyon 1

Charvet (1995). Biological methods for water quality assessment based on benthic macroinvertebrates. DEA dissertation, University of Claude Bernard-Lyon 1 France, 39 p.

CRE (Regional Council for the Environment)., (2009). Kit of lakes. Technical manual, 2th edition, 367p.

Cummins K., Klug M (1979). Feeding ecology of stream invertebrates.

Dajoz R (1985). Precis of ecology. 5th edition, Bordas, Paris, 525 p.

Derwich E., Benaabidate L., Zian A., Sadki O., Belghity D (2010). Physico-chemical characterization of the waters of the alluvial aquifer of the upper Sebou downstream from its confluence with Oued Fès. Larhyss Journal, 3680p.

Diguingue D (2001). Study of benthic macroinvertebrates and the diet of fish species in relation to the seasonal shrinkage of the water surface of the Comoe dam lake. Final dissertation, Polytechnic University of Bobo-Dioulasso. 83p.

Dussart B (1992). Limnology, the study of coastal waters (2nd edition). Boubee & Cie, Paris, 525 p.

Edwards P (1993). Environmental issues in integrated agriculture-aquaculture and wastewater-fed fish culture systems. In: Pullin RSV, Rosenthal H., Maclean JL, (Eds), Environment and aquaculture in developing countries. Manila, Philippines ICLARM Conference Proceedings;170p.

Ezenwa B, Ajani E (2018). Dissolved oxygen and fish growth in aquaculture systems: A review. International Journal of Fisheries and Aquatic Studies, 6(3), 417-423.

FAO. 2017. Aquaculture Management. Rome.

Foto., Koji E., Ajeagah G., Bilong., Njiné T (2012). Impact of dam construction on the diversity of benthic macroinvertebrate community in a periurban stream in Cameroon. International Journal of Biosciences, 2: 145p.

Foto M., Zebaze T., Nyamsi T., Ajeagah G., Njiné T (2011). Spatial evolution of the diversity of benthic macro-invertebrate populations in an anthropized watercourse in a tropical environment (Cameroon). European Journal of Scientific Research, 55(2): 300p.

Gaujous (1995). Pollution of aquatic environments: checklist. TEC & DOC, Paris.

Henry T., Dellapé P (2010). Acrolophyse, a new seed buy genus and two new species (Hemiptera:Rhyparochromidae: myodochini) from forest canopy fogging in Ecuador and Peru. Insect Systematics and Evolution 41:75-89.

Hilsenhoff W (1988). Rapid field assessment of organic pollution with a family-level biotic index. 7 (1): 65-68p.

Huang J, Gergel S (2023). Effectiveness of landscape indicators for explaining the variability of benthic macroinvertebrates in urban streams. 2023 May 12;342: 118130.

Hussain Q., Pandit A (2012). Macroinvertebrates in stream: A review of some ecological factor. International Journal of Fisheries and Aquaculture, 4, 114-123.

Jekayinfa O, Bawa-Allah K (2022). Assessing the potential toxicity of paint industry effluents to aquatic organisms using the whole effluent testing (WET) approach. Environ Monit Assess. 2022 Feb 11; 194(3):173.

Kolek L, Inglot M, Jarosiewicz P (2023). Nutrient cycling enhancement in intensive-extensive aquaculture through C/N ratio manipulation and periphyton support. Bioresour Technol. 2023 Jan; 368:128309.

Leynaud G., Verrel J (1980). Modifications of the aquatic environment under the influence of pollution. In: Gauthier Villars ed., pollution of continental waters. Impact on aquatic biocenoses, Paris, Besson; 1115 p.

Levêque C., Balian E., (2005). Conservation of Freshwater biodiversity: Hydrobiologia, 542, Article No. 23.

MDDEFP (2013). Guide to biological monitoring based on benthic macroinvertebrates of fresh water in Quebec, shallow watercourses with coarse substrate, department for monitoring the state of the environment, 2nd edition, 88p.

MDDELCC (2014). Surface water sampling protocol for trace metal analysis.

Moisan J (2010). Identification guide for the main benthic macroinvertebrates in freshwater in Quebec, 2010 – Voluntary monitoring of shallow watercourses, State of the Environment Monitoring Department, Ministry of Sustainable Development, Environment and Parks, ISBN: 978-2-550-58416-2 (print version), 82 p.

Mouissi S., Alayat H (2016). Use of Principal Component Analysis (PCA) for the Physico-Chemical Characterization of the Waters of an Aquatic Ecosystem: Case of Lake Oubéira (Extreme NE Algeria). J. Mater. About. Science. 2028-2508

Mbiye A (1997): Comparative spatio-temporal evolution of the biological quality of the water of Kabondo and Konga-Konga streams in Kisangani (Orientale Province), Unpublished memory, Faculty of Sciences. 50p.

Mustapha M (2017). Comparative assessment of the water quality of four types of aquaculture ponds under different culture systems.

Nathalie M (2000). Identification guide for benthic macroinvertebrates in the rivers of New Caledonia. Ministry of the Environment, Water Service (Paris), North Province and South Province of New Caledonia, 92 p.

Nathalie M (1999). Physicochemical and biological characterization of the rivers of New

Caledonia, proposal of a biotic index based on the study of benthic macroinvertebrates. Doctoral thesis, French Pacific University, France, 200 p.

Neveu A., Riou C., Bonhomme R., Chassin P., Papy F (2001). water in space rural life and aquatic environments, INRA. Paris

Nyamsi T (2004). Effects of discharges from a cellulose treatment plant on the quality of the waters of the Ntsomo: Biological and hydrological study of the watercourse. Memory of the Diploma of Advanced Studies. University of Yaoundé I. Faculty of Sciences. 41 p.

Nzieleu T (2006): Study of the determinism of the polymorphism of Brachionidae Rotifers in three bodies of water in Yaoundé: Yaoundé Municipal Lake, Mélen pond and Efoulan pond. DEA dissertation, Faculty of Sciences, University of Yaoundé I, 62 p.

Olivier D., Gessner O., François G., Eric C (2004). Impacts of stream acidification on litter breakdown: implications for assessing ecosystem functioning. Journal of Applied Ecology 41: 365–378

Partyka M, Bond R (2022). Wastewater reuse for irrigation of produce: A review of research, regulation, and risks. 2022 Jul 1; 828: 154385.

Patil P., Nagarnaik P (2012). Physico-chemical parameters for testing of water. A review. International journal of environmental sciences, 3,1194-1207.

Payne A (1986). The ecology of tropical lakes and rivers. John Wiley and sons, Chichester. 301p.

Peet R (1974). The measurement of specifies diversity. Annual Reviews of Ecology and Systematics. 5:285-307

Pielou E (1969). An introduction to mathematical ecology. Wiley-Interscience New York, 286 p.

Piper R., Kalger L., Tidefell U (1982). Fish hatchery management. US fish and wild life service, Washington DC.

Pouomogne V (1994). Feeding Tilapia Oreochromis niloticus in ponds. Evaluation of the potential of some agro-food by-products and methods of food intake. Ph.D. thesis in Fisheries from ENSAR, Rennes (France), 160 p.

Pourriot R (1980). Rotifers. In: ORSTOM, Durant and Levêque (ed), Flora and aquatic fauna of Sahelo-Sudanian Africa 1, Paris; 218 – 244

Reynolds C (1984). The natural history of biospeleology. Madrid. Mun. Nac. Cien. Nat Sc. SIC, Monographs. 7: 609-680.

lvidraco). Aquaculture

Rodier J., Legube B., Merlet N (2009). Water analysis, 9th edition, Dunod (Ed), Paris (France), 1526 p.

Scheffer M., Stephen R (2003). Catastrophic regime shifts in ecosystem; linking theory to observation.

Serrano L, Delorenzo M (2008). Water quality and restoration in a coastal subdivision stormwater pond. J Environ Manage. 2008 Jul;88(1): 43-52.

Shannon C., Weaver (1963). The mathematical theory of communication. Urbane: University of Illinois Press, 117 p.

Sorensen T (1948). A methods of establishing groups of equal amplitude in plant sociology based on similarity of species content, Det Kgh. Limnol. Oceanogr. 5:1-34.

Soulard (2007). Fundamental Water and Wetland Ecology. European Week

ATHENS: MP 7. Paris School of Mines, 66 p.

Tachet H., Richoux P., Bournaud M., Usseglio-Polatera P (2010). Freshwater invertebrates: systematics, biology, ecology. CNRS 2nd Editions, Paris. ISBN: 978-2-271-06945-0.

Timmons N (2002). Recirculating Aquaculture System (RAS) Technology, part 2.

Tuan H., Nguyen T., Truong H., Phuong T (2021). Correlation between weather parameters and water temperature in fish ponds in the Mekong Delta, Vietnam. Journal of Environmental Science and Health, Part A, 56(1), 41-50.Verneaux **J. (1973).** Rivers of Franche-Comté (Jura massif): Ecological research on the Doubs hydrographic network. Thesis of Doctor of Natural Sciences, 257 p.

Virginie A., Dumont B (2010). The normalized global biological index (IBGN): principles and evolution within the framework of the European framework directive on water. Waters & Territories Sciences, INRAE, 2010, 36-39p.

Walder M (1982). Statistics and calculation of probabilities. Edition Sirey; 347 p.

Whitehurst T., Lindsey B (1990). The impact of organic enrichment on benthic macroinvertebrate communities of a lowland river. 25: 625-655.

Wurtz A (1958). Can we conceive the typification of ponds on the same bases as those some lakes? In: Verh. boarding school Worm. Limnol.,13: 381-393.

Zhou M., Li L., Liang X., Liu Y., Yang, S (2021). Effects of dissolved oxygen and water temperature on the growth and survival of juvenile yellow catfish (Pelteobagrus fu