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**Biological Evaluation of the Water Quality in the Zit-emba
Reservoir using Freshwater Macroinvertebrates**

Presented by:

Bouaouiche Ibtihel Amani

Committee:

Chair: Pr. Metallaoui Sophia

University of 20 August 1955 - Skikda

Supervisor: MAB. Grini Halima

University of 20 August 1955 - Skikda

Examiner: MCA. Dziri Hamdi

University of 20 August 1955 - Skikda

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Dedication

To my beloved family

To my parents, whose unwavering support and endless sacrifices have shaped the person I am today.

To my precious sisters Douaa El Batoul, Tabssih Loudjaïne,

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Abstract

This study provides an ecological assessment of the Zit-emba reservoir in northeastern Algeria by employing freshwater macroinvertebrates as bioindicators of water quality. In light of increasing anthropogenic pressures on aquatic systems, the research adopts an integrative approach combining biological and physicochemical analyses. Four stations were selected based on accessibility and ecological heterogeneity. Over six seasonal sampling campaigns, 796 individuals belonging to seven taxonomic families were collected. Concurrently, key physicochemical parameters such as temperature, pH, dissolved oxygen, salinity, and turbidity were measured to support environmental correlation. The application of the Hilsenhoff Biotic Index facilitated the assessment of organic pollution levels, revealing spatial variations in ecological status, with some stations exhibiting signs of moderate to high degradation linked to human influence. The composition and structure of macroinvertebrate communities reflected distinct environmental gradients. These findings underscore the efficacy of macroinvertebrates as sensitive tools for biomonitoring and reinforce the role of biological approaches in aquatic ecosystem evaluation. The study advocates for the integration of such bioassessment methods into sustainable water resource management, particularly in regions with limited access to advanced laboratory infrastructure.

Key words: Zit-emba reservoir, macroinvertebrates, Hilsenhoff Biotic Index, bioassessment.

Résumé

Cette étude vise à évaluer la qualité écologique des eaux du barrage de Zit-emba, situé dans le nord-est de l'Algérie, en utilisant les macroinvertébrés aquatiques comme bioindicateurs. En réponse aux pressions croissantes sur les milieux aquatiques, cette recherche adopte une approche intégrée alliant analyse biologique et physico-chimique. Quatre stations d'échantillonnage ont été sélectionnées en fonction de leur accessibilité et de leur diversité écologique. Six campagnes de terrain ont permis de collecter 796 individus, répartis entre sept familles taxonomiques. Parallèlement, des paramètres physico-chimiques clés (température, pH, oxygène dissous, turbidité, salinité) ont été mesurés afin d'établir une corrélation environnementale. L'application de l'indice de tolérance de Hilsenhoff a révélé des niveaux variables de pollution organique, notamment dans les zones soumises à des influences anthropiques. L'analyse des données met en évidence une structuration communautaire différenciée selon les stations, traduisant des gradients écologiques marqués. Ce travail confirme la pertinence des macroinvertébrés comme outils de diagnostic environnemental. Il souligne l'importance d'intégrer les approches biologiques dans les programmes de surveillance des écosystèmes aquatiques, en particulier dans les contextes où les ressources techniques sont limitées. Les résultats obtenus offrent ainsi une base scientifique solide pour une gestion durable et adaptative des ressources hydriques.

Mots clés : Barrage de Zit-emba, macroinvertébrés, l'indice de Hilsenhoff, biosurveillance.

الملخص

تندرج هذه الدراسة في إطار التقييم البيئي للمياه العذبة، وتهدف إلى تقييم النوعية البيولوجية لمياه سد زيت العنبة في شمال شرق الجزائر، بالاعتماد على اللافقاريات المائية كمؤشرات حيوية فعالة لرصد التغيرات في جودة المياه. تأتي هذه المقاربة استجابةً لتزايد الضغوطات البشرية على النظم البيئية، والحاجة إلى أدوات تقييم موثوقة وغير مكلفة. تم اختيار أربع محطات للدراسة استناداً إلى: سهولة الوصول إلى محطات الدراسة والتنوع البيئي المحلي، حيث أُجريت ست حملات معاينة ميدانية لجمع العينات خلال فترة زمنية محددة. مكّنت الدراسة من جمع 796 فرداً من اللافقاريات، موزعين على سبع عائلات تصنيفية مختلفة، ما يعكس تنوعاً بيولوجياً متبايناً بين المواقع. وقد رافق هذا تحليل الخصائص الفيزيوكيميائية للمياه، مثل درجة الحرارة، ودرجة الحموضة (pH)، تركيز الأوكسجين، والملوحة، والعمارة. تم توظيف مؤشر Hilsenhoff، الذي أظهر تبايناً في درجات التلوث بين المحطات، مع تسجيل مؤشرات واضحة على تدهور بيئي يتراوح بين المتوسط و المرتفع، خاصةً في المناطق القريبة من التأثيرات البشرية المباشرة. تُبرز هذه النتائج أهمية اللافقاريات المائية كمؤشرات دقيقة على صحة النظم البيئية، وتدعم دمج التقييم البيولوجي ضمن استراتيجيات إدارة الموارد المائية. كما تؤكد على ضرورة تعزيز استخدام المؤشرات الحيوية في برامج المراقبة البيئية، خصوصاً في الحالات التي تفتقر إلى البنية التحتية المخبرية المناسبة.

الكلمات المفتاحية: سد زيت العنبة، اللافقاريات، مؤشر Hilsenhoff، المراقبة البيئية.

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Table of abbreviations

Abreviation	Signification
BMWP	Biological Monitoring Working Party
ASPT	Average Score Per Taxon
H'	Hilsenhuff index
S	Species richness
C	Abundance
IMS	IbtiMaScope
HBI	Hilsenhoff Biotic Index, using genus-level tolerance scores
FBI	Family-level Biotic Index, using tolerance scores at the family level
P_i	The relative frequency of species
ONNED	Observatoire National de l'Environnement et du Développement Durable (National Observatory of Environment and Sustainable Development)

ni	The number of individuals of a given species.
N	The total number of individuals
Xi	Number of individuals of taxon i
Ti	Tolerance score of taxon i
N	total number of individuals in the sample
Ct	The number of tolerant individuals
Ci	The number of intolerant individuals
TFC	Tolerant families count
Pt	Percentage of tolerant taxa
Pi	Percentage of intolerant taxa
T	Temperature

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Introduction

Water, the cornerstone of life, underpins the health of ecosystems and sustains human societies. It is essential for drinking, agriculture, industry, energy production, and biodiversity conservation. Although water covers approximately 71% of the Earth's surface with oceans containing over 99% of it freshwater resources in lakes, rivers, and reservoirs constitute only a small fraction of the global hydrosphere. Yet, these limited freshwater systems are of critical importance for sustaining terrestrial ecosystems and meeting human needs (Wetzel, 2001).

Reservoirs, as large engineered systems, play a central role in managing and storing freshwater from rivers and streams. They support a wide range of functions, including potable water supply, irrigation, hydroelectric power, flood control, navigation, and recreation. To fulfill these roles, reservoirs incorporate various structural and operational components such as spillways, intake systems, sediment management features, and occasionally, fish passage solutions. However, despite their utility, reservoirs can cause ecological disturbances, including habitat fragmentation, species displacement, and changes to aquatic ecosystems emphasizing the need for sustainable management (Guthrie Brown et al., 2025).

The quality of freshwater is among the most critical factors in maintaining ecological integrity and protecting human health (Damanik-Ambarita, 2016). In recent decades, freshwater ecosystems have faced increasing degradation due to anthropogenic pressures such as industrialization, agricultural expansion, and urban development. These activities introduce pollutants, degrade habitats, and alter hydrological regimes, thereby threatening both aquatic biodiversity and the availability of clean water. Algeria, like many other regions, is not immune to these challenges. In particular, the Zit Emba reservoir in the Skikda region—a crucial source of water for drinking and agriculture—is under growing pressure from industrial discharges, agricultural runoff, and untreated wastewater (Samai et al., 2023).

To monitor and protect such vital ecosystems, effective assessment tools are required. Traditionally, water quality monitoring has relied on physicochemical analyses, which, while useful for detecting specific contaminants, often provide only momentary snapshots of environmental conditions. In contrast, biological indicators, especially benthic macroinvertebrates, offer a more integrated and long-term perspective on ecosystem health. These organisms respond to a range of stressors and accumulate the effects of pollution over time, making them reliable bioindicators of both acute and chronic changes in water quality.

Macroinvertebrates are particularly useful due to their sensitivity to environmental disturbances, diversity of tolerance levels, and ease of sampling. Their community composition reflects ecological conditions and allows for the assessment of biological integrity in freshwater systems. Although widely

adopted globally, the use of macroinvertebrates as bioindicators remains underdeveloped in Algeria especially in reservoirs like Zit Emba.

This study seeks to bridge this gap by evaluating the ecological quality of the Zit Emba reservoir using macroinvertebrate communities in conjunction with physicochemical analyses. By exploring the relationships between invertebrate diversity, community structure, and environmental variables, the study aims to provide a more comprehensive assessment of the reservoir's ecological status and contribute to the development of effective monitoring strategies in Algerian freshwater systems. Despite their potential, these organisms remain underutilized as bioindicators in Algeria, particularly in the Zit Emba reservoir. This study aims to bridge this gap by exploring the relationship between invertebrate communities and key physicochemical factors, while also assessing the ecological status of various zones within the reservoir.

Additionally, this research aims to contribute to scientific knowledge by developing a practical, user-friendly educational platform, designed to support students and researchers in identifying invertebrate species, thereby bridging the gap between fieldwork and academic study.

Our work is structured into three chapters:

- The first chapter provides an overview of water quality assessment, focusing on bioindication and biomonitoring using aquatic macroinvertebrates. It also outlines the objectives of the identification application.
- The second chapter describes the study area, including the four sampling stations, and details the methods used for sampling and identifying macroinvertebrates. It also covers the design of the identification platform; including user needs analysis, technology choices, and system architecture.
- The third chapter presents the findings, including species identification, water quality index calculations, site comparisons, and a critical analysis of the results.
- Finally, the conclusion synthesizes the main insights and highlights potential future research directions.

Chapter 01: Bibliographic synthesis

1. Water Quality and Environmental Issues

The quality of freshwater resources is crucial for maintaining ecosystem health and human well-being, yet it is increasingly threatened by pollution, habitat loss, and climate change worldwide (Damanik-Ambarita et al., 2016). Industrial, agricultural, and urban activities introduce contaminants into freshwater systems, impacting aquatic life and human uses such as drinking water and irrigation. In Algeria, the Zit-emba reservoir in the Skikda region is a key freshwater source facing pollution from industrial effluents, agricultural runoff, and untreated wastewater (Samai et al., 2023).

Effective management of these challenges necessitates consistent and comprehensive water quality monitoring. Conventional physicochemical analyses provide valuable data on specific contaminants but often lack the ability to reflect the overall ecological status of aquatic environments (Lopez-Lopez & Seden-Diaz, 2015). Consequently, biological monitoring techniques, particularly the assessment of macroinvertebrate communities, have emerged as robust tools for evaluating the long-term health of freshwater ecosystems. Macroinvertebrates serve as reliable bioindicators, offering integrative insights into cumulative environmental impacts and the biological integrity of water bodies (Kenney et al. 2009).

2. Bioindication and Biomonitoring

While traditional physicochemical analyses are often performed to monitor water quality, they only offer snapshot data and may fail to detect long-term environmental changes. In contrast, biological monitoring, or biomonitoring, provides a more dynamic and ongoing assessment of water quality. Biomonitoring involves the use of living organisms, known as bioindicators, which can reflect the cumulative effects of pollution and habitat alteration over time (National Research et al., 2006).

Bioindicators are organisms that are particularly sensitive to changes in environmental conditions. They serve as an early warning system for identifying potential ecological issues in aquatic ecosystems (Wallace & Webster, 1996). Among bioindicators, aquatic macroinvertebrates (organisms visible to the naked eye that live in water for at least part of their life cycle) are widely used due to their diverse responses to pollution, ease of collection, and well-established role in food webs.

Macroinvertebrates, which include insects, mollusks, and crustaceans, have varying tolerance levels to pollutants. For example, species like mayflies (Ephemeroptera), stoneflies (Plecoptera), and caddisflies (Trichoptera) are typically found in clean, unpolluted waters, whereas other species such as non-biting midges (Chironomidae) and aquatic worms (Oligochaeta) are tolerant of polluted conditions (Bonada et al., 2006). This makes macroinvertebrate communities a useful tool for assessing the status of water quality.

Furthermore, macroinvertebrates are an integral part of freshwater ecosystems, playing key roles in nutrient cycling, organic matter decomposition, and serving as a food source for a variety of aquatic organisms (Nieto et al., 2017). Therefore, understanding the diversity and abundance of macroinvertebrates in an aquatic system provides valuable insights into its overall ecological health.

3. The Role of Aquatic Macroinvertebrates

Aquatic macroinvertebrates play an essential role in the functioning of freshwater ecosystems. They contribute to the biological diversity of aquatic habitats by providing a link between primary producers (e.g., algae and aquatic plants) and higher trophic levels (e.g., fish and birds). Many species of macroinvertebrates are also valuable in the cycling of organic material and the breakdown of detritus (Chakraborty et al., 2022).

In terms of water quality assessment, macroinvertebrates are ideal bioindicators because they are sedentary (many species remain in the same location for long periods), diverse, and exhibit specific responses to pollution. Because different macroinvertebrate taxa have different tolerances to pollutants, the composition and abundance of macroinvertebrate communities can indicate the health of a water body (Burgazzi et al., 2021). Some species are sensitive to organic pollution, while others can tolerate more polluted conditions.

The diversity of macroinvertebrate communities is often inversely related to the level of pollution in a water body. In heavily polluted waters, sensitive species are replaced by more tolerant ones. For example, the presence of mayflies, stoneflies, and caddisflies suggests good water quality, while the dominance of pollution-tolerant species such as chironomid midges or oligochaetes can signal degraded water quality (Bowa et al., 2018).

4. Biotic Indices Used

Several biotic and ecological indices have been developed to quantify water quality based on the presence, abundance, and diversity of macroinvertebrates. These indices help translate complex biological data into accessible and meaningful indicators of ecological health. In this study, four key indices are applied to assess the water quality of the Zit emba reservoir in Skikda, Algeria: the Biological Monitoring Working Party (BMWP) score, the Average Score Per Taxon (ASPT) (Zamora-Munoz C, et al 1995; bawa et al., 2018), hilsonhuff biotic index the Shannon-Wiener Diversity Index, and metrics of abundance and species richness.

The BMWP score assigns numerical values to different macroinvertebrate families according to their tolerance or sensitivity to pollution. Taxa that are highly sensitive to environmental disturbances receive higher scores, while more tolerant organisms receive lower scores. A higher overall BMWP

score therefore reflects better water quality (Mason, 2002 ; Zeybek et al., 2014). The ASPT, derived by dividing the BMWP score by the number of taxa identified, provides a standardized average that accounts for both community composition and pollution sensitivity.

Complementing these biotic indices, the Shannon-Wiener Index is used to evaluate the diversity of macroinvertebrate communities. It incorporates both species richness (the number of distinct species or taxa present) and evenness (how evenly individuals are distributed among those species), offering insight into ecosystem stability and resilience. A higher Shannon-Wiener value typically indicates a more diverse and balanced ecosystem, often associated with healthier aquatic environments.

Additionally, abundance (the total number of individuals observed) and species richness are considered to provide a broader ecological context. While high abundance might indicate favorable conditions, it must be interpreted alongside species richness and diversity; dominance by a few pollution-tolerant taxa could still indicate degraded water quality (Qipi et al., 2023).

Together, these indices offer a robust, multi-faceted assessment of the ecological integrity of the Zit-emba reservoir, enabling a more precise evaluation of anthropogenic impacts and guiding efforts in environmental monitoring and protection.

Chapter 02: Materials and Methods

1. Site presentation:

1.1. Geographic position:

The Zit Emba Reservoir is a vital multipurpose freshwater system located in northeastern Algeria, straddling the Skikda and Guelma Provinces. Its geographic coordinates are approximately $X= 883,50$; $Y= 207,50$; $Z= 80;50$ (Vnoukov et Kovalev, 2000), placing it within the Mediterranean basin, which strongly influences its hydrology and climate (Bougdah & Amira, 2017).

The reservoir lies in the municipality of Bekkouche Lakhdar (Skikda Province), with the downstream basin located in Skikda and the central and upstream portions extending into Guelma (Harrat & Achour, 2011). It is bordered to the north by Ben-Azzouz (Skikda), to the south by Roknia and Bouati-Mahmoud (Guelma), to the east by Berrahal and Eulma (Annaba), and to the west by Aïn Charchar and Es-Sebt (Skikda) (Belhadj, 2006).

The reservoir plays a strategic role in regional development, supplying drinking water, supporting agriculture, and sustaining aquatic ecosystems (Bougdah & Amira, 2017).

Hydrologically, the Zit Emba Reservoir receives its inflows from Oued El Hammam and Oued Mechekel and drains into the Kebir West River. It has a surface area of 8.1 km², a maximum depth of 41 meters, and a total storage capacity of approximately 120 million cubic meters (Bougdah & Amira, 2017). It also serves an important ecological function by trapping around 67% of suspended solids and 49% of dissolved solids annually. Recent studies have employed artificial intelligence to model its irregular hydrological behavior (Lefoula et al., 2023),

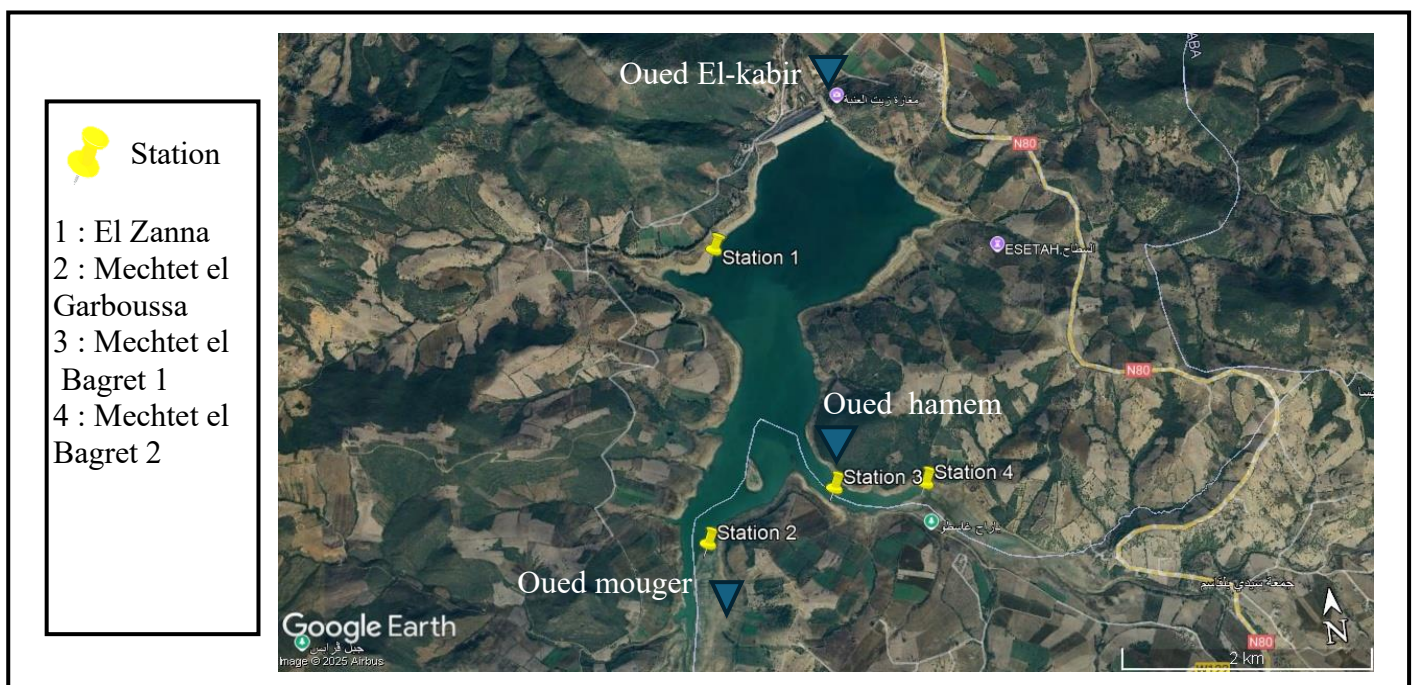


Figure 1 : Stations and revers distribution

Valley Morphology	Trapezoidal valley with steep slopes
Vegetation on Slopes	Covered by shrubs and predominantly grasslands

1.4 Physical and Environmental Characteristics of the Zit-emba Reservoir Watershed:

1.4.1. Topographic and Geomorphological Features:

The Zit-emba reservoir watershed exhibits a rugged relief dominated by steep slopes and a trapezoidal valley structure. Elevation in the catchment ranges from approximately 1,200 meters at the source to about 50 meters at the reservoir site. This steep gradient contributes to rapid surface runoff and increased erosive forces during rainfall events. Approximately 68% of the basin lies between 600 and 200 meters above sea level, indicating a significant altitudinal variation that directly influences water flow dynamics and sediment transport (Vnoukov & Kovalev, 2000).

1.4.2. Soil Composition and Fertility Constraints:

The soils of the Zit-emba catchment are primarily developed on marl and clay formations. These substrates result in fine-textured soils that are structurally weak and exhibit limited water infiltration capacity. The region's soils are notably poor in organic matter and essential nutrients such as nitrogen and phosphorus, which restrict their agricultural potential. Their erodibility, combined with steep topography and climatic variability, increases the risk of surface degradation and sediment loss (Roose & Arabi, 1990).

1.4.3. Erosion Vulnerability and Sedimentation Issues:

Due to a combination of steep slopes, erodible soils, and limited vegetation cover, the Zit-emba watershed is highly vulnerable to water-induced erosion. Research indicates that erosion severity in the basin ranges from moderate to high, depending on land cover and slope intensity. This ongoing erosion contributes to sedimentation within the reservoir, which gradually reduces its storage capacity and affects its long-term operational efficiency. Preventive soil and water conservation strategies are therefore critical (Gliz et al., 2015).

1.4.4. Vegetation and Natural Land Cover:

The upper regions of the watershed are covered by spontaneous vegetation, mainly shrubs and herbaceous species, which play a key role in stabilizing soils and controlling erosion. These natural plant communities thrive in minimally disturbed environments and are adapted to the semi-arid climate of northeastern Algeria. Although beneficial, this vegetative cover is not uniformly distributed, and in areas with intense slope gradients, its erosion control effectiveness remains limited (Boudiaf et al., 2012).

1.4.5. Human Impact and Land Use Patterns:

Human activities in the Zit Emba watershed are relatively limited. Agricultural practices and infrastructure development are minimal, which has helped preserve the natural landscape. However, this lack of anthropogenic pressure also implies a scarcity of active soil conservation and watershed management interventions. To ensure the sustainability of the reservoir and prevent accelerated sedimentation, integrated watershed management practices must be introduced and enforced (Boudiaf et al., 2012).

2. Sources of Pollution:

The Oued Hammam, the second main tributary feeding the Zit Emba Dam after Oued Mougger, receives various sources of pollution, including:

- Industrial wastewater from the tomato cannery and olive oil mills in Bouati Mahmoud.
- Domestic sewage discharged from the towns of Bouati Mahmoud and Ouled Ali.
- Thermal water effluents from the Hammam Ouled Ali hot springs (ONEDD,2010; Grini, 2013).

2.1. Types of Pollution:

Several types of pollution have been reported in the study area. Among them, two types appear to be particularly concerning:

2.1.1. Industrial Pollution:

The discharges from the tomato cannery located in Bouati Mahmoud (Guelma Province) are suspected to cause significant alterations in the chemical composition of the Oued Hammam's waters, which ultimately feed the Zit-emba reservoir (Belhadj, 2006).

The major source of water pollution in the Oued Hammam and the primary factor deteriorating the water quality of the Zit-emba reservoir is the untreated industrial wastewater released by the cannery.

If these discharges are not effectively controlled, they may lead to an irreversible ecological disaster, including reduced levels of dissolved oxygen and mass fish mortality (ONEDD, 2010; Grini, 2013).

2.1.2. Natural Pollution (Geogenic Contamination):

The presence of metallic ore deposits in the region has resulted in elevated levels of heavy metals such as lead (Pb), mercury (Hg), and zinc (Zn) (Belhadj et al., 2011).

The concentrations of Hg and Pb in surface waters in the area exceed permissible limits, indicating a significant level of contamination affecting the reservoir's water quality (Boudoukha et al., 2012).

High mercury concentrations up to 0.093 mg/L have been recorded at the emergence of the Hammam Ouled Ali thermal spring. However, as water flows downstream, these concentrations decrease

due to natural dilution processes, confirming the natural (geogenic) origin of this contamination (Belhadj et al., 2011).

3. Climate Study:

3.1. Climatic Characteristics:

The climate of the study area is largely influenced by its geographic position, particularly its proximity to the Mediterranean Sea (approximately 29 km away) and the region's varied topography (Vnoukov & Kovalev, 2000; Grini, 2013).

3.1.1. Temperature:

The region exhibits a mild Mediterranean climate, with cool winters and hot summers. January is typically the coldest month, with minimum temperatures reaching approximately 7°C, whereas August is the hottest, with maximum temperatures averaging around 33.68°C (Grini, 2013).

3.1.2. Precipitation:

Skikda Province is among the most humid regions in Algeria, particularly during the winter months. Conversely, summer is characterized by a significant reduction in rainfall, making it the driest season of the year (Grini, 2013).

3.1.3. Relative Humidity:

Relative humidity levels in Skikda are generally higher in winter than in summer. January records the highest humidity, with average values exceeding 70% over the observed period (1984–2011). These high levels are primarily attributed to the moisture-laden air masses from the nearby sea.

3.1.4. Wind:

The prevailing winds in the study area originate mainly from the north and south. Wind speeds tend to be highest during the winter months, while a noticeable decline in wind intensity is observed throughout the summer season (Grini, 2013).

4. The study approach:

This study aims to assess the ecological quality of the Zit Emba reservoir through the establishment of faunistic inventories of freshwater macroinvertebrates and the analysis of their relationship with physicochemical parameters. By surveying representative habitats across four stations using a standardized sampling protocol informed by prior literature, the research provides insights into the biological health of the aquatic ecosystem.

As part of this work, a desktop application is also being developed to facilitate the identification of freshwater macroinvertebrates based on their morphological traits. This tool is intended to support

students, researchers, and environmental professionals particularly those lacking access to advanced taxonomic keys by offering an accessible and scientifically grounded resource for biomonitoring and environmental assessment.

5. Selection of Sampling Stations:

Among the initially surveyed locations, four stations were selected for this study (Fig. 2). The choice of these specific stations was guided by several criteria, including accessibility, the presence of diverse biotopes, and their proximity to urban settlements and agricultural areas factors which allow for a more accurate assessment of potential anthropogenic impacts on the reservoir. Additionally, these stations are distributed in areas influenced by streams and wadis feeding into the Zit-Emba reservoir, enabling spatial representation of the system.

In practice, these four stations were also the only sites that were realistically accessible during fieldwork, which further justified their inclusion in the sampling design.

5.1. Description of sampling sites :

- **Station 1: El Zanna**

This station is located in the western section of the reservoir. It represents conditions potentially influenced by lateral inflows and relatively stable hydrodynamic zones.

- **Station 2: Mechtet El Garboussa**

Positioned in the southern part of the reservoir, this site may reflect the impact of direct catchment runoff and anthropogenic pressures from the surrounding land use.

- **Station 3: Mechtet El Bagrat 1**

Located in the southeastern region of the reservoir, this station was selected to capture transitional ecological conditions between the southern and eastern zones.

- **Station 4: Mechtet El Bagrat 2**

Also situated in the southeastern sector, in close proximity to Station 3, this site allows for a more detailed spatial comparison within this ecologically relevant area.



Figure 2 : Aerial photograph of station 1(Source:Google earth pro 2025).

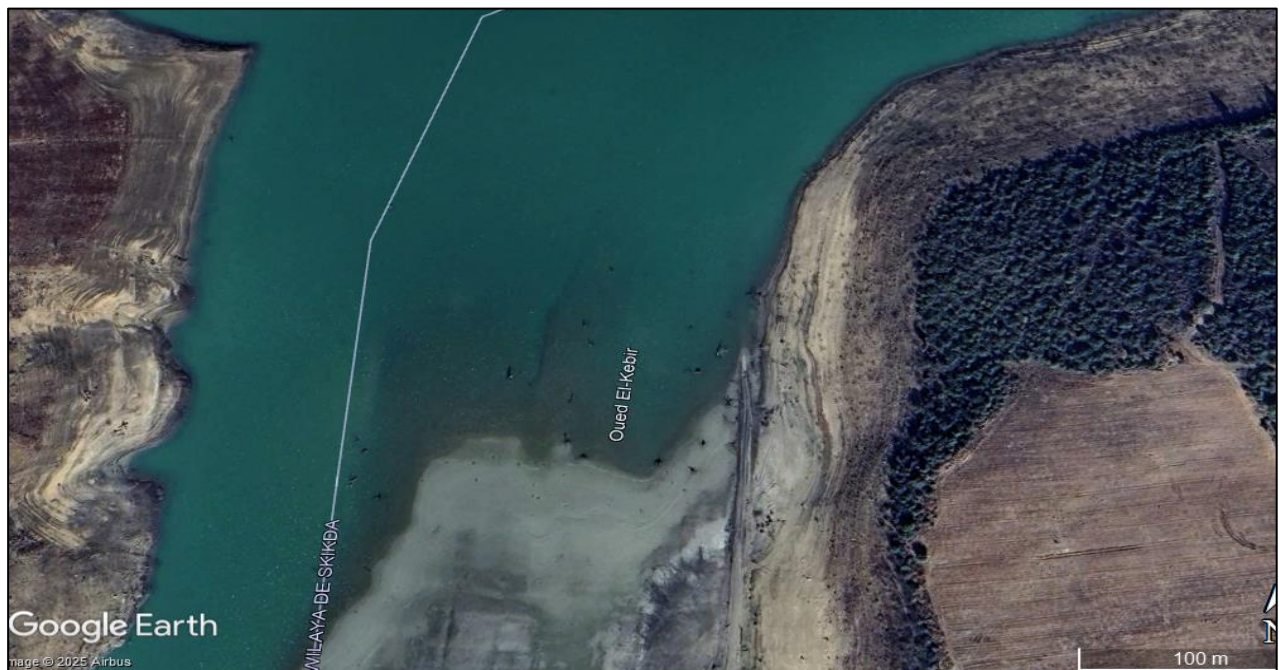


Figure 1 : Aerial photograph of station 2(Source:Google earth pro 2025).

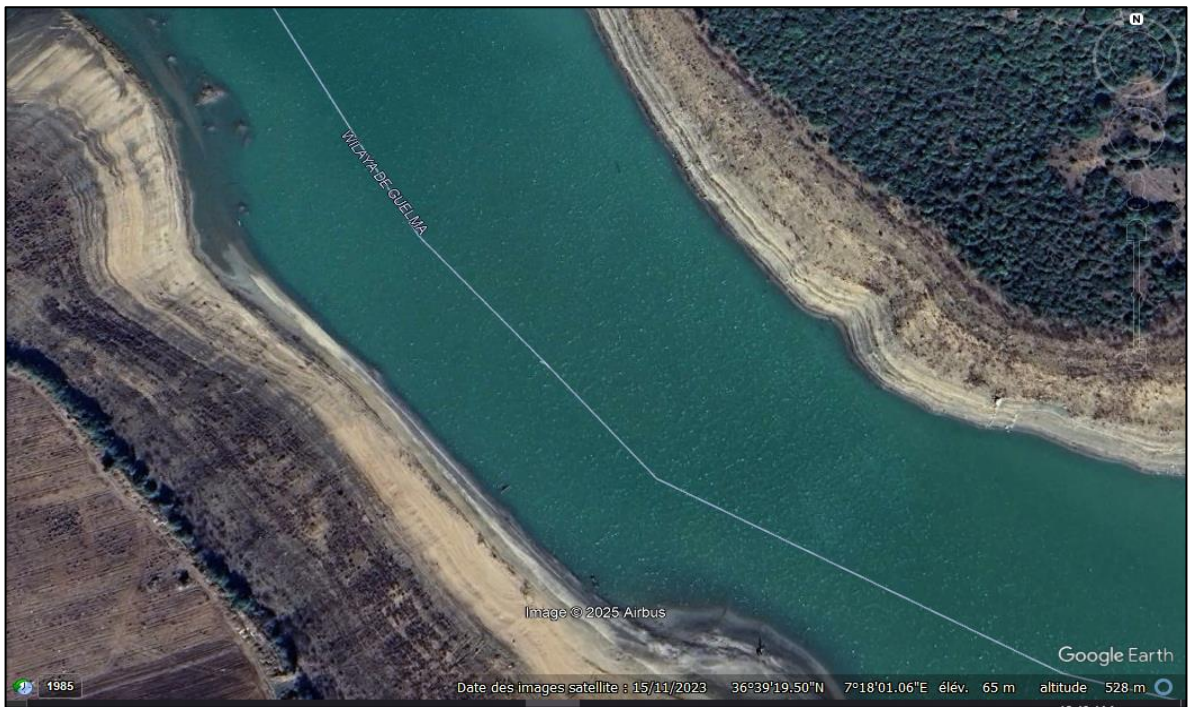


Figure 3 : Aerial photograph of station 3(Source:Google earth pro 2025).



Figure 4 : Aerial photograph of station 4 (Source:Google earth pro 2025).

Table 2 : General characteristics of the study sampling stations

Station	Names	Location	Substrate	Water flow	Aquatic Vegetation	Riparian Vegetation	Sunlight Exposure	Activities	General remarks
S1	El zanna	Bekkouche Lakhdar (Skikda) the outlet of the El Zanna stream into the reservoir	clay and silt	Average	Duckweed	Carthannus lanatus L., Ditrichia graveolons (L.) Greuter , Plantago lanceolata L., Trifolium sp, Persicaria sp., Polygonum sp., Leontodon saxatilis Lam., Spergularia boconei (Scheele) Asch. & Graebn.	Very exposed	Intense agricultural activity	Turbid water , Pumping, Solid and liquid discharges
S2	Mechet El garboussa	Azzaba (Skikda) Near to the outlet of Mougger stream		Moderately high flow	Duckweed		Very exposed	Intense agricultural activity	Slightly turbid water, Fertilizer input
S3	Mechet El bagret -1-	Bouati Mahmoud (Guelma) The outlet of the El Hamam stream into the reservoir	Clay, silt, and sand	Average				Intense agricultural activity & fishing	Clear water
				None					
S4	Mechet El bagret -2-			None	Absent		Exposed	Fishing	Clear water

6. Field Sampling

6.1. Macroinvertebrate Sampling

6.1.1. Sampling Period

Macroinvertebrate sampling was conducted over a four-month period, from March to May 2025. During this time, a total of 6 sampling campaigns were carried out.

6.1.2. Material used:

- ❖ Kick-net.
- ❖ measuring wheel.
- ❖ Plastic sterile containers for water samples.
- ❖ Glass sterile containers for invertebrate's samples.
- ❖ Cooler box for transporting and preserving water samples.
- ❖ A box for transporting invertebrate's samples.
- ❖ 95% ethyl alcohol (used as a preservative agent).
- ❖ Waterproof labels for sample identification.
- ❖ Backpacks for carrying field equipment.
- ❖ Cell phone camera for photographic documentation.
- ❖ Rubber boots for working in aquatic environments.
- ❖ Field clipboard pad for data recording.
- ❖ Pencils.
- ❖ Thermometer for on-site temperature measurements.
- ❖ Waterproof sampling suit for protection in wet environments.
- ❖ Sterile sampling bottles for water collection.
- ❖ Tweezers (forceps) for specimen handling.
- ❖ Field clipboard for data recording.
- ❖ Black and red pens for clear note-taking and color-coded labeling.
- ❖ Disposable medical gloves to prevent contamination.

6.1.3. Field Sampling Methods :

Macroinvertebrates were collected using a kick-net, the organisms were manually dislodged from the substrate by hand.

6.2 Sampling Protocol

6.2.1 Macroinvertebrate sampling :

Based on : (Moisan et pettilier 2008 modified by Grini, 2013)

A 100-meter stretch of stream or riverbed was selected as the representative sampling station. Within this section, all relevant habitat types (including riffles, runs, and pools) were included. Kick-net samples were collected at various depths and positions some along the edges and others toward the center to maximize the diversity of collected taxa.

- ❖ A total of 20 net sweeps were conducted, covering an approximate total surface area of 3 m².
- ❖ Each individual net sweep was transferred into a standard collection bucket. Once all 20 sweeps were completed, the entire sample was transferred onto a 600 µm mesh sieve or net. The net was then rinsed in clean water and gently shaken to remove fine sediments. Coarse debris was also rinsed and discarded after visual inspection for organisms.
- ❖ After allowing excess water to drain from the sample, the remaining material was transferred into a sample container pre-filled with 95% ethanol to preserve the specimens. To ensure effective preservation and avoid damage to the organisms, containers were not overfilled with material.
- ❖ Each container was labeled with a waterproof label indicating the date, station name and/or number, and other relevant metadata.

6.2.2. Water sampling

Water sampling was conducted at all four study stations using a standardized and carefully controlled method to ensure the reliability and comparability of the results.

6.2.2.1. Sampling Method

Based on (Rodier et al., 2009)

- ❖ Water was collected at each station at least 3 meters away from the shoreline and at a depth of approximately 30 centimeters, in order to minimize contamination from surface films, sediment resuspension, and bank runoff.
- ❖ Prior to collection, sampling bottles were rinsed three times with water from the reservoir to reduce the risk of cross-contamination and ensure accurate sample preservation.
- ❖ A total volume of 1.5 liters of reservoir water was collected per station to carry out physicochemical analyses.
- ❖ Each sample container was clearly labeled with the sampling date and the name or code of the station to ensure proper traceability.

6.2.3. Conservation:

The water samples were immediately stored at 4 °C to preserve their physical and chemical integrity. This temperature is recommended in standard protocols to inhibit microbial activity, slow down biological processes, and prevent chemical transformations that could alter key water quality parameters such as dissolved oxygen, nutrient concentrations, and pH. Cooling the samples ensures that the analytical results obtained in the laboratory accurately reflect the environmental conditions at the time of sampling. This approach follows established guidelines for the conservation of water samples prior to physicochemical analysis (Rodier et al., 2009).

6.2.3.1 Physicochemical parameters analyses:

Table 3 : The physicochemical parameters analysed of water

Parameter	Abbreviation	Unit
Temperature	T°C	°C
Hydrogen potential (pH)	pH	—
Salinity	S	g/L
Electrical Conductivity	EC or Cond	µS/cm
Dissolved Oxygen	O ₂	mg/L
Turbidity	Turb	NTU
Nitrite	NO ₂ ⁻	mg/L
Ammonium	NH ₄ ⁺	mg/L

7. In the laboratory:

7.1 Identification of macroinvertebrates:

Macroinvertebrate samples were sorted and identified under appropriate lighting using forceps, Petri dishes, specimens were first separated from organic debris and sediment, then identified to the family level using standard taxonomic keys and identification guides (Moisan et Pelletier, 2010; Tachet et al., 2010). Identification was based on morphological characteristics such as body segmentation, appendage structure, and respiratory organs.

Table 4 : Laboratory Equipment Used

Category	Equipment	Use
Observation Tools	Binocular magnifiers	Observation of specimens High-magnification observation
	Microscopes	
	Stereomicroscope	Detailed morphological observation
Sample Handling Tools	Forceps (tweezers)	Handling and manipulation of specimens
	Petri dishes	Holding and separating specimens
	Rectangular tray	Support surface for sorting
Measurement Instruments	Vernier caliper	Measurement of specimen dimensions
Slide Preparation Tools	Slides and cover slips	Mounting for microscopic observation

Once isolated, each macroinvertebrate was examined under a stereomicroscope to observe specific morphological features critical for taxonomic identification. These features include body shape, number and type of legs, antennae, gill structures, and presence of cerci or cases. Identification was carried out using taxonomic keys and reference guides (Tachet et al.2010), allowing for classification to the family level based on observable traits. When necessary, slides were prepared for detailed examination of finer structures.

8. Data analysis methods:

8.1. Ecological composition indices:

8.1.1. Species richness “S”:

Species richness corresponds to the total number of species present in the community under consideration within a given ecosystem (Ramade, 2009).

8.1.2. Abundance “ C ”:

It corresponds to the contribution of each species in terms of individuals relative to the total number of individuals (Dajoz, 1971; Grini 2013)

Calculated by the formula :

$$C = n_i/N \times 100$$

8.1.3. Ecological Structure Indices

Species richness depends on the number of species and the regularity with which individuals are distributed among those species. Numerous indices have been developed to assess taxonomic diversity (Dajoz, 1982; Moisan and Pelletier, 2008).

❖ Shannon-Wiener Diversity Index:

The Shannon-Wiener diversity index is the most commonly used. This index considers the number of individuals for each taxon.

The formula used to calculate the Shannon-Wiener index (H') is as follows:

$$H' = -\sum p_i \log_2(p_i)$$

Where:

- P_i : the relative frequency of species where : $P_i = n_i/N$.
- n_i : the number of individuals of a given species.
- N : the total number of individuals.

The value **3.322** is used to convert the logarithm to base 2:

$$H' = -3.322 \sum p_i \log(p_i)$$

❖ Evenness (Equitability):

This is the ratio between the effective diversity of the community (H') and its theoretical maximum diversity, considering species richness ($H \text{ max}$) (Ramade, 2009).

$$e = \frac{H'}{H \text{ max}}$$

where :

- $H \text{ max} = \log_2 S$
- S = specific richness

8.1.4. Tolerance or Intolerance to Pollution:

The percentage of one or two dominant taxa is a variable often used as a simple indicator of tolerance to pollution. Thus, a community dominated by a few taxa may indicate the presence of stress. Variables or scores based on species tolerance to organic pollution are frequently used. These tolerance scores, ranging from 0 to 10, have been assigned to various taxa (Hilsenhoff, 1988 in Moisan and Pelletier, 2008).

Taxa with scores < 4 are considered pollution-intolerant, while those with scores > 6 are considered tolerant.

❖ Percentage of tolerant taxa (Pt%):

The values are calculated using:

$$P_t\% = \frac{C_t}{C} \times 100$$

Where:

- C_t : number of tolerant individuals.
- C : total number of individuals.

❖ Percentage of intolerant taxa (Pi%):

$$P_i\% = \frac{C_i}{C} \times 100$$

Where:

- C_i : number of intolerant individuals.
- C : total number of individuals.

❖ Hilsenhoff Index

This index takes into account the tolerance scores of each organism within the community. Depending on the taxonomic level of identification, the Hilsenhoff Index has different names:

- HBI: Hilsenhoff Biotic Index, using genus-level tolerance scores
- FBI: Family-level Biotic Index, using tolerance scores at the family level

$$FBI = \sum \frac{x_i - t_i}{n}$$

Where:

- x_i : number of individuals of taxon i
- t_i : tolerance score of taxon i
- n : total number of individuals in the sample

Table 5 : The interpretation scale of the results obtained using the FBI is as follows (Hilsenhoff, 1988; Moisan & Pelletier, 2008).

FBI Value Range	Interpretation
0.00 to 3.75	Excellent: no organic pollution
3.76 to 4.25	Very good: slight probable organic pollution
4.26 to 5.00	Good: probable moderate organic pollution
5.01 to 5.75	Fair: fairly substantial organic pollution
5.76 to 6.50	Fairly poor: substantial organic pollution
6.51 to 7.25	Poor: very substantial organic pollution
7.26 to 10.00	Very poor: severe organic pollution

9. Application architecture (IMS):

9.1. Overview:

IbtiMaScope is a web-based application developed to support the identification of freshwater macroinvertebrates and assist in water quality assessments. Designed primarily for students, researchers, and citizen scientists, the tool enables users to identify organisms based on morphological characteristics across multiple taxonomic levels phylum, class, order, The platform integrates ecological data, seasonal occurrence, habitat preference, and difficulty rating to support ecological studies and environmental monitoring efforts.

9.2. Architectural Style:

The application adopts a three-tier architecture that separates concerns across distinct layers:

- **Presentation Layer:** Provides an interactive, responsive user interface built in HTML, CSS, and JavaScript.
- **Logic Layer:** Processes user input and manages data interaction logic such as language translation, species filtering, and identification flow.
- **Data Layer:** Includes structured species data, trait descriptions, taxonomy details, and ecological metadata embedded within JavaScript.

This modular design ensures the application is easy to maintain, scale, and extend with future capabilities such as database integration or AI-powered identification.

9.2.1. Components and Layers :

❖ **User Interface (UI) :**

- **Technologies:** HTML5, CSS3, Font Awesome for icons, Google Fonts for typography.
- **Features:**
 - Language selection dropdown (supports EN, FR, AR, DE, ES).
 - Light/dark mode toggle.
 - Real-time clock
 - Responsive layout.
 - Dropdowns for taxonomic filtering (phylum → class → order → ex of families).
 - Identification result display with ecological data and image.
 - Action buttons for clearing input, saving as PDF, and reporting sightings.

❖ **Business Logic Layer :**

- **Functions:**
 - Filters species based on user-selected traits.
 - Displays ecological descriptions (e.g., habitat, seasonality, tolerance).
 - Dynamically updates interface elements according to selected language.

- Manages theme switching (light/dark mode).
- Methods: Implemented in JavaScript within embedded `<script>` tags

❖ Data Layer :

- Format: JSON-like objects within JavaScript arrays
- Contents:
 - Taxonomic hierarchy (phylum → order)
 - Orders descriptions and ecological functions
 - Habitat preferences and seasonal availability
 - Difficulty ratings for identification
 - Orders images (where available)

The data is embedded directly into the frontend for fast loading and offline access, making it suitable for field use.

❖ Data Flow :

1. User selects traits (e.g., Phylum → order).
2. The app filters species data from the dataset based on selected criteria.
3. Matching species is displayed with its scientific info, ecology, image, and other metadata.
4. **User may save result as PDF or report a sighting.**

❖ Technology Stack :

- Frontend: HTML5, CSS3, JavaScript.
- UI Libraries: Font Awesome, Google Fonts.
- Framework: None (lightweight and framework-free for speed and simplicity).
- Translation Handling: In-script translation dictionary (multilingual support).
- Data Storage: In-memory JavaScript array objects (planned future integration with Firebase or SQLite).

❖ Security and Performance :

- Security: All data is client-side, reducing exposure; input controls are validated.
- Performance: Fast load times due to preloaded data, no server-side dependencies.
- Accessibility: Responsive design ensures usability across mobile and desktop devices.

❖ Scalability and Future Improvements:

The current architecture is structured to easily allow:

- Connection to an external ecological database or cloud backend (e.g., Firebase).
- Expansion to include genus/species levels.
- Enhanced reporting and export tools.
- Support for community-contributed observations.

❖ A part of the code :

```

},
Copepoda: {
  description: "Small crustaceans found in nearly every freshwater and marine habitat.",
  characteristics: "Tear-shaped body, single median eye, antennae used for swimming"
},
Insecta: {
  description: "Insects are a class of invertebrates within the arthropod phylum. They have a chitinous exoskeleton, three-part body, and three pairs of jointed legs.",
  characteristics: "Three body segments (head, thorax, abdomen), compound eyes, one pair of antennae"
},
Bivalvia: {
  description: "Aquatic mollusks with two hinged shells, including clams, oysters, and mussels.",
  characteristics: "Two-part shell, filter-feeding lifestyle, no distinct head"
},

```

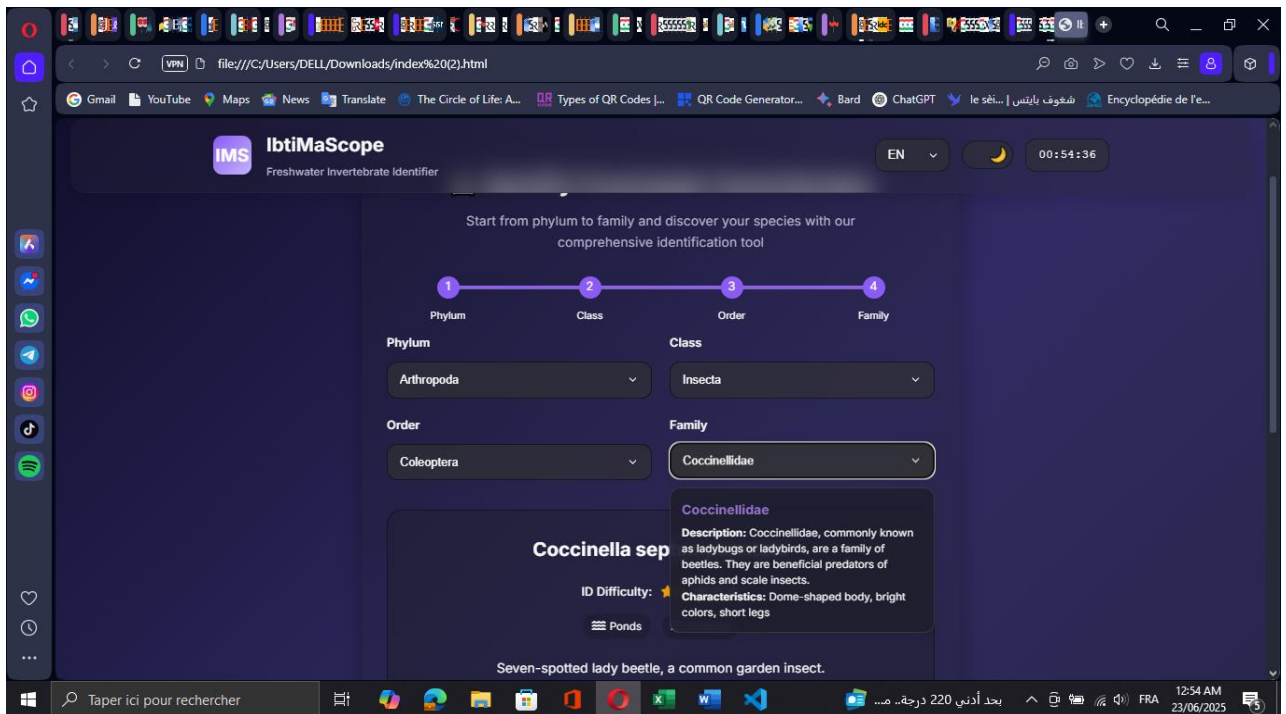


Figure 5 : The user interface of IbtimaScope

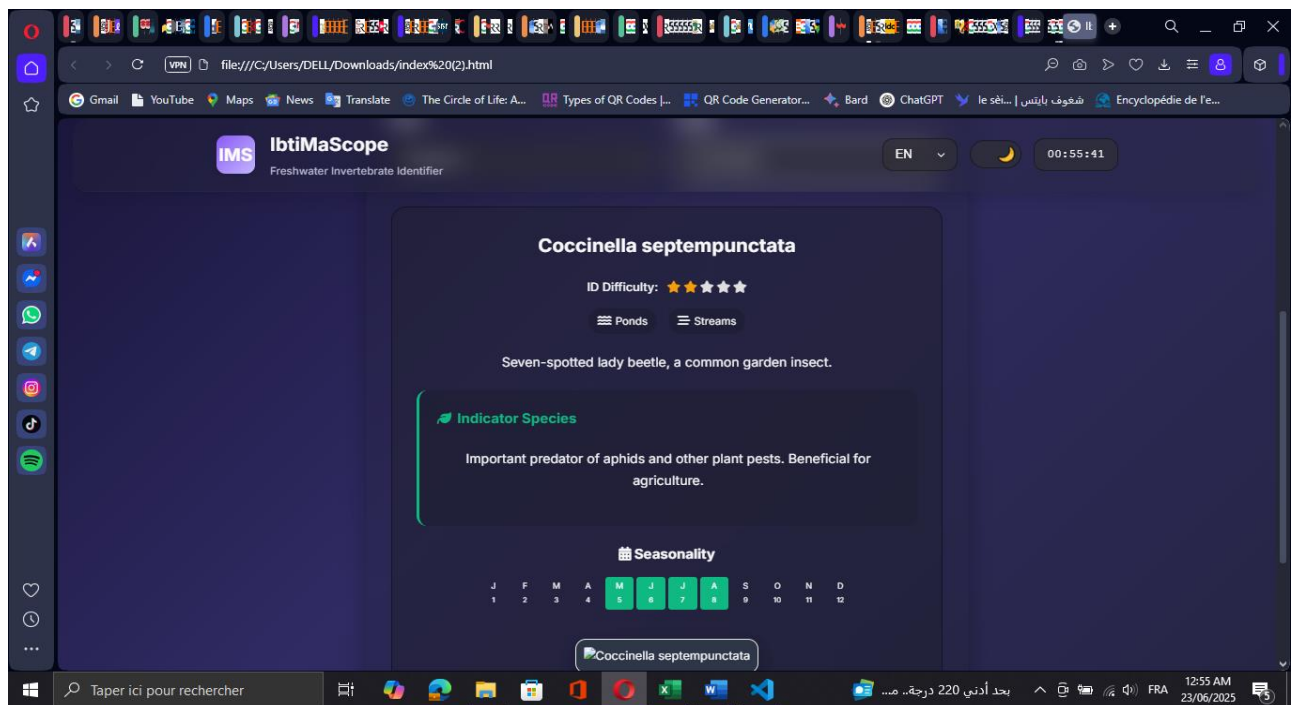


Figure 6 : Example on how our application identifies an order

Chapter 3: Results and discussion

1. Results :

1.1. Comprehensive analysis of the macroinvertebrate fauna :

Based on five sampling campaigns conducted over a period of three months (March, April, and May), a total of 796 individuals (Figure 8) were recorded and observed, distributed among five taxonomic groups.

Table 6 : Taxonomic Groups Recorded in the Study

Phylum /Class	Taxa	Number of families	Total abundance
CRUSTACEA	Atyidae (shrimp)	1	278
INSECTA	Corixoidea (water boatmen)	1	391
	Chironomidae (non-biting midges)	1	42
	Ceratopogonidae (biting midges)	1	8
ARACHNIDA	Arachnida (aquatic spiders)	1	1
MOLLUSCA	Unionidae (freshwater mussels)	1	48
NEMATODA	Nematoda (roundworms)	1	28
	TOTAL	7	796

Although the identification of macroinvertebrates was based on strict taxonomic principles, the available identification keys did not allow for the precise classification of all specimens.

Therefore, the taxonomic level (Table 6) considered for this study is the family level. A total of seven macroinvertebrate taxa were identified, including three belonging to the class Insecta (43%). Crustacea accounted for (15%), while Mollusca, Nematoda, and Arachnida each represented approximately (14%) (Figure 7).

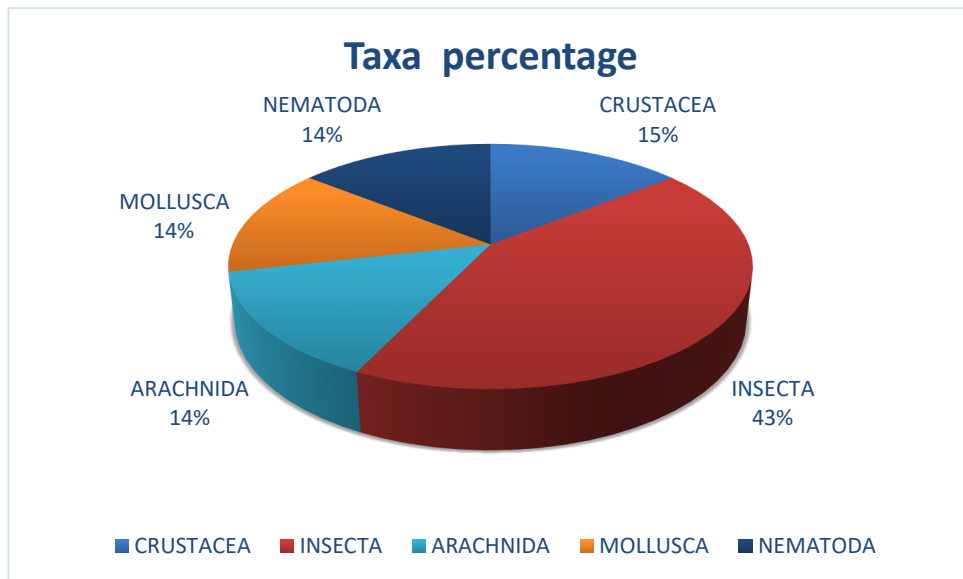


Figure 8 : The main inventoried taxonomic groups.

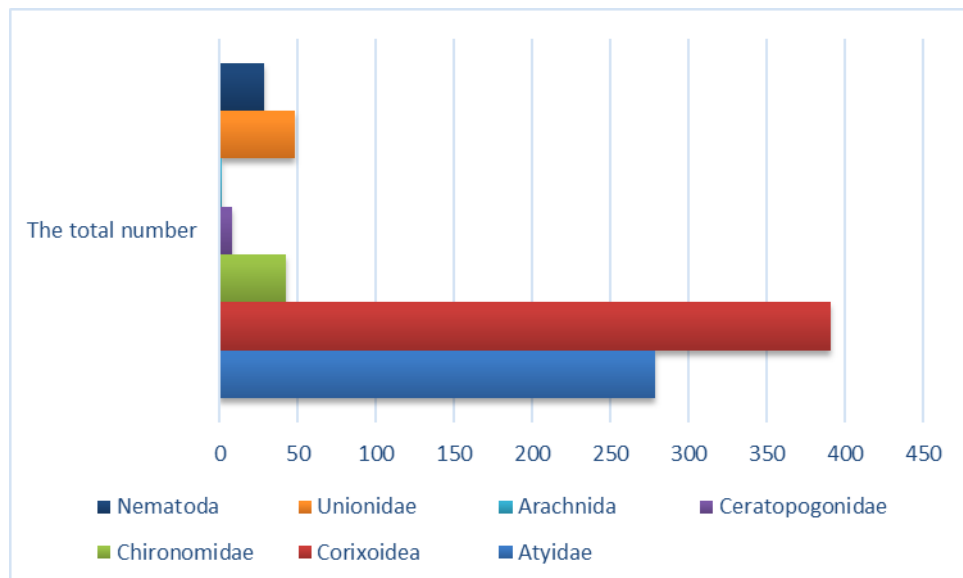


Figure 7 : Number of individuals recorded in each family.

1.2. Faunal composition of macroinvertebrates :

➤ Species richness « S » :

Table 7 : the species richness of the study zones.

Stations	Station 1	Station 2	Station 3	Station 4
Species richness « S »	7	6	4	0
Total	7			

The results presented in this table (Tab. 7) show that the species richness values of the collected families are close in the first three zones, with 7 families in zone 1, 6 families in zone 2, and 4 families in zone 3. The highest value is recorded in zone 1. In contrast, a clear difference is observed in zone 4, which shows a minimum species richness of 0.

➤ **Relative abundance of faunal groups:**

The analysis of the collected community (Fig.11) reveals a clear dominance of Corixoidea, representing 46.2% (391 individuals) of the total sampled fauna. This group was abundant across all sampling stations and consistently present during the entire study period. Corixoidea was followed, in order of numerical abundance, by Atyidae (32.8%, 278 individuals), Unionidae (5.7%, 48 individuals), Chironomidae (4.9%, 42 individuals), and Nematoda (3.3%, 28 individuals). In contrast, Ceratopogonidae (0.9%, 8 individuals) and Arachnida (0.1%, 1 individual) exhibited very low abundances.

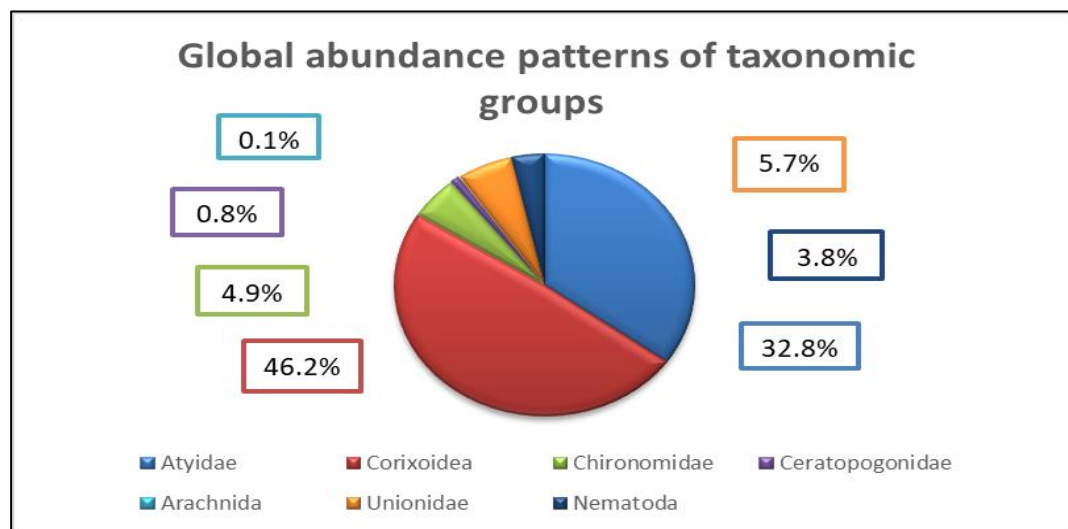


Figure 9 : Global abundance patterns of taxonomic groups

▪ **Relative abundance of taxonomic groups by order of importance:**

- The Crustaceans collected (Fig.11) belong to the order Decapoda and are represented exclusively by the family Atyidae, accounts for all individuals in this group, with a total of 278 specimens (32.8% of the total fauna). This species was recorded at all sampled stations, indicating its ecological tolerance and wide distribution across the study area.
- The Hemiptera (Fig.11) are represented by the superfamily Corixoidea, which is the most dominant taxonomic group in the study, accounting for 391 individuals, i.e., 46.2% of the total abundance.

- The Diptera (Fig.11), one of the most diverse orders observed, includes the family Chironomidae, which represents 4.9% (42 individuals) of the entire faunal composition. The Ceratopogonidae family was also recorded, with only 8 individuals (0.9%).
- Bivalves (Fig.11) are represented by the family Unionidae, with 48 individuals (5.7% of the total fauna).
The Nematodes were present with 28 individuals (3.3%), suggesting a moderate abundance within the benthic community.
- Arachnids, on the other hand, were very poorly represented with only one individual (0.1%), indicating a marginal presence in the aquatic ecosystem.

1.2. Indexes of structure:

The values of the Shannon-Weaver diversity index (H') for the study stations are reported in the following table.

Table 8 : The Shannon Diversity Index (H') and evenness (E)

	Station 1	Station 2	Station 3	Station 4	Total
H'	1,6308	0,6251	0,839	0	3,09483033
Log S	0,84509804	0,77815125	0,602059991	0	2,2253
H max	2,8074	2,585	2	0	7,3923
E	0,5809	0,2418	0,4195	0	1,2422

The values reported in the table (Tab.8) show significant differences between the stations in terms of diversity and the balance of macroinvertebrate communities. Station 1 exhibits the highest Shannon-Weaver diversity index ($H' = 1.6308$), indicating a relatively high level of diversity. In contrast, the lowest values some of which are even null ($H' = 0$) observed in Stations 2 and 4, suggest a very low or absent biological diversity.

The value of Log S, representing the logarithm of species richness, follows a similar trend. It reaches its maximum in Station 1 (0.845), highlighting greater taxonomic richness compared to the other stations. Station 4 shows a value of zero, confirming the absence of diversity. Regarding the maximum theoretical diversity (H max), the highest value is also recorded in Station 1 (2.8074), while the other stations display lower values, with the minimum again at zero in Station 4.

➤ The equitability index (E) :

which reflects how evenly individuals are distributed among taxa, varies considerably across stations. It is highest in Station 1 (0.5809), indicating a relatively balanced community structure. The other stations display much lower values, or even zero, pointing to a strong imbalance likely caused by the dominance of a single taxon.

1.3. Biological indices :

- Tolerance and intolerance :

- ❖ Station 1 :

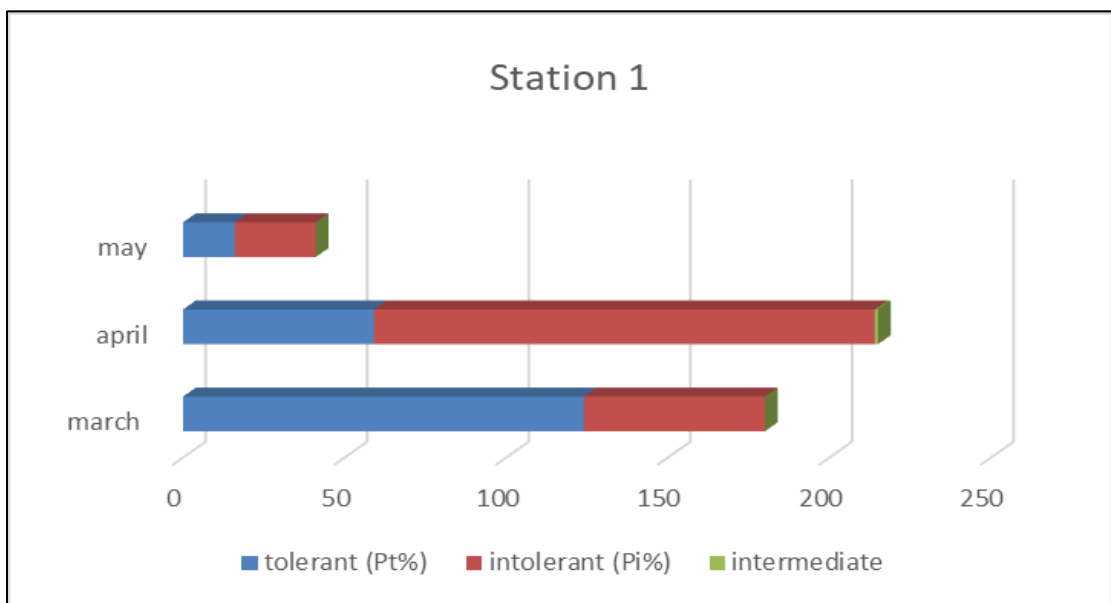


Figure 10 : Percentage of Tolerant and Intolerant Taxa in station 1

According to the chart (Fig. 12), tolerant taxa (Pt%) are consistently present across all three sampling months (March, April, and May). Their relative abundance appears particularly high in March and April, indicating a strong presence of taxa adapted to environmental stress or pollution. In contrast, intolerant taxa (Pi%) are only noticeably present during April, suggesting that sensitive species capable of thriving in cleaner conditions were limited to this period. The intermediate taxa show a minimal and relatively stable presence throughout the study period.

❖ Station 2 :

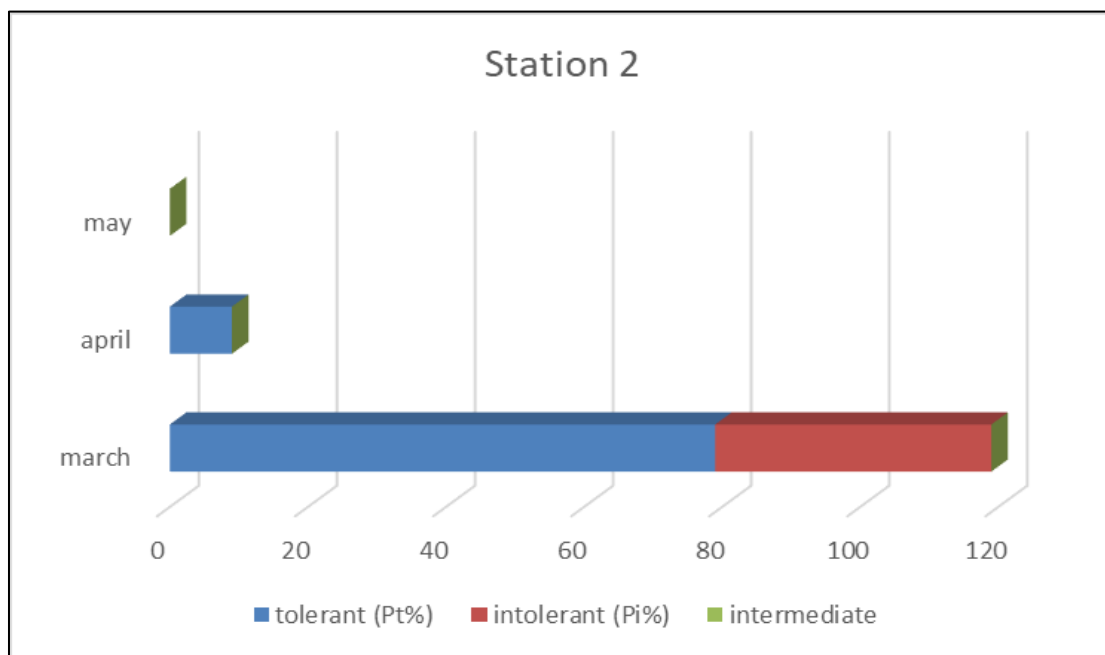


Figure 11 : Percentage of Tolerant and Intolerant Taxa in Station 2

According to the graph (Fig. 13), tolerant taxa were consistently present across all three months of observation (March, April, and May), accounting for approximately 80%, 10%, and 4%, respectively. In contrast, intolerant taxa were only detected in March, where they comprised about 40% of the total taxa. Intermediate taxa were present in all three months but in relatively low proportions.

❖ Station 3 :

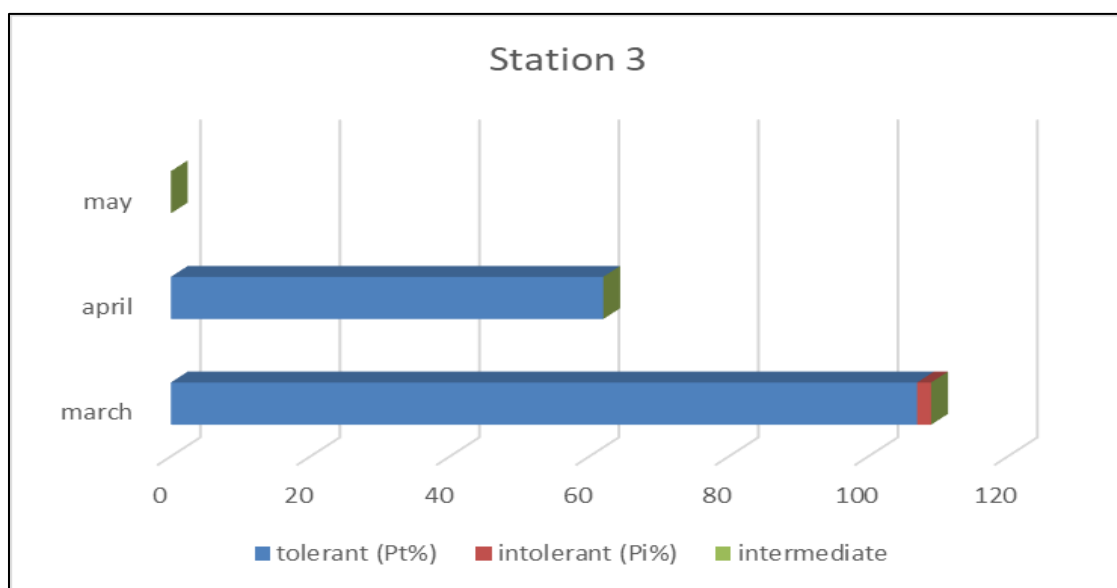


Figure 12 : Percentage of Tolerant and Intolerant Taxa in station 3

According to the graph (Fig 14), tolerant taxa dominated the assemblages throughout the study period (March, April, and May), with particularly high proportions in March and April, reaching approximately 110% and 65%, respectively, and a small presence in May. Intolerant taxa were detected only in March, comprising a very small percentage (around 2%). Intermediate taxa were present at all three sampling times, but always in low proportions.

❖ **Hilsonhoff index :**

Table 9 : The calculated values of the Hilsenhoff Index

Station	Station 1	Station 2	Station 3	Station 4
March	6,091322314	5,968603286	7,023573201	0
April	4,970219638	7,666666667	7,666666667	0
May	5,243902439	0	0	0

Table 10 : The interpretation scale of the Hilsenhoff Index (FBI).

Interval	0 - 3,75	3,76 - 4,25	4,26 - 5	5,01 - 5,75	5,76 - 6,5	6,51 - 7,25	7,26 - 10
quality	Excellent	Very good	Good	Fair	Fairly poor	Poor	Very poor
color							

❖ **Station 1 :**

Based on (Fig.15) the abundance of macroinvertebrate families observed at station 1 , the Hilsenhoff Family Biotic Index (FBI) was calculated for the three sampling months. As shown in Figure (), the FBI value in March exceeds 6, indicating fairly poor water quality In April, the index improves slightly, falling to around 5, indicating a good water quality. By May, the FBI further decreases, approaching the threshold of 5, indicating a trend toward good water quality. This gradual improvement in FBI scores over the study period suggests a progressive reduction in organic load, possibly due to seasonal hydrological changes or reduced anthropogenic input. Nevertheless, the persistently elevated values in March and April reflect a period of ecological stress, highlighting the need for continued monitoring and potential management interventions.

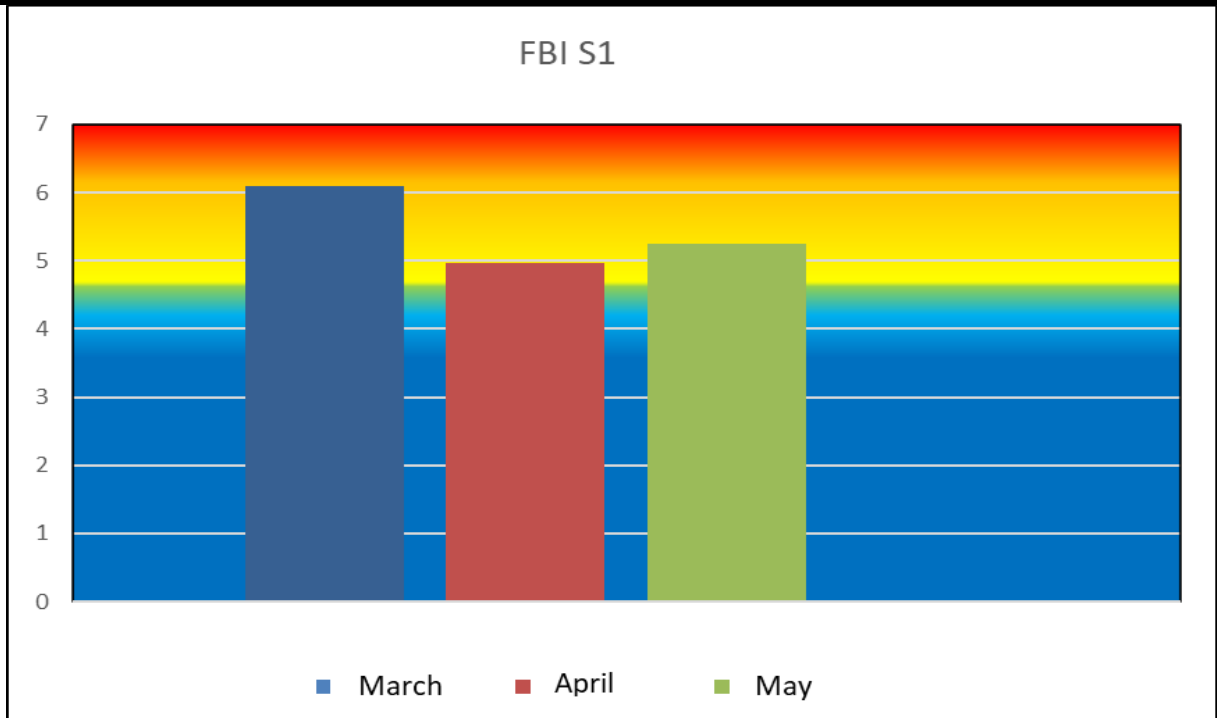


Figure 13 : Hilsenhoff Index Values (FBI) for Station 1

❖ Station 2 :

The abundance of macroinvertebrate taxa collected at this station during the study period enabled the calculation of the Hilsenhoff Family Biotic Index (FBI) for the months of March and April. According to the graph (Fig. 15), the water quality in March is categorized as fair, with an FBI value close to 6,

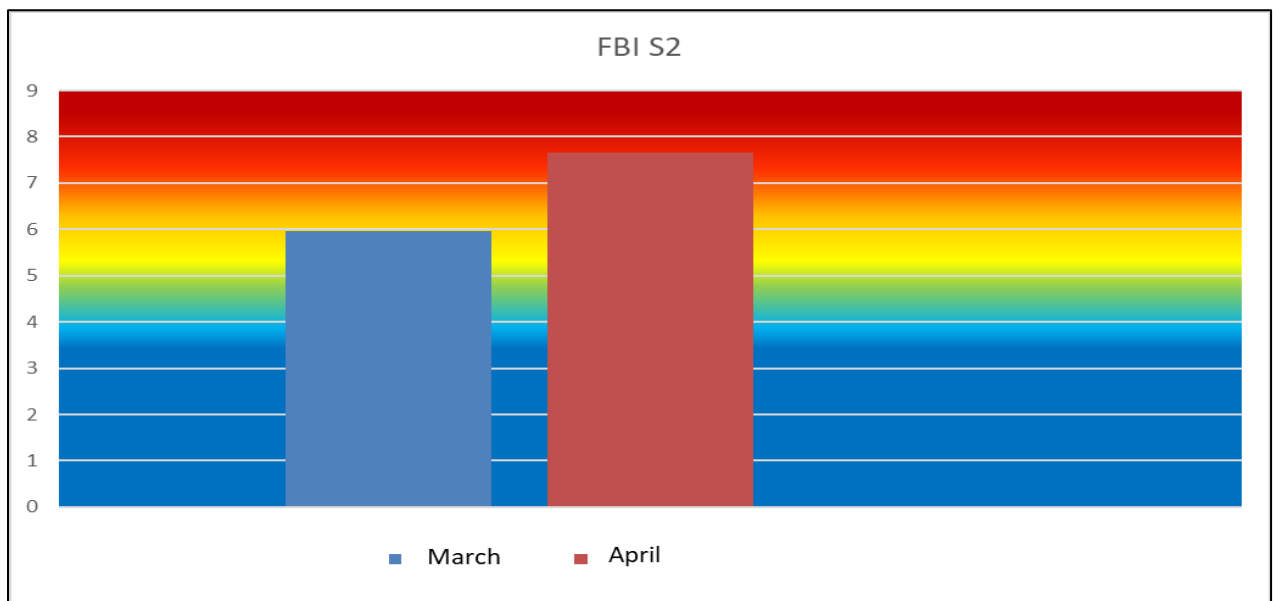


Figure 14 : Hilsenhoff Index Values (FBI) for Station 2.

suggesting moderate organic pollution. However, in April, the index increases significantly, exceeding 7.5, which corresponds to poor water quality. This clear upward trend in the FBI values indicates a progressive degradation of ecological conditions at the station over time, possibly driven by intensified anthropogenic pressure or seasonal environmental shifts.

❖ Station 3 :

The abundance of macroinvertebrate taxa recorded at station 3 during the sampling period enabled the calculation of the Hilsenhoff Family Biotic Index (FBI) for the months of March and April. As shown in (Fig.17) the FBI value for March is approximately 7.0, indicating poor water quality. In April, the index rises even further to nearly 7.7, corresponding to a very poor ecological condition. This steady increase in FBI values between the two months reflects a clear deterioration in water quality at station 3

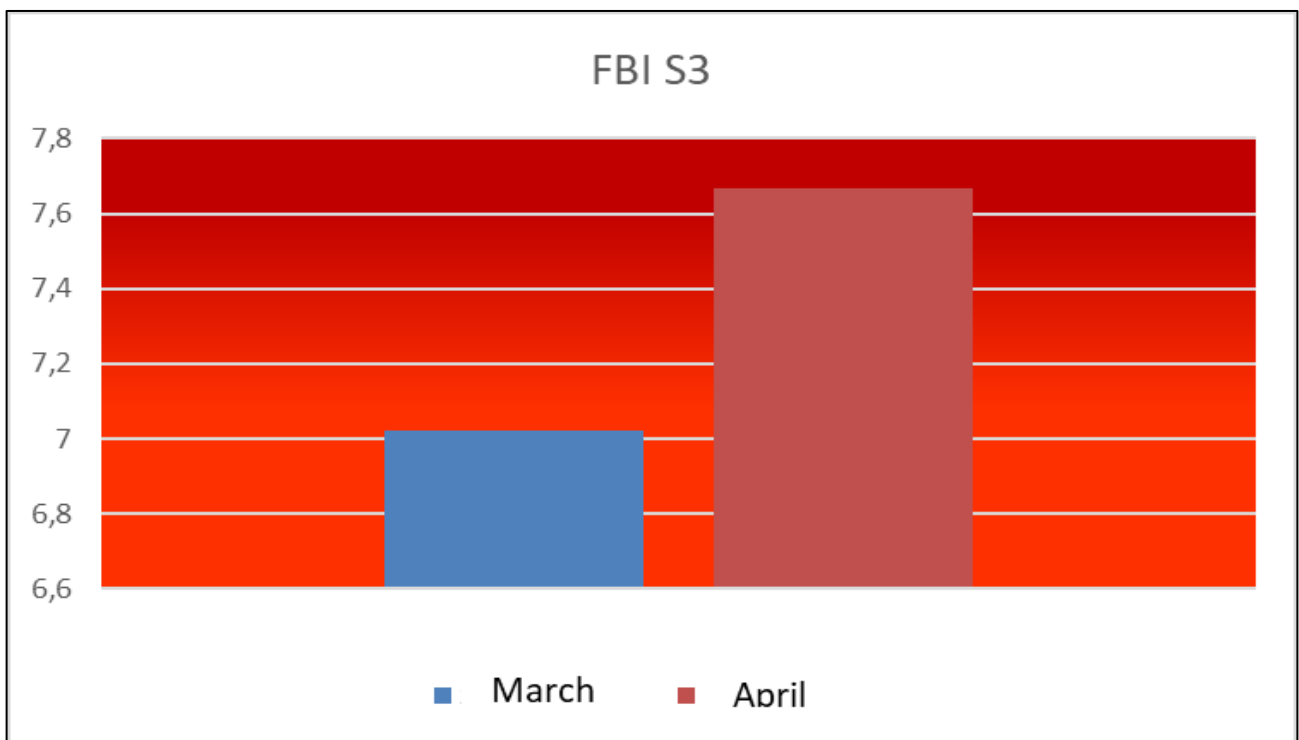


Figure 15 : Hilsenhoff Index Values (FBI) for Station 3.

1.4. The physicochemical parameters of water:

1.4.1. The analysis of physicochemical parameters during (March, April and may):

Table 11 : Analysis of physicochemical parameters during sampling months.

Stations	March				April				May			
	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4
Temperature	16,5	19	18	18	17,3	17,3	17,3	18,3	18	17	16	17
PH	7,66	7,68	7,78	7,78	8,39	8,38	8,34	8,33	7,43	7,61	7,7	/
Conductivity	856	809	807	836	711	708	758	717	/	/	/	/
Salinity	0,2	0,1	0,1	0,2	0,1	0,1	0,1	0,1	0,1	0,1	0,1	/
o2	96,8	9,9	9,12	10,21	9,5	9,64	/	/	10	10	10	/
O2	9,9	9,51	89,7	101,2	104	106	/	/	110	110	109	/
Turbidity	21,6	39,6	56,9	41	8,15	9,91	9,41	9,44	9,89	5,01	7,15	/
No2	<0,02	<0,02	<0,02	<0,02	<0,02	<0,02	<0,02	<0,02	<0,02	<0,02	<0,02	/
NH4	0,11	0,17	0,04	0,07	0,01	0,02	0,02	0,01	0,028	0,023	0,029	/



Figure 16 : The variations in physicochemical parameters across the 4 Stations of the Zit Emba in 3 months

2. Discussion:

According to the table (Tab. 11) , the overall water quality of the reservoir ranges from good to very poor. A marked deterioration in water quality is particularly evident during the period extending from March to April, as reflected by the increasing values of the Hilsenhoff Biotic Index (FBI). This trend indicates a progressive rise in organic pollution levels, shifting the ecological status of the dam's waters from acceptable to highly degraded.

Over a three-month sampling period (March–May 2025), a total of 796 aquatic macroinvertebrate individuals were collected across four zones: El Zanna, Mechtet El Bagrat, Mechtet El Garboussa 1, and Mechtet El Garboussa 2. Seven macroinvertebrate families were identified: Atyidae, Chironomidae, Ceratopogonidae, Arachnida, Unionidae, Nematoda, and Corixoidea. The low taxonomic richness observed in this study is indicative of ecological stress, especially when compared to (Grini, 2013) in the same region, which reported 3,298 individuals distributed among 37 families.

The sharp decline in both richness and abundance suggests a deterioration of habitat quality, likely due to cumulative anthropogenic pressures. Armitage et al. (1983) emphasized that high family richness and evenness are generally associated with diverse, healthy freshwater ecosystems. In contrast, a reduction in richness often reflects organic enrichment, pollution, or habitat simplification.

The Corixoidea family appeared as the most dominant group in both the current and previous studies. In 2025, it represented approximately 49% of the total macroinvertebrate population, compared to 85% in the findings of Grini (2013). This significant numerical dominance of a pollution-tolerant taxon is commonly associated with degraded or disturbed aquatic ecosystems, often indicating a state of ecological imbalance (Czerniawska-Kusza, 2005). The noticeable decline in its relative abundance between the two periods could point to localized environmental improvements or seasonal variation, although such interpretations remain speculative without consistent long-term monitoring..

Atyidae, the second most abundant family with 278 individuals, reflects moderately favorable habitat conditions. These freshwater shrimps are known for their adaptability to environmental variations, particularly salinity and temperature changes. Their increased abundance compared to (Grini, 2013) suggests the presence of microhabitats that still support relatively stable ecological conditions (Armitage et al., 1983).

Chironomidae, with 42 individuals, ranked third in abundance. Their presence across multiple zones highlights their ecological importance and their ability to tolerate nutrient-rich or low-oxygen conditions. Grini, 2013 study reported a much higher representation of Chironomidae, comprising 72% of the Diptera population. This aligns with Hilsenhoff's interpretation of this group as tolerant to organic pollution and suitable as indicators of water quality degradation (Hilsenhoff, 1977).

Unionidae and Nematoda, with 48 and 28 individuals respectively, reflect sediment conditions and organic matter availability. Unionidae typically inhabit soft substrates and moderately clean waters, while Nematodes are known to thrive in enriched sediments, often in degraded systems (Czerniawska-Kusza, 2005). Their presence in both datasets confirms their ecological relevance across a range of conditions.

Rare taxa such as Ceratopogonidae (8 individuals) and Arachnida (1 individual) were only marginally recorded. These low abundances likely indicate limited suitable niches or elevated environmental sensitivity. The absence of such groups from (Grini, 2013) dataset could be due either to underreporting or an even more restricted presence at the time.

A particularly alarming finding in the 2025 study was the complete absence of macroinvertebrates at the Mechtet El Bagrat 2 station. Field observations at this site revealed the presence of oil films, hydrocarbon leaks, and emissions from irrigation motors environmental stressors likely surpassing the tolerance limits of even the most resilient taxa. In contrast, while no site in (Grini, 2013) study recorded a total absence of fauna, the overwhelming dominance of a single tolerant group in that study can similarly be interpreted as a sign of severe ecological degradation and functional collapse of the aquatic community.

Finally, the absence of sensitive indicator families commonly belonging to the orders Ephemeroptera, Plecoptera, and Trichoptera in both the current and (Grini, 2013) highlights the degraded condition of the aquatic ecosystem. These families play a key role in biological monitoring programs such as the BMWP and are among the first to disappear in response to pollution (Armitage et al., 1983; Czerniawska-Kusza, 2005).

Ceratopogonidae and Arachnida, which appeared only marginally in your study (8 and 1 individual, respectively). Their scarcity likely reflects limited ecological niches and/or high sensitivity to pollutants. This aligns with global bioassessment frameworks, where rare or specialist taxa are among the first to disappear under chronic disturbance (Hilsenhoff, 1977).

A particularly concerning observation in the 2025 study was the complete absence of macroinvertebrates at the Mechtet El Bagrat 2 station. This site exhibited clear signs of severe pollution, including hydrocarbon contamination, emissions from irrigation motors, and surface oil films conditions likely surpassing the ecological tolerance limits of even the most pollution-resistant taxa. Although the 2013 study did not report a total faunal absence at any station, it documented a pronounced dominance by a single tolerant group, a pattern that may reflect a comparable collapse in biological diversity and ecosystem integrity.

The absence of pollution-sensitive taxa like Ephemeroptera, Plecoptera, and Trichoptera in both datasets confirms long-standing ecological deterioration in this system. These taxa are hallmark

indicators of good water quality (Armitage et al., 1983), and their disappearance signifies poor ecological status Hilsenhoff framework.

As part of this dissertation, a desktop application was developed to assist in the identification of freshwater macroinvertebrates at the family level. The app is designed to guide users through an intuitive process using morphological keys, simplified descriptors, and a regional reference database tailored to North African freshwater fauna. During the analysis phase, the application proved effective in correctly identifying all seven families recorded in this study, including both dominant and low-abundance taxa. While not a replacement for taxonomic expertise, the tool serves as a valuable aid that supports and complements the work of specialists acilitating faster preliminary identification, especially in educational or resource-limited settings, and improving the overall accessibility and consistency of biological assessments.

The app's performance highlights the potential of digital tools in supporting standardized and accessible biomonitoring practices, especially for students, researchers, and professionals operating in contexts where taxonomic expertise or laboratory resources may be limited. Its use contributed to a more efficient and consistent identification workflow, reinforcing the scientific validity of the macroinvertebrate-based water quality assessment conducted in this research. Future enhancements could focus on expanding the database and refining the morphological criteria to enable genus-level identification, allowing for more detailed ecological interpretations and greater taxonomic resolution in field assessments.

Conclusion and perspectives:

This dissertation has contributed to the ecological assessment of a freshwater system through the analysis of aquatic macroinvertebrate communities across four zones, supported by physicochemical data and bioindication indices. The findings revealed a low taxonomic richness, with dominance by pollution-tolerant families such as Corixoidae and Chironomidae, and a notable absence of sensitive taxa like Ephemeroptera and Plecoptera. These patterns reflect a moderately to highly disturbed aquatic environment, shaped by cumulative anthropogenic pressures including organic pollution, habitat alteration, and chemical contamination.

By applying biotic indices such as the Hilsenhoff Biotic Index (HBI) and BMWP, the study provided a clear, evidence-based interpretation of water quality across sampling sites. The use of macroinvertebrates as biological indicators reinforced their reliability in tracking ecological degradation, complementing physicochemical measurements and offering insight into habitat health over time.

From March to May, the physicochemical parameters measured across the four stations showed significant variations reflecting seasonal changes in the aquatic environment. Water temperature remained relatively stable, ranging from 16.5°C to 19°C, with a slight warming trend observed over the months. pH values, which were predominantly alkaline in April (ranging from 8.33 to 8.39), decreased in May toward more neutral levels. This shift may be attributed to rainfall-induced dilution or fluctuations in biological activity. Conductivity dropped significantly from March to April, suggesting an influx of less mineralized freshwater. Salinity remained very low (0.1–0.2 ppt), confirming the freshwater nature of the sampled sites. Dissolved oxygen levels reached high saturation values, particularly in May (up to 110%), likely linked to increased photosynthetic activity. Turbidity, which was notably high in March (up to 56.9 NTU at Station S3), decreased sharply in the following months, indicating a gradual clarification of the water. Nitrite concentrations (NO_2^-) consistently remained below the detection threshold. In contrast, ammonium (NH_4^+) levels declined markedly over time, which could indicate reduced inputs of organic matter or enhanced nitrification processes. These dynamics reflect sensitive environmental changes during the study period, influenced by both climatic and hydrological factors.

A key innovation in this dissertation was the development and successful deployment of a desktop identification application, designed to assist in the recognition of macroinvertebrate families. Its integration into the research process significantly improved the speed and consistency of species-level identification, reducing reliance on taxonomic expertise and enhancing the standardization of ecological monitoring. The tool demonstrated strong potential as a resource for education, fieldwork, and local capacity-building, especially in regions where ecological knowledge or laboratory access is limited.

Taken together, the ecological findings and the digital innovation presented in this work highlight the importance of combining field-based biodiversity studies with practical technological tools. This integrated approach not only improves data quality and accessibility but also supports broader conservation goals by enabling scalable, cost-effective biomonitoring strategies.

As freshwater ecosystems continue to be shaped by human activities and climate variability, the methodology and tools presented here offer a valuable framework for ongoing ecological assessment, biodiversity protection, and informed environmental management. Future work should focus on expanding the app's taxonomic scope, integrating real-time monitoring capabilities.

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Appendices

Appendix 01: the sampling table

Date	Zone	Family 1	Family 2	Family 3	Family 4	Class 5	Family 6	phylum 7	Temperature (°C)	Time	Total
1 March	Zone 1	18	42	0	0	0	0	0	16	11:09	60
1 March	Zone 2	7	36	0	0	0	5	0	20	14:00	48
1 March	Zone 3	2	57	0	0	0	3	0	18	16:26	62
1 March	Zone 4	0	0	0	0	0	0	0	16	17:30	0
15 March	Zone 1	38	55	16	5	1	6	0	17	10:00	121
15 March	Zone 2	33	23	3	3	0	9	0	18	12:03	71
15 March	Zone 3	0	78	23	0	0	3	0	18	14:25	104
15 March	Zone 4	0	0	0	0	0	0	0	16	15:31	0
5 April	Zone 1	63	23	0	0	0	0	0	18	10:30	86
5 April	Zone 2	0	3	0	0	0	0	0	18	12:00	3
5 April	Zone 3	0	43	0	0	0	0	0	16	12:53	43
5 April	Zone 4	0	0	0	0	0	0	0	18	13:30	0
19 April	Zone 1	36	7	0	0	0	5	0	17	10:00	48
19 April	Zone 2	0	0	0	0	0	6	0	17	12:30	6
19 April	Zone 3	0	0	0	0	0	11	0	20	14:04	11
19 April	Zone 4	0	0	0	0	0	0	0	19	15:00	0
26 April	Zone 1	56	9	0	0	0	0	15	17	10:55	80
26 April	Zone 2	0	0	0	0	0	0	4	17	12:20	4
26 April	Zone 3	0	0	0	0	0	0	8	17	13:43	8
26 April	Zone 4	0	0	0	0	0	0	0	18	14:35	0
10 May	Zone 1	25	15	0	0	0	0	1	18	10:30	41
10 May	Zone 2	0	0	0	0	0	0	0	17	12:40	0
10 May	Zone 3	0	0	0	0	0	0	0	18	13:35	0
10 May	Zone 4	0	0	0	0	0	0	0	17	14:15	0
	total	278	391	42	8	1	48	28	H'	Total N	796