Research Article

**International Review of Aquatic Ressources Research, Management and Engineering** **Vol 8, Serie 1 Pages 30-41**

Submission (14 September 2026) Accepted and Published (10 November 2026) www.ijarme.org

# Environmental characterization and ecological bio-diversity of benthic macroinvertebrates in exploitable aquatic resources within the Doba oil-producing region, Chad – Central Africa

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**Abstract**

The study of environmental quality and the diversity of benthic macroinvertebrates in the Doba oil-producing basin in Chad represents a major ecological and public health issue. Doba, a town in southern Chad and the capital of the Logone Oriental region, has played a central role in the oil industry since the 2000s. Since that time, this region of Central Africa has been subjected to intense industrial pressure linked to oil extraction, which directly compromises the viability of surface and groundwater resources used by local populations. These activities alter water quality as well as the integrity of aquatic and riparian habitats, leading to a loss of biodiversity—most notably among aquatic macroinvertebrates. Assessing the status of biological communities provides data that reflect both the chemical quality of the water and the condition of the habitat. Methods based on biological assessment utilize living organisms to offer a comprehensive overview of the environmental conditions and pressures affecting aquatic ecosystems. The families identified include Dytiscidae, Belostomatidae, Nepidae, Atyidae, Gomphidae, Libellulidae, Hydrometridae, Tabanidae, Chironomidae, Coenagrionidae, Corduliidae, Pilidae, Lymnaeidae, and Naucoridae. The Dytiscidae family is represented by 5 species, followed by the Gomphidae and Libellulidae with 3 species each, and the Belostomatidae and Nepidae with 2 species each; the remaining families are represented by a single species. The species *Cylister vulneratus* is among the 14 species found in the aquatic environment at Debeu. *Caridina africana* is represented by 10 individuals, *Libellula* sp. by 8, *Laccotrephes* sp. by 7, and *Lestinogomphus* sp. by 7; the remaining species are sporadic. Various groups of species have been used for such assessments, with benthic macroinvertebrates remaining one of the most useful groups. To ensure the sustainability of water resources utilized in Doba, several biomonitoring measures are necessary: establishing a permanent biomonitoring network—using biological scoring systems adapted for Central Africa to regularly assess the ecological status of rivers—and systematically combining physicochemical monitoring (testing for polycyclic aromatic hydrocarbons—PAHs—and heavy metals) with the inventory of macroinvertebrates. Furthermore, it is essential to protect water abstraction zones, limit unregulated agricultural activity, and regulate the management of industrial effluents around drinking water sources in order to curb ecological risks.

**Keywords**: Environmental quality, Benthic macroinvertebrate diversity, Oil-producing basin, Doba in Chad

## I. Introduction

The study of environmental quality and the diversity of benthic macroinvertebrates in the Doba oil basin in Chad represents a major ecological and public health issue. Since the 2000s, this region of Central Africa has been subject to intense industrial pressure linked to oil extraction, which directly compromises the viability of surface and groundwater resources used by local populations. Benthic macroinvertebrates—insects, mollusks, crustaceans, and worms that live on the beds of watercourses—serve as essential bioindicators for assessing the health of these hydrosystems. In addition to the establishment of extraction

infrastructure, the proliferation of human-driven land clearing in the surrounding areas (such as "trap fields") exacerbates runoff and erosion, affecting ponds, rivers, and traditional wells. The infiltration or accidental discharge of hydrocarbon residues alters the water's dissolved oxygen levels, pH, and conductivity. A film of oil or grease on the surface blocks light, limits photosynthesis, and suffocates bottom-dwelling fauna. This chemical pollution is compounded by an increased bacteriological vulnerability of the groundwater and surface water used for human consumption. In a healthy ecosystem, the benthic community is diverse and balanced. In areas under stress from oil-related and other human activities, the taxonomic structure undergoes a radical reorganization, characterized by a decline in species richness. This structural shift leads to a drastic drop in diversity indices (such as the Shannon or Simpson indices) and reflects a loss of biological integrity in the aquatic resource (Talhaoui et al., 2020).

In areas of human activity (agriculture, urbanization, mining), benthic diversity often declines due to several factors: Physico-chemical degradation—the influx of nutrients (nitrates, phosphates) or pollutants alters pH and turbidity, and reduces dissolved oxygen. Substrate clogging—the deposition of fine particles (resulting from erosion or mining) fills the gaps between stones, where many species reside. Habitat modification—the removal of riparian vegetation (bank-side plants) increases water temperature and reduces the variety of micro-habitats (such as dead wood, roots, and mosses). Biodiversity plays a crucial role in the functioning and natural development of all aquatic ecosystems. According to Gravel et al. (2010), high biodiversity enhances the stability and adaptability of the entire community of living organisms within an environment when faced with changing environmental conditions (Peres-Neto et al., 2013). Macroinvertebrates are one component of this biodiversity; however, they remain relatively poorly understood, despite their vital role in food webs. Benthic macroinvertebrates are widely used for the biomonitoring of watercourse quality, as they possess several attributes that make them effective environmental indicators (Barbour et al., 1999). A better understanding of these organisms and how they function will lead to improved management of aquatic ecosystems. Environmental disturbances resulting from anthropogenic activities—such as agriculture, livestock watering, industrial operations, and the fulfillment of basic human needs—are proliferating across many regions of the globe, leading to imbalances in biodiversity and the pollution of both groundwater and surface water (Parent-Raoult, C. and Boisson, J.-C., 2007). The objective of this study is to evaluate environmental variables and characterize the diversity of benthic macroinvertebrates in the Doba oil-producing region of Chad.

## II. Study Area, Materials and Methods

Doba is a town in southern Chad and the capital of the Logone Oriental region; it has been known for its central role in the oil industry since the 2000s. Located approximately 400 km southeast of N'Djamena, Doba is one of the major towns in southern Chad. According to the official census, it had a population of 18,052 in 1993, while more recent estimates suggest a population of around 49,647. Doba lies at the heart of the Doba oil basin, where major reserves were discovered in 1996. Extraction began in 2003, transforming both the local and national economies. A 1,070 km-long pipeline connects Doba to the port of Kribi (Cameroon). The oil sector dominates economic activity, although agriculture—including the cultivation of millet and cotton, as well as livestock farming—remains present. The population is composed primarily of people from the Sara ethnic groups. The town's cultural life is shaped by local traditions and community celebrations. Today, Doba remains a strategic hub in southern Chad—serving as both an administrative and an oil-industry center—with its development remaining closely linked to the exploitation of hydrocarbons (Figure 1).

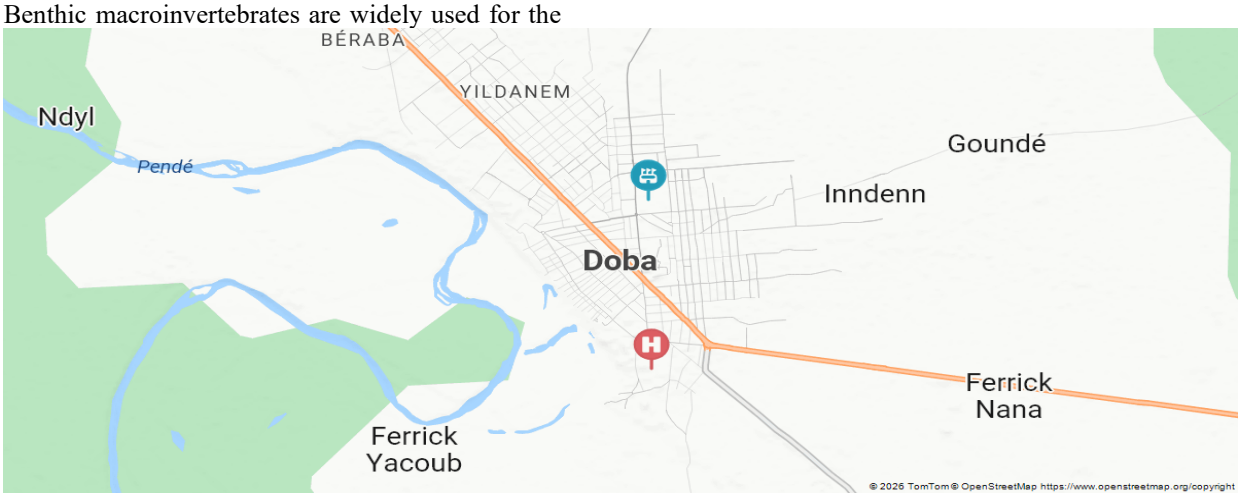



Figure 1: Map of the Doba area showing the different zones.

Physicochemical analysis of water allows for the assessment of its quality by measuring parameters such as pH, conductivity, turbidity, hardness, alkalinity, and the presence of dissolved chemical compounds. pH indicates whether water is acidic, neutral, or basic (French Standardization Association [AFNOR], 2004). It is measured using a potentiometric method—employing a glass electrode and a reference electrode—which helps detect chemical species present in the water. Conductivity assesses the overall mineralization of water by measuring the conductance between two metal electrodes; high conductivity indicates a high concentration of dissolved ions. Turbidity measures the reduction in water transparency caused by suspended particles; it is determined by comparing the light scattered and transmitted within a sample. High turbidity can promote bacterial growth and reduce the effectiveness of disinfection. The color of water may be of mineral (ferric iron) or organic (tannins) origin. "True color" is measured after removing suspended particles and is expressed in mg/L of Pt (platinum). Alkalinity—measured via the TA (alkalimetric titer) and TAC (total alkalimetric titer)—quantifies the water's capacity to neutralize acids, which is linked to the presence of hydrogencarbonates, carbonates, and hydroxides. TA accounts for free hydroxides and carbonates, while TAC also includes hydrogencarbonates. Hardness (TH) reflects the concentration of calcium and magnesium, which originate from the leaching of the terrain through which the water has passed. It is expressed in terms of water hardness and influences the formation of limescale deposits. Nitrogenous compounds: Nitrogen can be organic (proteins, amino acids) or inorganic (nitrates, nitrites, ammonium). Measuring these is essential for assessing pollution levels and the nutritional quality of the water. Physicochemical analyses are conducted in a laboratory using samples collected according to specific protocols. Measurement techniques may include potentiometric, colorimetric, or conductimetric methods, or visual comparison against standard solutions. Specialized laboratories can also analyze heavy metals, pesticides, and other organic chemical substances to ensure water safety. These analyses make it possible to: monitor the potability of the water and its compliance with health standards. Monitoring pollution in natural and industrial waters, preventing risks to human health and aquatic life, and optimizing water treatment for consumption or industrial use—physicochemical analysis provides a comprehensive overview of water quality, which is essential for public health, water resource management, and environmental protection.

The term "aquatic macroinvertebrates" refers to a group of organisms—including insects, crustaceans, mollusks, and worms—that spend at least one phase of their life cycle in an aquatic environment and are large enough to be retained by a 0.5 mm mesh net. The macroinvertebrates studied primarily inhabit the bottom of watercourses, ranging from the banks to the center of the riverbed. They colonize various types of surfaces (or substrates), which may be mineral (boulders, stones, gravel, sand, etc.) or organic (plants, branches, leaf litter, tree roots, silt, etc.) in nature. Macroinvertebrates are sensitive to environmental conditions, such as variations in water quantity and quality, and the diversity of aquatic habitats (e.g., the nature of the substrate, flow velocity). This report examines the impact of specific sampling practices—specifically during the collection phase (i.e., while the Surber sampler is in the water)—with a focus on the volume of substrate collected. This is analyzed from both a technical perspective (the resulting faunal lists and the assessment of river quality) and an economic perspective (the time required for laboratory sorting). The two methods compared are outlined below: 1) Agitating/scrubbing the substrate in front of the net: For instance, when sampling "stony" substrates, large stones are scrubbed within the river, while finer-grained material is simply raked with the fingers or agitated; this approach dislodges macroinvertebrates into the net while limiting the total volume of substrate collected.

The volume collected is generally in the range of 0.1 to 0.2 liters. Plant substrates are agitated, combed through with the fingers, and rubbed in front of the Surber sampler. 2°) Collection of the substrate containing macroinvertebrates: For the "stones" substrate, for example, the entire range of particle sizes (from stones to sand) is collected within the Surber sampler, then pre-sorted in the field using a 5 mm sieve, with a visual check of the discarded material. The remaining volume typically consists of 0.5 to 0.75 liters of material to be sorted. Plant substrates are placed into the Surber sampler and then cut or pulled loose. To ensure the study could be completed within the timeframe of a Master 2 internship (6 months), we chose to examine only three types of substrates—morphologically distinct, commonly found in rivers (stones, hydrophytes), or particularly rich in organisms (leaf litter). Furthermore, we selected two sites that, to our knowledge, possess good water quality and good morphological condition, in order to ensure a diverse fauna. 1°) A net (the "inner net") is placed inside a hand net (the "outer net"—photo 1). The edges of the inner net are folded back to prevent any contamination of the outer net (photo 2), and a Surber frame is then positioned against the hand net (photo 3) to delineate a 1/20 m² area and minimize lateral loss. 2°) The entire assembly is placed on the

riverbed, facing the current; the habitat is then agitated, rubbed, and/or combed through in the water for approximately sixty seconds, taking care not to dislodge an excessive amount of substrate. 3°) Both nets are withdrawn toward the rear without moving the Surber frame. The inner nets are quickly removed, and the outer net (the frame of the *haveneau*—a type of hand-held sampling net) is pressed against the frame of the Surber sampler; 4°) the substrate within the frame is then entirely collected into the outer net; 5°) the contents of the two nets (from phases "a" and "b") are processed separately. The substrate is emptied onto a sieve and may undergo preliminary sorting (all discarded material is visually inspected to ensure no taxa are present) to maintain a maximum sample volume of 0.5 to 0.75 liters, after which it is placed into a jar.

## III. Results and Discussion

The physicochemical results are presented in Tables IA, IB, IC, and ID, and the macroinvertebrate data in Table II. The wells in the village of Komebase are moderately oxygenated, with a temperature of 24.5°C, low mineralization, and high oxidizability, indicating the presence of organic matter.

Tableau I A : Physico- Chimical variables of the aquatic medium assesed

| Stations | O(%) | O (mg/L) | T (°C) | pH (UC) | Con (µS/cm) | TDS (mg/L) | Salinité (PSU) | Co (Pt-Co) | MES (mg/L) | Turbidité (FAU) | Alcalinité (mg/L) | Dioxyde de carbone dissous (mg/L) | Oxyd (mg/L) | Az (mg/L) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Komebase Village 1 Puits 1 | 65,2 | 4,99 | 24,6 | 8,46 | 24,5 | 12,3 | 0 | 131 | 9 | 9 | 110 | 18 | 6,9 | 0,24 |
| Komebase Village 1 Puits 2 | 72,4 | 5,53 | 24,5 | 8,57 | 29,7 | 14,8 | 0 | 152 | 7 | 16 | 28 | 8,8 | 4,5 | 0,21 |
| Komebase Village 1 Puits 3 | 61,4 | 4,68 | 24,6 | 8,44 | 29,4 | 14,7 | 0 | 108 | 9 | 33 | 16 | 7 | 6,1 | 0,29 |
| Komebase Village 1 Puits 4 | 10,9 | 0,83 | 24,8 | 8,63 | 41,1 | 20,6 | 0 | 508 | 111 | 131 | 42 | 7 | 31 | 0,59 |
| Komebase Village 1 Puits 5 | 56,7 | 4,32 | 24,7 | 8,17 | 46,9 | 23,5 | 0 | 276 | 42 | 73 | 30 | 16 | 13 | 0,58 |
| Komebase Village 2 Puits 1 | 12,1 | 0,92 | 20,6 | 8,75 | 44,2 | 22,1 | 0 | 470 | 91 | 65 | 48 | 19 | 9,7 | 0,53 |
| Komebase Village 2 Puits 2 | 63,6 | 4,83 | 24,8 | 8,33 | 38,9 | 19,5 | 0 | 105 | 6 | 16 | 242 | 18 | 0,2 | 0,28 |

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Komebase Village 2 Puits 3 | 52,9 | 4,01 | 24,7 | 8,45 | 26 | 13 | 0 | 69 | 2 | 4 | 38 | 8,8 | 0,4 | 0,13 |
| Komebase Village 2 Puits 4 | 62 | 4,72 | 24,7 | 8,46 | 25,6 | 12,8 | 0 | 52 | 1 | 4 | 74 | 26 | 16 | 0,05 |
| Komebase Village 2 Puits 5 | 61 | 4,63 | 24,9 | 8,57 | 25,5 | 12,7 | 0 | 415 | 62 | 107 | 76 | 7 | 25 | 0,65 |
| | | | | | | | | | | | | | | |

At Debeu, oxygenation levels are high at the bridge, well 1, and the boreholes; the temperature remains at 24°C. The pH is basic, mineralization is low, and the color level is high. It exhibits high alkalinity, high oxidizability, and a high alkalimetric value.

Table IB: Physico-chemical variations of certain environmental factors

| Stations | Oxygéne dissoous (%) | Oxygéne dissous (mg/L) | Tem (°C) | pH (UC) | Con (µS/cm) | TDS (mg/L) | Salinité (PSU) | Cou (Pt-Co) | MES (mg/L) | T (FAU) | Alca (mg/L) | Dioxyde (mg/L) | O (mg/L) | Azote |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Debeu Pont Entrée | 64,1 | 4,85 | 20,3 | 8,88 | 26 | 12,7 | 0 | 193 | 6 | 1 | 22 | 5,28 | 8,1 | 0,3 |
| Debeu Pont Milieu | 73,4 | 5,55 | 24,9 | 8,98 | 22 | 11 | 0 | 197 | 17 | 15 | 54 | 8,8 | 10 | 0,2 |
| Debeu Pont Sortie | 17,1 | 1,29 | 21,2 | 8,9 | 18 | 8,87 | 0 | 139 | 2 | 1 | 78 | 17,6 | 13 | 0,1 |
| Debeu Puits 1 | 70,5 | 5,33 | 20,9 | 8,75 | 28 | 14 | 0 | 105 | 5 | 14 | 50 | 5,28 | 4,9 | 0,1 |
| Debeu Puits 2 | 16 | 1,21 | 25,1 | 9,01 | 42 | 20,7 | 0 | 103 | 1 | 6 | 40 | 12,3 | 14 | 0,9 |
| Debeu Puits 3 | 67,5 | 5,1 | 25,1 | 8,8 | 26 | 13,1 | 0 | 313 | 30 | 59 | 54 | 10,6 | 1 | 0,7 |
| Debeu Puits 4 | 59,3 | 4,48 | 20,3 | 8,69 | 18 | 9,03 | 0 | 188 | 12 | 20 | 14 | 5,28 | 1 | 0,4 |
| Debeu Puits 5 | 35,2 | 2,65 | 20,4 | 8,83 | 52 | 25,9 | 0 | 115 | 1 | 13 | 68 | 8,8 | 5,7 | 0,1 |
| Debeu Forage | 63,5 | 4,79 | 25,2 | 8,57 | 24 | 11,8 | 0 | 24 | 0 | 0 | 64 | 17,6 | 5,1 | 0 |
| | | | | | | | | | | | | | | |

Table I C: Physico-chemical variation of the aquatic hydrosystems.

In Kombese Village, the wells exhibit moderate oxygenation, average conductivity, low water turbidity, high concentrations of carbon dioxide and organic matter, and elevated nitrogen levels. Organic content is high, as is the concentration of suspended solids in the water.

| Stations | O(%) | O(mg/L) | Te(°C) | pH(UC) | Con(µS/cm) | TDS(mg/L) | Sal(PSU) | Col(Pt-Co) | MES(mg/L) | Tu(FAU) | Al(mg/L) | Diox(mg/L) | Oxy(mg/L) | Azote(mg/L) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Komebase Village 3 Puits 1 | 62 | 4,73 | 24,8 | 8,41 | 103 | 51,6 | 0 | 76 | 6 | 16 | 30 | 19,36 | 6,32 | 0,28 |
| Komebase Village 3 Puits 2 | 15 | 1,12 | 24,7 | 8,86 | 60 | 29,7 | 0 | 160 | 4 | 9 | 44 | 8,8 | 22,52 | 0,36 |
| Komebase Village 3 Puits 3 | 36 | 2,76 | 21,8 | 7,92 | 189 | 94,7 | 0 | 13 | 0 | 0 | 70 | 23,88 | 49,77 | 1,01 |
| Komebase Village 3 Puits 4 | 66 | 5,03 | 22 | 8,47 | 40 | 19,8 | 0 | 131 | 16 | 25 | 100 | 26,4 | 3,16 | 0,24 |
| Komebase Village 3 Puits 5 | 69 | 5,21 | 21,3 | 8,19 | 47 | 24 | 0 | 33 | 0 | 0 | 60 | 31,6 | 2,57 | 0,07 |
| Komebase Village 4 Puits 2 | 18 | 1,36 | 21,3 | 9,13 | 70 | 34,9 | 0 | 179 | 21 | 29 | 46 | 15,84 | 16,2 | 0,99 |
| Komebase Village 4 Puits 3 | 35 | 2,63 | 24,9 | 8,69 | 20 | 9,89 | 0 | 43 | 0 | 0 | 28 | 13,84 | 6,72 | 0,12 |
| Komebase Village 4 Puits 4 | 66 | 5,01 | 24,8 | 8,5 | 43 | 21,8 | 0 | 42 | 0 | 0 | 34 | 3,52 | 20,94 | 0,09 |
| Komebase Village 4 Puits 5 | 20 | 1,52 | 24,8 | 8,84 | 30 | 15 | 0 | 42 | 0 | 0 | 34 | 5,28 | 11,85 | 0,11 |
| Marigot Kome 1 | 21 | 1,56 | 24,8 | 9,1 | 42 | 21 | 0 | 133 | 24 | 28 | 26 | 14,08 | 13,43 | 0,25 |
| Marigot Kome 2 | 12 | 0,9 | 24,9 | 9,16 | 61 | 30,3 | 0 | 77 | 7 | 17 | 34 | 14,81 | 19,36 | 0,16 |
| Komebase Village 2 Forage | 64 | 4,81 | 25 | 8,23 | 168 | 83,9 | 0 | 19 | 0 | 0 | 12 | 33,44 | 9,48 | 0,21 |

Table ID: Physicochemical parameters assessed
In the aquatic environments of Djen and Loule, we observe oxygenation levels of around 60%, low mineralization, and a high presence of organic matter and carbon dioxide. The temperature is relatively high—at 25°C—and the water's coloration [conductivity] can reach 1700 µS/cm.

| Stations | Oxy (%) | Oxy(mg/L) | Tem (°C) | pH (UC) | Cond (µS/cm) | TDS (mg/L) | Sal (PSU) | Col (Pt-Co) | MES (mg/L) | Tu(FAU) | Alcalinité (mg/L) | Diox(mg/L) | Oxy (mg/L) | Almg/L) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Djen Puits 1 | 70,7 | 5,32 | 25 | 8,9 | 21,1 | 10,6 | 0 | 179 | 14 | 18 | 34 | 17,6 | 13,6 | 0,21 |
| Djen Puits 2 | 23,8 | 1,79 | 25 | 8,99 | 35,1 | 17,5 | 0 | 236 | 20 | 26 | 24 | 14,08 | 13,2 | 0,42 |
| Djen Puits 3 | 23,8 | 1,79 | 25 | 8,75 | 41,1 | 20,6 | 0 | 1000 | 64 | 87 | 32 | 29,92 | 15,8 | 0,86 |
| Djen Puits 4 | 54,5 | 4,1 | 25 | 9,28 | 114 | 57 | 0,1 | 1700 | 141 | 199 | 42 | 14,08 | 18 | 1,16 |
| Djen Puits 5 | 32 | 2,4 | 25 | 9,13 | 55,3 | 27,7 | 0 | 1604 | 150 | 209 | 46 | 5,28 | 20 | 1,42 |
| Boro Pont Entrée | 31,9 | 2,39 | 24 | 9,08 | 21,7 | 10,6 | 0 | 385 | 5 | 6 | 52 | 1,76 | 11,9 | 0,67 |
| Boro Pont Sortie | 52,4 | 3,93 | 26 | 9,03 | 16,8 | 8,41 | 0 | 357 | 18 | 24 | 34 | 10,56 | 15 | 0,48 |
| Loulé Entrée | 76,6 | 5,78 | 24 | 8,95 | 23,2 | 11,6 | 0 | 302 | 40 | 40 | 58 | 7,04 | 20,3 | 0,83 |
| Loulé Milieu | 33,8 | 2,54 | 24 | 8,89 | 21 | 10,5 | 0 | 1416 | 39 | 45 | 30 | 14,08 | 11,3 | 0,64 |
| Loulé Sortie | 24,8 | 1,86 | 24 | 9 | 26,9 | 13,3 | 0 | 1444 | 31 | 44 | 20 | 8,8 | 12,3 | 0,49 |
| Loulé Puits | 35,4 | 2,65 | 25 | 8,8 | 21,8 | 10,9 | 0 | 411 | 46 | 70 | 28 | 21,12 | 13,8 | 0,52 |

Table I E: Physicochemistry of aquatic environments – wells
In the Mbonya area, oxygenation is moderate, the pH is basic, conductivity is low, suspended solids are at a moderate level, oxidizability is high, and alkalinity is very low.

| Stations | Ox (%) | Oxy (mg/L) | Te (°C) | pH (UC) | Cond (µS/cm) | TDS (mg/L) | Sal(PSU) | Co (Pt-Co) | MES (mg/L) | Tu (FAU) | Al (mg/L) | Dio (mg/L) | Oxy (mg/L) | Az (mg/L) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mbonya Puits 1 | 76,5 | 5,77 | 25 | 8,86 | 29,6 | 14,8 | 0 | 91 | 0 | 0 | 56 | 3,52 | 8 | 0 |
| Mbonya Puits 2 | 17,3 | 1,3 | 25,2 | 8,84 | 28,1 | 14,1 | 0 | 151 | 3 | 2 | 80 | 8,8 | 9 | 0 |
| Mbonya Puits 3 | 76,6 | 5,77 | 25,3 | 8,73 | 88,4 | 44,2 | 0 | 440 | 68 | 111 | 28 | 28,16 | 17 | 0 |
| Mbonya Puits 4 | 79,6 | 5,95 | 25,1 | 8,79 | 67,1 | 33,6 | 0 | 114 | 11 | 16 | 70 | 22,88 | 7 | 0 |

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mbonya Puits 5 | 90,4 | 6,81 | 25 | 9,02 | 70,9 | 35,4 | 0 | 74 | 5 | 11 | 46 | 17,6 | 16 | 0 |
| Mbonya Sortie 1 | 28,4 | 2,14 | 25,3 | 8,8 | 38,7 | 19,2 | 0 | 183 | 15 | 16 | 40 | 15,84 | 3 | 1 |
| Mbonya Sortie 2 | 25,7 | 1,93 | 24,4 | 9,05 | 28,2 | 14,1 | 0 | 144 | 3 | 0 | 14 | 17,6 | 1 | 0 |
| Mbonya Sortie 3 | 34,2 | 2,56 | 25,3 | 8,95 | 19,06 | 9,53 | 0 | 77 | 4 | 4 | 22 | 15,84 | 8 | 1 |
| Mbonya Entrée 1 | 43,1 | 3,24 | 25,2 | 8,99 | 16,68 | 8,33 | 0 | 108 | 2 | 1 | 22 | 63,36 | 12 | 0 |
| Mbonya Entrée 2 | 67,3 | 5,07 | 24,4 | 9,03 | 17,01 | 8,47 | 0 | 134 | 11 | 15 | 34 | 14,08 | 3 | 0 |
| Mbonya Entrée 3 | 63,4 | 4,77 | 25,1 | 9,05 | 17,96 | 8,96 | 0 | 85 | 10 | 19 | 16 | 3,52 | 13 | 0 |
| | | | | | | | | | | | | | | |

Low biodiversity of benthic macroinvertebrates is observed. The families identified are Dytiscidae, Belostomatidae, Nepidae, Atyidae, Gomphidae, Libellulidae, Hydrometridae, Tabanidae, Chironomidae, Coenagrionidae, Corduliidae, Pilidae, Lymnaeidae, and Naucoridae. The Dytiscidae are represented by 5 species, followed by the Gomphidae with 3 species, the Libellulidae with 3 species, the Belostomatidae with 2 species, and the Nepidae with 2 species; the remaining families are represented by a single species each. *Cylister vulneratus* is the most abundant species in the aquatic environment at Debeu, with 14 individuals. *Caridina africana* is represented by 10 individuals, *Libellula* sp. by 8, *Laccotrephes* sp. by 7, and *Lestinogomphus* sp. by 7; the other species occur only sporadically.

Table II: Macroinvertebrates identified in the oil-producing area

| Family | Genus and specie | Debeu S | Mbonya E2 | Loule M | Debeu E | MK1 | MK2 | Loule E | Mbonya S3 | BE | BS | Mbonya E1 | Debeu M | Mbonya S2 | Mbonya E3 | Mbonya S1 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Dytiscidae | *Hydaticus dorsiger* | 0 | 0 | 2 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | *Cybister vulneratus* | 3 | 7 | 5 | 3 | 4 | 8 | 0 | 3 | 2 | 0 | 11 | 14 | 1 | 0 | 5 |
| | *Cybister vicinus* | 0 | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| | *Hydrocanthus micans* | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | *Hydrovatus sp* | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 6 | 0 | 0 | 0 |
| Blostomatidae | *Appasus sp* | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| | *Hydrocyrius sp* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 |

| | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Nepidae | *Laccotrephes ater* | 0 | 1 | 6 | 1 | 0 | 1 | 5 | 0 | 1 | 9 | 7 | 2 | 7 | 6 | 4 |
| | *Ranatra linéaris* | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 |
| Atyidae | *Caridina africana* | 0 | 0 | 1 | 0 | 0 | 0 | 6 | 0 | 10 | 0 | 0 | 0 | 0 | 0 | 0 |
| Gomphidae | *Phyllogomphus brunneus* | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | *Lestinogomphus angustus* | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 7 | 0 | 3 | 0 | 5 | 0 | 0 |
| | *Neurogomphus sp* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |
| Libellulidae | *Libellula sp* | 0 | 0 | 2 | 0 | 0 | 0 | 4 | 0 | 0 | 0 | 8 | 4 | 4 | 0 | 0 |
| | *Orthetrum sp* | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 |
| | *Brachythemis leucosticta* | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 4 | 0 | 0 | 0 | 0 | 0 | 0 |
| Hydrométridae | *Hydrometra sp* | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Glossiphoniidae | *Hemiclepsis sp* | 0 | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 1 | 2 | 1 | 0 | 0 | 0 | 0 |
| Hydrophilidae | *Boresus sp* | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Tabanidae | *Heamatopota sp* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 1 | 0 | 0 | 0 |
| Chironomidae | *Ablabesmyia sp* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 0 |
| | *Chironomus sp* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 |
| Coenagrionidae | *Coenagrion sp* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 0 |
| Corduliidae | *Epitheca bimaculata* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| Pilidae | *Lanistes sp* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 2 | 0 | 0 | 0 | 0 |
| Lymnaeidae | *Biomphalaria Pfeifferi* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 |
| Naucoridae | *Naucoris sp* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 4 | 0 | 1 | 0 | 1 |

## IV. Discussion

Macroinvertebrates play a central role in preserving and enhancing the ecological quality of our water bodies. Although often little known to the general public, these small aquatic organisms are essential indicators of the health of aquatic ecosystems. Their presence, diversity, and abundance reveal the ecological status of ponds, lakes, pools, and other water bodies. Macroinvertebrates encompass a broad category of aquatic organisms, including aquatic insects, crustaceans, mollusks, and other creatures visible to the naked eye. They form a crucial link in the food chain, serving as prey for many fish and amphibians. These living organisms colonize diverse aquatic habitats—ranging from rivers to settling basins—and help maintain ecological balance. Whether in natural ponds or irrigation reservoirs, macroinvertebrates occupy a variety of ecological niches. They thrive in environments as varied as rural pools and hillside reservoirs, which are often rich in organic sediment. This aspect of their

existence reflects both their adaptability and their significance within the ecological cycle. They play an active role in the decomposition of organic matter and in controlling populations of aquatic plants, which can often become invasive (Niemi et al., 1990).

The role of macro-invertebrates extends well beyond that of a simple ecological indicator. They are active participants in the natural purification of water. By filtering and breaking down organic matter, they contribute to water quality and clarity. They also play a part in structuring sediments—a crucial activity, particularly in retention basins and reservoirs used for snowmaking. Macro-invertebrates are genuine partners in the fight against aquatic pollution; by absorbing excess nutrients and consuming overabundant algae, they prevent the eutrophication of water bodies. In doing so, they reduce the risk of excessive proliferation of invasive aquatic plants. These organisms act as true regulators of the aquatic environment. We recognize the importance of macro-invertebrates and their central role in the ecological excellence of aquatic habitats. Our efforts focus on ecological and sustainable measures to balance and preserve water bodies. Through innovative techniques, we address sedimentation and aquatic imbalances, providing a healthy environment for biodiversity to thrive. Studying and protecting macro-invertebrates allows for a deeper understanding of the ecological dynamics of water bodies (Niemi et al., 1990). Such knowledge is essential for developing more effective management strategies, thereby ensuring the long-term resilience of aquatic environments. It is also vital to raise awareness among the general public and local stakeholders regarding the importance of macro-invertebrates. Their preservation is a guarantee of the ecological excellence of our precious aquatic environments. Pollution of an aquatic habitat—for instance, through oil discharges—typically reduces the number of species and/or the diversity of macro-invertebrates present in that environment. Indeed, only a small number of species can survive in a polluted environment; these are known as "tolerant" species. Consequently, such an environment contains a large number of individuals belonging to only a few species. In a healthy environment, one finds a moderate number of individuals, but a high diversity of species. Since both sensitive and tolerant organisms can be present in healthy environments, it is the absence of sensitive groups and the presence of tolerant groups that indicate whether the ecosystem under study is under stress, according to the French Standardization Association (AFNOR, 2004).

It is well established that climate change will have consequences for biodiversity, and that organisms will respond to these changes in a variety of ways. Such shifts will affect the ecological services provided to us by natural ecosystems and watercourses. Consequently, understanding these changes within a given territory is essential for developing appropriate strategies to mitigate or adapt to the impacts of climate change (Peres-Neto et al., 2013). Monitoring bioindicators can be particularly useful in this regard, as it facilitates the collection of data needed to develop models that predict the effects of climate change on biodiversity (EPA, 2012). Changes in air temperature and precipitation patterns lead to shifts in water temperature, flow rates, hydrological cycles, and degree-days. These alterations, in turn, disrupt aquatic ecosystems—responses that can be documented through, for example, changes in community composition, the number of reproductive cycles, evolutionary adaptations, and the geographic distribution of communities (EPA, 2012). The temperature tolerance of benthic macroinvertebrates (BMIs) is one of the traits monitored to better understand the consequences of climate change for benthic communities (EPA, 2012; Barbour et al., 1999).

Benthic macroinvertebrates are organisms lacking a backbone that are visible to the naked eye (or with a magnifying glass) and spend all or part of their life cycle on the bottom of watercourses, lakes, or wetlands—either on or within the substrate. This diverse group primarily includes: insects (caddisfly larvae, mayflies, stoneflies, chironomids/midges, and beetles); mollusks (gastropods and bivalves); crustaceans (amphipods and isopods); and worms (annelids, oligochaetes, and leeches). Macroinvertebrates serve as essential biological tools for assessing the ecological status of aquatic environments (such as rivers, streams, and coastal areas). They exhibit varying degrees of sensitivity to pollution: each species has its own specific tolerance level regarding physico-chemical disturbances (such as dissolved oxygen, pH, nitrates, or pesticides) and morphological alterations (such as substrate clogging or the artificial modification of riverbanks). Sensitive species (highly sensitive taxa)—such as stoneflies or mayflies—disappear very quickly when water becomes polluted; their presence is an indicator of very high water quality. Tolerant species—such as certain oligochaetes or chironomid larvae—can withstand heavily degraded environments or those enriched with organic matter; their overabundance often signals pollution or an ecological imbalance. Furthermore, they act as temporal integrators: unlike chemical analyses, which provide only a "snapshot" of water conditions at a specific moment in time, macroinvertebrates have lifespans lasting several months, meaning they reflect the cumulative impact of past pollution. Within the aquatic food web, they occupy a central position: they transform organic matter (dead leaves, wood, microalgae) and serve as a primary food source for many predators, such as fish, amphibians, and birds (Gravel et al., 2010). In forested or tropical

environments, they play an active role in the recycling of organic carbon and the decomposition of plant litter that has fallen into the water (Talhaoui et al., 2020).

IV. Conclusion

Physicochemical analysis of water—which involves measuring parameters such as pH, conductivity, turbidity, hardness, alkalinity, and the presence of dissolved chemical compounds—reveals a degradation in the quality of water from wells, springs, and boreholes in areas near the oil fields of Doba (Chad). A low level of biodiversity among benthic macroinvertebrates is observed in the Doba oil basin in Chad, which presents a major ecological and public health concern. Doba is a town in southern Chad and the capital of the Logone Oriental region; it has played a central role in the oil industry since the 2000s. The families identified include Dytiscidae, Belostomatidae, Nepidae, Atyidae, Gomphidae, Libellulidae, Hydrometridae, Tabanidae, Chironomidae, Coenagrionidae, Corduliidae, Pilidae, Lymnaeidae, and Naucoridae. The Dytiscidae family is represented by 5 species, followed by the Gomphidae and Libellulidae with 3 species each, and the Belostomatidae and Nepidae with 2 species each; the remaining families are represented by a single species. In the aquatic environment of Debeu, 14 species have been identified, including *Cylister vulneratus*. *Caridina africana* is represented by 10 individuals, *Libellula* sp. by 8, *Laccotrephes* sp. by 7, and *Lestinogomphus* sp. by 7, while the remaining species appear only sporadically. Measures to combat the overexploitation of oil resources, regulate agricultural activities, and restrict other human endeavors that degrade water quality should be considered. Such actions would help mitigate disturbances that harm aquatic ecosystems and pose health risks to the human population in the Doba area. Future research in this field should ideally encompass both the dry and rainy seasons, incorporating additional environmental parameters to assess seasonal variability and clarify the ecological preferences of the region's benthic macroinvertebrate taxa. Understanding the consequences of natural resource extraction and the human impact on water quality requires addressing the issue in all its complexity. Furthermore, the collection of data could facilitate the development of an index based on benthic macroinvertebrates that are sensitive to conditions in oil-extraction zones.

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