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**DÉPARTEMENT DE BIOLOGIE ET DE PHYSIOLOGIE VÉGÉTALES**

**DEPARTMENT OF PLANT BIOLOGY**

# Impact assessment of industrial and fishing activities on water quality and the diversity of algal species in the seacoast of Kribi, South Region of Cameroon

**Thesis presented in view of obtaining a Professional Master's Degree in Environmental Sciences**

**Specialization: Environmental Sanitation and Restoration**

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# DEDICATION

This work is dedicated to my wife for her incredible support and to the rest of my family.

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# TABLE OF CONTENT

# LIST OF FIGURES

# LIST OF TABLES

# LIST OF ABBREVIATIONS

| | |
|---|---|
| **BOD** | Biological oxygen demand |
| **COD** | Chemical oxygen demand |
| **CBD** | Convention on Biological Diversity |
| **DO** | Dissolved oxygen |
| **EU** | European Union |
| **IMO** | International Maritime Organization |
| **MINEPDED** | Ministry of the Environment, Protection of Nature and Sustainable Development |
| **MINEPIA** | Ministry of Livestock, Fisheries and Animal Industries |
| **MINRESI** | Ministry of Scientific Research and Innovation |
| **MINEPAT** | Ministry of Economy, Planning and Regional Development |
| **MINDEF** | Ministry of Defense |
| **MINFI** | Ministry of Finance |
| **MINTRANS** | Ministry of Transport |
| **MPA** | Marine Protected Area |
| **OECD** | Organization for Economic Co-operation and Development |
| **PAK** | Port Autonome de Kribi |
| **SCS** | Suivi, Contrôle et Surveillance (Monitoring, Control and Surveillance) |
| **TED** | Turtle Exclusion Device |
| **TDS** | Total dissolved solutes |
| **TSS** | Total suspended solids |
| **UNEP** | United Nations Environment Program |
| **VMS** | Vessel Monitoring System |
| **WHO** | World Health Organization |

# ABSTRACT

The coastal region of Kribi is experiencing rapid urban development due to industrial and fishing activities. This development raises environmental concerns, particularly with regard to water quality and marine biodiversity. The present research is a contribution to the assessment of the impact of industrial and fishing activities on water quality and algal diversity in the coastal region of Kribi, Southern Cameroon. Field trips were carried out between August 2023 and April 2024. The methodology involved surveys, seawater sampling and analysis of physico-chemical and microscopic parameters, and the proposition of a management plan. The results identified 14 sampling points stretching from Londji to the seaport area. Physico-chemical parameters showed that phosphate ion ($PO_4^{3-}$) (43.7 - 241.25mg/L) and total dissolved solids (TDS) (1619.50 - 2167 ppm) are well above marine water quality standards. With regard to phytoplankton, a high level of algal diversity was observed in some of the points. An algal diversity of 64 species divided into 35 families and 38 genera was inventoried. The Spoil zone and Phase II zone record the highest diversity with 268 and 118 individuals respectively, of which *Chaetoceros peruvianus* and *Ceratium declinatum* are the most represented with 140 and 114 individuals respectively. This algal diversity is a necessary database for monitoring biological indicators of seawater quality. This research proposes a management plan (to the tune of 1,085,000,000CFAF) to mitigate the negative impacts of anthropogenic activities, including waste management awareness initiatives and improvement of regulations for industrial and fishing activities that encourage sustainable practices. Assessing the impact of anthropogenic activities in Kribi highlights the need for an integrated approach to protect water quality and algal biodiversity, while ensuring the sustainability of natural resources. Collaboration between local stakeholders, authorities and the scientific community is essential to develop effective environmental management strategies.

Keywords: Pollution; industrial activities; fishing activities; water quality; algal diversity; Kribi.

# RESUME

La région côtière de Kribi connaît un développement urbain rapide dû aux activités industrielles et de pêche. Ce développement soulève des préoccupations environnementales, notamment en ce qui concerne la qualité de l'eau et la biodiversité marine. Le présent travail de recherche est une contribution à l'évaluation de l'impact des activités industrielles et de pêche sur la qualité de l'eau et la diversité algale dans la zone côtière de Kribi, au Sud Cameroun. Des descentes de terrain ont été menées entre Aout 2023 et Avril 2024. La méthodologie a consisté à faire les enquêtes, échantillonner les eaux de mer, et analyser les paramètres physico-chimiques et microscopiques. Les résultats ont permis d'identifier 14 points de prélèvement allant de Londji à la zone portuaire. Les paramètres physico-chimiques ont montré que l'ion phosphate ($PO_4^{3-}$) (43,7 - 241,25mg/L) et solides totaux dissous (TDS) (1619,50 - 2167 ppm) sont largement au-dessus des normes de qualité des eaux marines. En ce qui concerne le phytoplancton, on note une grande diversité algale dans certains des points. Une diversité algale composée de 64 espèces réparties en 35 familles et 38 genres a été inventoriée. La zone de déblais et la zone phase II enregistre la plus grande diversité avec 268 et 118 individus parmi lesquels *Chaetoceros peruvianus* et *Ceratium declinatum* sont les plus représentées avec 140 et 114 individus, respectivement. Cette diversité algale est une base de données nécessaire pour le suivi des indicateurs biologique de la qualité de l'eau de mer. Cette recherche propose un plan de gestion (à la hauteur de 1 085 000 000 FCFA) pour atténuer les impacts négatifs des activités anthropiques, notamment des initiatives de sensibilisation à la gestion des déchets et l'amélioration des réglementations relatives aux activités industrielles et de pêche qui encouragent les pratiques durables de l'environnement marin. L'évaluation de l'impact des activités anthropiques à Kribi met en évidence la nécessité d'une approche intégrée pour protéger la qualité de l'eau et la biodiversité algale, tout en assurant la durabilité des ressources naturelles. La collaboration entre les acteurs locaux, les autorités et la communauté scientifique est essentielle pour développer des stratégies de gestion environnementale efficaces.

**Mots-clés :** Pollution, activités industrielles, activités de pêche, qualité de l'eau, diversité algale, Kribi.

# CHAPTER I: GENERALITIES

## I.1. INTRODUCTION

Water is the second most important need for life to exist after air. As a result, water quality has been described extensively in the scientific literature. The most popular definition of water quality is "the physical, chemical, and biological characteristics of water" (Hassan, 2020). Water quality is a measure of the condition of water relative to the requirements of one or more biotic species and/or to any human need or purpose (Hassan, 2020). The water body acquires these characteristics from a suite of complex interactions between water, atmosphere, soils, and lithology. There are three water quality parameters that help to measure the quality of water, which include physical, chemical and biological parameters. The physical parameters include color, taste, odor, temperature, turbidity, solids, and electrical conductivity. Chemical parameters on the other hand include pH, acidity, alkalinity, chlorine, hardness, dissolved oxygen, phosphates, nitrates, ammonium ions, chemical oxygen demand and biochemical oxygen demand. The third type of parameter involves biological aspects which include bacteria, algae and viruses (Breitburg et *al.*, 2018).

Coastal environments include several different habitat typologies, from shorelines to estuaries, and rocky and muddy environments. All these ecosystems are very vulnerable to anthropogenic pressures, climate fluctuations, stressing the need to monitor their quality status and suggest possible measures for the remediation and recovery of their natural equilibria (Bergamasco et *al.*, 2021). The Coastal region of Kribi being a natural attraction due to its beautiful natural environment (a long shore line with beautiful beaches) pulls a lot of activities whose end results can pose negative impacts on water quality and algal diversity. These activities among others include coastal construction, oil and gas exploitation and exploration, fishing, industrial activities, mining, energy production, household and agricultural activities. Such activities generate an array of different wastes and a majority of the wastes in one way or the other end up in the marine environment via diverse routes, being potential sources of marine ecosystem disruption.

Among the so many living organisms that depend on good water quality are Algae that exist in diverse forms. Algae can occupy a diverse ecosystem, such as fresh water and marine water (ocean, ponds, lakes, rivers and stream), due to their adaptability in extreme conditions and their quick response to environmental changes. Due to their quick responses towards pollutants, algae are often used as indicators of water pollution (Pore and Dhulap, 2023).

Therefore, there is a need to assess and monitor human activities in the coastal region so as to better understand how they impact marine water quality and algal diversity. This understanding will help setup a better management plan for sustainability. This therefore prompted the current study to assess the impacts of industrial and fishing activities on water quality and algal diversity on the sea coast of Kribi – Cameroon.

## PROBLEMATIC

The State of Cameroon in its structuring plan and the Head of State's Vision 2035 of an emerging nation, has located on the facade of Kribi many developmental and industrial projects (the Kribi Deep-Water Harbour, the railway line project, the gas Power Plant of Kribi, several cement plants, agro-industries, and fisheries). This increase in industrialization, urban development and population growth creates significant pressure on the marine coastal environments, marked by potential high water pollution and considerable changes in biological compartments. One of the most visible changes within biological compartments among many others could be the appearance of harmful algal blooms (HABs).

With the advent of the Kribi Industrial and Urban Port Complex (KIPC) and its accompanying industrial activities, coupled with illegal, unreported, and unregulated fishing and other anthropogenic activities, this project was designed with the goal of finding out how industrial and fishing activities impact the quality of marine waters and the diversity of algal species in the Kribi sea coast locality and to propose a management plan that would help mitigate the impacts.

## RESEARCH QUESTIONS

1. What is the opinion of the local residents in the study area on seawater quality in relation to industrial and fishing activities?

2. How do industrial activities (e.g., pollution, waste discharge) and fishing activities (e.g., overfishing, habitat destruction) impact the quality of the sea and the diversity of algal species?

3. What measures can be put in place to better manage industrial and fishing activities in order to protect marine ecosystems in the study area?

## RESEARCH HYPOTHESIS

### Main Hypothesis:

The industrial and fishing activities in the Kribi seacoast region might have a significant impact on the water quality and diversity of algal species in the area.

### Specific Hypotheses:

- The local residents believe that industrial and fishing activities impact seawater quality in various ways
- Uncontrolled industrial and fishing activities have negative impacts on seawater quality and the diversity of algal species.
- Good measures put in place can mitigate the impacts of industrial and fishing activities on seawater quality and algal diversity in the study area.

## OBJECTIVE

### General Objectives:

- To assess the impacts of industrial and fishing activities on water quality and algal diversity on the sea coast of Kribi – Cameroon.

### Specific Objectives:

- To determine the perception of the local residents concerning seawater quality
- To assess the impacts of industrial and fishing activities on the marine environment
- To propose measures for a better management of the coastal region

## I.2. LITERATURE REVIEW

### I.2.1. Oceans and Marine waters

Marine water, encompassing the vast bodies of saltwater that cover over 70% of the Earth's surface, is a significant and dynamic component of our planet. These vast oceans, seas, and coastal waters are not only interesting in their beauty but also play a fundamental role in shaping our climate, ecosystems, and even the evolution of life itself. Marine water, also known as saltwater, contains a mixture of dissolved salts and minerals, primarily sodium chloride (table salt). This saline composition makes it distinct from freshwater found in rivers, lakes, and underground aquifers. Marine water has an average salinity of about 35 parts per thousand, which translates to approximately 3.5% salinity (Rashid and Romshoo, 2012). Salinity can vary in different parts of the world's oceans and seas, influenced by factors like temperature and evaporation rates. The marine ecosystem is subdivided into oceans, estuaries, coral reefs, and coastal ecosystems. The oceans, which hold about 97.5% of Earth's water, play a pivotal role in regulating our planet's climate (Constanza et *al.*, 1997). Therefore, there is a great need to protect this environment from anthropogenic activities for Man's well-being.

### I.2.2. Generalities on Algae

- **Definition**

Algae are chlorophyllous organisms, most of which grow in water and/or wetlands. They belong to the thallophytes, forming thalli without leaves, stems, and roots or conducting vessels. This thallus can be solitary, filamentous or colonial. Algae possess chlorophyll pigments, chlorophyll a being the most common. Their metabolism is dominated by autotrophic life, with light as the main source of energy source (Ba, 2006).

Algae are generally cosmopolitan organisms, distributed according to the major climatic divisions. There are cold water, temperate and intertropical Algae (Ba, 2006). Although indigenous to aquatic environments, they can also be found on land and on damp rocks, and even in the air. They can also be endophytic in animal and plant tissues (Lude et Coste, 1996).

Wastewater from various anthropogenic activities is characterized by a high pollutant load, which gives the medium selective properties. Thus, the Algae commonly found in these environments generally belong to 4 major phyla, depending on the type of chlorophyll, aquatic life the nature of the pigments and cell reserves: these are the *Cyanophytes* or Blue Algae Chlorophytes or green algae, *Euglenophytes* and *Chrysophytes* or brown algae, more specifically the class of Diatoms (Anonymous 1, 2005).

- **Main groups of Algae**

There are two main groups of algae namely microalgae and macroalgae. Microalgae are also known as phytoplankton. Apart from the giant seaweeds that fall in the groups Brown Algae (*Phaeophyta*), Green Algae (*Chlorophyta*), and Red Algae (*Rhodophyta*), there exist other groups of algae (Kennedy, 2019).

- **Role of Algae in Marine Ecosystems**

Algae, the "little-known superheroes" of the sea, are much more than slimy green clumps. These tiny plant powerhouses play a vital role in the health and vitality of our oceans. Algae, particularly phytoplankton, are vital to marine ecosystems as they perform photosynthesis converting sunlight into energy. They are responsible for producing approximately 50% of the Earth's oxygen and form the base of the aquatic food web. Through photosynthesis, algae absorb carbon dioxide and release oxygen, thus playing a critical role in regulating atmospheric gases (Falkowski, & Raven, 2007).

  - **Role of Algae as bio-indicators of pollution**

Algae are used as bio-indicators of pollution. The use of algae as indicators of water quality began in the mid-twentieth century with the saprobic system (Gökçe & Didem, 2016). The concept of biological indicators of pollution in the saprobic system is based on the fact that pollutant loads in the aquatic environment trigger a series of processes over time and space that create different environmental conditions, leading to the appearance of population successions (Yu et al., 2019).

In wetland ecosystems, the algal flora is highly diversified, and certain algae (Diatoms) are used extensively in the reconstruction of palaeoenvironments or palaeoclimates (Nguetsop, 1997; Gasse, 2002), as well as in the determination and control of organic and industrial pollution using the high algal yield lagooning method (LHRA) (Deviller, 2003).

  - **Role of Algae as water purifiers**

Numerous authors, such as Galamo et *al* (1983) and Madigan et *al* (1997), report that in aquatic ecosystems, algae play the role of the first link in the trophic chain, as agents of self-purification of water. Algae incorporate elements of pollution into their organisms. They assimilate simple compounds such as carbon dioxide, water, nitrates and phosphates obtained by aerobic bacteria, responsible for mineralization of soluble organic matter in suspension. During this assimilation and thanks to sunlight, they carry out photosynthesis to ensure their metabolism and release oxygen, which is essential for aquatic life (Elster et *al.*, 1994; Hang et *al.*, 1999). They also secrete substances that increase the pH of the environment during the hours of the day. This increase is very active in destroying pathogens. Algae also fix ammonia, thus reducing the oxygen demand normally linked to bacterial nitrification of ammonia into nitrate (Gloyna, 1972; Nya, 2001).

- **Commercial Role of algae**

According to survey reports carried out during this study, despite the fact that a vast majority of the local residents have limited knowledge on the role of algae in the marine ecosystem, they use algae in various ways including food, cosmetics, pharmaceutics, decoration and for research.

### I.2.3. Influence of environmental factors on algal growth

Environmental factors directly influence primary production by acting on algal growth and photosynthesis (Kengne, 2000; Nya, 2001; Soh et *al.*, 2014).

As photosynthetic organisms, algae derive their carbon from atmospheric $CO_2$ and dissolved bicarbonates. Carbon rarely limits algal growth, whatever their concentration in the water. They are in fact capable of managing low concentrations of atmospheric concentrations of $CO_2$.

- **Temperature**

Temperature has a direct influence on the metabolism of algae. Each species has an optimum temperature for development. Depending on their tolerance to temperature variations, a distinction is made between eurythermic algae (high tolerance of a wide range of temperatures) and stenothermic algae (low tolerance). For example; *Chlorella* sp. is green microalga known for its resilience in various temperature conditions, thriving both in freshwater and marine environments. Spirulina is a blue-green alga from the *Cynaopyceae* class that can grow in a wide temperature range, often found in warm, alkaline waters. *Phaeodactylum tricornutum* is another high temperature tolerant diatom that can adapt to different temperatures and is often used in aquaculture and biotechnology due to its versatility (Nya, 2001; Soh et *al.*, 2014). As for stenothermic algae, we have the likes of *Porphyra* sp., a red alga commonly used in sushi (nori) that thrives in specific low temperature ranges particularly in cooler coastal waters; brown algae like *Focus vesiculosus* (bladderwrack) prefer stable, cooler temperatures and are sensitive to temperature fluctuations. They are usaually adapted to specific habitats where temperature conditions remain relatively stable (Nya, 2001; Soh et *al*., 2014).

- **pH**

pH determines the hydrogen potential of a medium. The pH of natural water is most often between 6.6 and 7.8 (Fonkou, 1996). Variations are usually small in bodies of water, with the amplitude depending on the mineralization of the water and the vegetation present (Kengne et *al*., 2008). This parameter is a determining factor in the distribution of diatoms. Nguetsop (1997) distinguishes between:

- Acidobiont diatoms, found in water with a pH of less than 7, with optimum development at 5.5 (e.g. *Chlorella* spp., *Dunaliella* spp., Coccolithophores (e.g. *Emiliania huxleyi*), *Phaeocystis* spp., and *Cryptomonas* spp.);

- Acidophilic diatoms, which develop in water with a pH close to 7 and optimally at a pH below 7 (e.g. *Cymbella* spp., *Cyclotella* spp.);

- Indifferent or neutrophilic diatoms, which develop optimally at a pH equal to or close to 7 (e.g. *Gomphonema* spp., *Fragilaria* spp.);

- Alkaliphilic diatoms, which are found at pH levels close to 7, with optima 7 (e.g. *Nitzschia* spp.);

- Alkalibiont diatoms, which thrive in basic or alkalinic environments (e.g. *Navicula* spp., *Cyclotella* spp., *Asterionella* spp., *Fragilaria* spp., *and Nitzschia* spp.).

- **Conductivity**

Conductivity is a measure of water's ability to conduct electric current. It is measured in Siemens per meter (S/m). In many practical applications, especially for water quality testing, it is often expressed in microsiemens per centimeter (µS/cm). Lower conductivity values are indicative of better water quality. Measuring it gives an approximate idea of the overall mineralization of the water. A relationship between conductivity and mineralization has been established by French regulations. Based on this, Rodier (1996) distinguishes between the following degrees of mineralization:

- Conductivity <100 µS/cm, mineralization is very low;

- 100 µS/cm< conductivity <200 µS/cm, mineralization is low;

- 200 μS/cm< conductivity <333 μS/cm, mineralization is moderately accentuated;

- 333 μS/cm < conductivity <666 μS/cm, mineralization is medium;

- 666 μS/cm< conductivity <1000 μS/cm, mineralization is significant;

- Conductivity > 1000 μS/cm, mineralization is excessive.

- **Phosphorus**

Phosphorus is an essential factor in the growth of algae. Algae need it for the synthesis of their phosphates and various photosynthetic catalysts. It seems that all soluble forms of phosphorus (mineral phosphorus in the form of orthophosphates $PO_4^{3-}$etc... and in the form of mineral polyphosphates $P_2O_9^{3-}$etc...) can be assimilated by algae (Gamrasni and Phelippot, 1976; Nya, 2001).

Phosphorus is present in water in particulate form (bound to colloids) and soluble form (orthophosphates) (Banas, 2001).

In freshwater, soluble phosphorus is present in the water body and in the interstitial water of the sediment, while phosphorus in particulate form is stored in the sediment and can be re-emitted in suspension (Despreaux, 1990).

- **Nitrogen**

In algae, nitrogen is assimilated in its ionized mineral form (ammonium, nitrates or nitrites); it is only very slowly taken up in its molecular form ($N_2$) by certain blue-green algae. As a nutrient source, nitrogen is a fundamental component of amino acids, proteins, nucleic acids, and chlorophyll. Its availability directly impacts algal growth rates and cellular function (Anderson et *al.*, 2002). Increased nitrogen availability typically leads to enhanced growth rates in marine algae. This is particularly evident in phytoplankton blooms, which can occur in nutrient rich waters (Gilbert et *al.*, 2011). The availability of nitrogen can influence the composition of algal communities. Different species have varying nitrogen requirements, which can lead to shifts in dominance among species during blooms (Nixon, S.W., 1995).

- **Biological oxygen demand ($BOD_5$)**

This parameter defines the quantity of dissolved oxygen used by phytoplankton and micro-organisms for biodegradation. It is a function of temperature, phytoplankton density and organic phytoplankton density and the concentration of organic matter. The overall health of marine ecosystems can be affected by BOD levels. Low oxygen conditions can harm fish and other marine organisms, disrupting the food web and altering the ecological balance (Howarth, R.W., 1998). In some cases, the types of algae that proliferate in high-BOD conditions can include harmful species that produce toxins, posing risks to marine life and human health (Paerl, et *al.*, 2013).

### I.2.4. Opinion of local residents on water quality in relation to industrial and fishing activities in the seacoast of Kribi

Marine water is vulnerable to pollution from various sources, including industrial runoff, plastic waste, oil spills, and nutrient discharges. These pollutants can harm marine life and ecosystems. Overfishing and illegal, unreported, and unregulated (IUU) fishing practices can deplete fish stocks and disrupt marine food webs. Rising sea temperatures, ocean acidification, and extreme weather events are all associated to climate change. These impacts can harm marine ecosystems, particularly coral reefs and polar environments. Coastal development, coral bleaching, and habitat degradation from destructive fishing practices can lead to the loss of critical marine habitats (Envi-rep, 2011). The introduction of non-native species to marine environments can disrupt local ecosystems and out-compete native species (Peters et *al.*, 2006).

Impacts of human activities on the ocean have been shown to be substantial, ubiquitous and changing. The resulting cumulative impact of these activities often leads to ecosystem degradation or even collapse, and studies of individual marine ecosystems (e.g., coral reefs, kelp forests, and seagrasses) have shown declines in conditions globally due to increasing anthropogenic stressors (Lawan et *al.*, 2023). Ongoing and emerging policy around managing for cumulative impacts to the oceans creates a pressing need to understand how, and how fast, cumulative impacts are changing. Expansion of existing uses of the ocean and emerging new ones – including offshore energy, ocean farming, and ocean mining – requires an understanding of what else is impacting those locations, how those new uses will add to existing impacts, and critically whether the cumulative impact of these ocean uses is changing, and how quickly (Halpern et *al.*, 2019).

The discharge of various pollutants into the aquatic environments is the outcome of countless anthropogenic activities, threatening the health of the living beings and damaging the quality of the environment by rendering water bodies unsuitable (Peters et *al.*, 2006). Aquatic environments are pickers for anthropogenic contamination and industrial wastes and leaks, whether chemicals or solid pollutants. These wastes can be heavy metals, detergents, microfibers, plastic or non-plastic origin, etc., and contributes to aquatic pollution problems. Aquatic environments are addressee for plenty of pollutants and their outrageous toxic actions (Peters et *al.*, 2006).

Most aquatic ecosystems have a natural tendency to dilute pollution to some extent, but severe contamination of aquatic ecosystems results in alteration in the fauna and flora of the community. The onset of human civilization in itself discloses the history of aquatic pollution. Moreover, aquatic pollution did not receive significant consideration until a threshold level was reached with hostile outcomes on the ecosystems and living organisms including humans. Therefore, pollution and its effects are considered as one of Man's greatest crimes against himself. Pollutants may cause primary damage, with direct identifiable impact on the environment, or secondary damage in the form of minor perturbations in the delicate balance of the biological food web that are detectable only over long time periods. Thus, maintaining the quality of aquatic ecosystems represents one of the most formidable challenges facing global society in the twenty first century (Bashir et *al.*, 2020).

### I.2.5. Specific pollutants or contaminants associated with industrial and fishing activities impacting marine water quality and algal diversity

Uncontrolled fishing practices and industrial activities, such as irregular waste deposition can result in the contamination of aquatic environments. Human settlements, industries, and agriculture are the main sources of water pollution (Bashir et *al.*, 2020). The pollution from nutrients such as Nitrogen and Phosphorus represents the largest source of degradation in the coastal waters, which include some of the richest and most productive habitats in the oceans (Howarth et *al.*, 2000).

Table I. Sources and route of pollutant discharge into aquatic environments

| CONTAMINATION | SOURCE | ROUTE |
|---|---|---|
| Oxygen demanding wastes (Organic pollutants) | Domestic sewage, human and animal waste (such as wastes from canneries and wood pulp mills) | Thrown, dumped or released into streams and rivers or into gutters, drains from where they may get washed by run-off into water bodies |
| Infectious disease agents | Domestic sewage, human and animal wastes | Washing, swimming or working in paddy rice fields and on irrigated land |
| Plant nutrients such as nitrates, phosphates and others | Fertilized farmlands, ashes, and detergents | Run-off from pesticides associated with farmlands |
| Pesticides (insecticides and herbicides) | Organic and inorganic chemicals | Run-off from pesticides associated with farmlands |
| Industrial effluents which include DDT, dyes, mercury and cadmium | Textile factories, distilleries pulp and paper mills, fertilized plants, chemical and allied industry, food, beverages and tobacco industries, soap, detergents and confectionery industries | Human discharges |
| Eroded sediments | Deforestation and accelerated soil erosion | Soil erosion, urban storms water run-off and dredging activities |
| Other solid wastes | Metals, plastics, artificial fibres, etc. | Dumping by human beings due to poor management of waste disposal |
| Petroleum products | Drill cuttings, drilling mud (fluids used to stimulate the production process), accidental discharges of crude oil and grease, phenol, cyanide, sulphide, suspended solids, chromium and biologically oxygen demanding organic matter | Petroleum exploration, exploitation, refining, transportation, storage, marketing, use and ruptured oil pipelines. |

### I.2.6. Impact of fishing activities on water quality and algal communities

Before looking at the impacts of fishing activities on water quality and algal diversity on the seacoast of Kribi, let's try to get a review on how this sector has been operating in the region.

- **Overview of the fisheries sector in the Kribi region**

Fishing is mainly small-scale and industrial, and takes place at sea and in open waters and coastal areas such as rivers, mangroves and estuaries.

#### I.2.6.1. Small-Scale Fishing

There are 796 players in the sector (Table II) and 1556 canoes in the region. 80% of the fishermen are Cameroonian, with the remainder coming from neighbouring countries (Nigeria, Benin and Equatorial Guinea). The average percentage of Cameroonians operating in the artisanal fishing sector is 17.2%. It is therefore attractive for local authorities and entrepreneurs to invest in the fisheries sector in this area with the highest number of Cameroonians operating in the sector. A total of 39 fishing camps and fishing villages are located in the Kribi-Campo coastal region. It is estimated that 76% operate using non-motorized canoes and 32% have motorized canoes (MINEPIA, 2010).

Table II. Number of actors in the fisheries sector in the Kribi-Campo region

| Actors | Number | Cameroonians | Nigerians |
|---|---|---|---|
| Fishermen | 226 | 92.04% | 7.96% |
| Fishmonger | 72 | 81.94% | 18.06% |
| Assistant fishermen | 430 | 95.58% | 4.42% |
| Factory workers | 68 | 83.82% | 16.18% |
| Total | 796 | | |

Fishing takes place all year round. The high season generally runs from September-October to March-April. In July-August, it is impossible to go out to sea, as it is too rough.

Artisanal fishing boats mainly comprise:

- Small canoes, 4-6m long, that use hooks and lines to catch catfish and especially threadfins. These small canoes carry 2 men on board;

- Medium-sized plank canoes 7-8m long use nets 100-300m long, 3-9m deep and with a mesh size of 35 to 90mm to catch curlews, threadfins and other demersal fish, and also medium-sized plank canoes, 8-10m long, which use Bonga monofilament nets (600-800m long, 12-16 high and 40-45mm mesh size) to catch Bonga. Sardinella nets generally have 600-800 m long, 10-14 m deep and have a mesh size of 35-40mm.

- Large canoes made of solid wood or planks used for fishing Bonga with encircling nets. The net is generally 200-700m long, 7-12m deep and has a mesh size of around 38mm (Envi-rep, 2011).

**I.2.6.2. Industrial (or large-scale) Fishing**

Commercial fishing along the coast of Cameroon and the study area uses trawlers ranging in size from 20 to 25m with a gross registered tonnage (GRT) of 50-250 tons. In each case, they trawl from the side with a mesh size generally 30 to 41mm. There are two types: shrimp boats and trawlers.

- Shrimp boats.
- The first category includes vessels of between 50 and 100 GRT with a 345 horsepower and 20-22 m in length. This category of shrimp trawlers uses trawls of 30 to 34 mm stretched mesh. Because of their relatively small size, they are capable of coastal fishing.
- Shrimp boats in the second category are generally 25 m long, 100-250 GRT and powered by a 520hp engine. They are designed for deep-sea fishing, but border problems with neighbouring Nigeria in March 1983 forced them to confine themselves to Cameroonian territorial waters.
- Trawlers

There are two categories of trawlers. Trawlers in the first category are generally 22 m long, 50-100 GRT and powered by a 430 to 440hp engine. They have nets with stretched meshes of 36 to 41 mm. The second category comprises vessels 27 to 31m long, with 142-177 GRT and an engine of 600 to 650 horsepower (MINEPIA, 2010).

Fisheries research is underdeveloped in the region due to a lack of scientific and technical research staff. The region’s only research station, CERECOMA, lacks scientific staff and a research laboratory (Envi-Rep, 2011). However, thanks to the efforts of national and regional institutions, research into pollution and fish stock assessment has been carried out in the study area. It is estimated that fish production in the region is 1600-3000tons annually (CSIR, 2002) and this has reduced considerably to around 2000tons annually (MINEPIA, pers. comm. 2010).

- **Impact of fishing activities, effects on water quality**

Fishing activities, particularly bottom trawling and dredging, can disturb sediments and re-suspend nutrients and contaminants in water column (Dellapenna et *al.*, 2006; Eriksson et *al.*, 2010). This can lead to increased turbidity, nutrient levels, and the release of pollutants, affecting water quality. The cleaning and processing of fish onboard vessels can also contribute to the introduction of organic matter, nutrients, and chemicals into the water, potentially degrading water quality (Suarez-Abelenda et *al.*, 2014).

- **Effects on algal abundance and composition**

The nutrient enrichment and changes in water quality caused by fishing activities can lead to shifts in the abundance and composition of algal species (Pearson and Rosenberg, 1978; Seitz et *al.*, 2014). Increased nutrient levels can promote the growth of opportunistic, fast-growing algal species, such as filamentous green algae and cyanobacteria, leading to the formation of algal blooms, a condition known as eutrophication (Cloern, 2001; Paerl and H., 2008). The physical disturbance of the seafloor by fishing gear can also directly affect benthic algal communities, leading to a decrease in the abundance and diversity of macro algae and an increase in the dominance of more resilient, opportunistic species (Eriksson et *al.*, 2010; Thrush and Dayton, 2002).

- **Ecosystem-level effects**

The changes in water quality and algal communities can have cascading effects on the broader ecosystem, impacting the abundance and diversity of other organisms, such as invertebrates, fish, and higher trophic levels (Estes & Palmisano, 1974; Menge, 1995). The loss of diverse algal communities can lead to a reduction in the overall productivity and resilience of the ecosystem (Duffy, 2003; Stachowicz et *al.*, 2002).

**I.2.8. Legislative, legal and institutional framework for waste and environmental management.**

**I.2.8.1. International frameworks**

At the international level, there are a handful of laws and conventions that have been established and put into force to guide environmental management. These laws and conventions, once ratified by concerned parties, are to be applicable at the national and local levels. Some key international laws and treaties related to water pollution include:

- **United Nations Convention on the Law of the Sea (UNCLOS, 1982):**
- **London Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter** (1972):
- **International Convention for the Prevention of Pollution from Ships (MARPOL, 1973/1978):**
- **Convention on the Protection and Use of Transboundary Watercourses and International Lakes** (Helsinki Convention, 1992):
- **Ramsar Convention on Wetlands of International Importance (1971):**
- **Abidjan Convention for Co-operation in the Protection and Development of the Marine and Coastal Environment of the West and Central African Region (23 March 1981).**
- **International Convention on oil pollution preparedness, response and cooperation (OPRC) 1990 in London.**
- **International Convention on Liability in the event of damages caused by Hydrocarbons Pollution by Vessels (CLC), (1992).**
- **International Convention relating to intervention on the high seas in cases of oil pollution casualties, of 1969 in Brussels (Ratified by Cameroon on 14 May 1984).**

These international agreements establish principles, guidelines, and obligations for countries to address water pollution, either in the marine environment or in shared freshwater resources. Countries that have ratified these conventions are required to implement their provisions through national laws and regulations.

### I.2.8.2. Legislative and legal framework for waste management in Cameroon

The following legislative texts establish the normative bases for the environment in Cameroon and provide a framework for this study:

- Law no. 89/27 of 29th December 1989 on toxic and hazardous waste

- Law no. 96/12 of 5th August 1996 relating to environmental management
- Law no. 98/005 of 14th April 1998 to lay down regulations governing water resources
- Law no. 98/015 of 14th July 1998 relating to establishments classified as dangerous, unhealthy or obnoxious
- Law no. 2011/25 of 14th December 2011 on the development of associated gas
- Law no. 2012/006 of 19th April 2012 to institute the gas code
- Law no. 2016/017 of 14th December 2016 on the mining code.

The following regulations contain provisions relating to environmental issues:

**Decrees**

- Decree no. 2005/0577/PM of 23 February 2005 laying down the procedures for carrying out environmental impact assessments;

- Decree no. 2012/2809/PM of 26 September 2012 setting the conditions for waste sorting, collection, transport, recovery, recycling, treatment and final disposal;
- Decree no. 2001/718/PM of 03 September 2001 on the organization and operation of the Interministerial Environment Committee;
- Decree no. 2001/165/PM of 08 May 2001 specifying the procedures for protecting surface water and groundwater against pollution;
- Decree no. 2001/163/PM of 08 May 2001 regulating the protection perimeters around points for catchment, treatment and storage of drinking water;
- Decree no. 2001/162/PM of 08 May 2001 laying down the procedures for appointing sworn agents to monitor and control water quality;
- Decree n° 2001/16/PM of 08 May 2001 specifying the terms and conditions for the abstraction of surface water or groundwater for industrial or commercial purposes;
- Decree n° 99/899/CAB/PM of 29 December 1999 relating to the National Consultative Commission for the Environment and Sustainable Development;

- Decree n° 99/820/PM of 09 November 1999 setting the conditions for the approval of natural or legal persons to operate pollution control laboratories;
- Decree n° 99/821/PM of 09 November 1999 setting the conditions for the approval of natural or legal persons to carry out inspections and audits of establishments classified as dangerous, unhealthy or inconvenient;
- Decree no. 99/822 of 09 November 1999 laying down the conditions for appointing inspectors and inspectors of establishments classified as dangerous, unhealthy or inconvenient and of gas and water vapour pressure equipment;
- Decree no. 99/818/PM of 09 November 1999 laying down the conditions for the establishment and operation of establishments classified as dangerous, unhealthy or inconvenient;

**Orders**

- Order no. 037/PM of 19 March 2003 creating, organizing and operating a national risk observatory;

- Order no. 0069/MINEP of 08 March 2005 setting out the various categories of operations subject to an environmental impact study;
- Order no. 0233/MINEF of 28 February 2000 relating to the creation of environmental control and protection stations.

### I.2.8.3. Institutional Framework for Waste Management and Pollution Control

**Ministries and Public Authorities**

- **The Ministry of the Environment, Nature Protection and Sustainable Development (MINEPDED)**

It plays an arbitration role in waste management and its impact on the environment.

Responsible for:

- Monitoring and ensuring compliance with environmental sanitation standards
- Examining files relating to waste disposal, recycling and burial in liaison with the relevant authorities;
- Compliance with environmental sanitation standards;
- Periodic inspection of landfill sites; etc.

- **Ministry of Livestock, Fisheries and Animal Industries (MINEPIA)**

MINEPIA is responsible for, among other things: the development, implementation and evaluation of State policy on livestock, fisheries and the harmonious development of animal industries.

- **Ministry of Housing and Urban Development (MINHDU)**
- **Ministry of Public Health (MINSANTE)**

#### I.2.8.4. Decentralized territorial authorities (sub divisional councils and city councils, formerly urban councils)

**City Councils**

The City Councils apply the waste management policies defined by the Ministries. The main role of the city councils is technical and financial management, and the full implementation of hygiene and sanitation projects. The Kribi City Council has delegated the technical management of waste to HYSACAM. Delegation consists of entrusting a private company with the task of providing the public household waste management service under the supervision of a public institution that has a right of oversight over the administration of the service.

- **Sub divisional Councils**

Sub divisional councils are responsible for household waste collection at local level. This work is the responsibility of the hygiene and environment department, coordinated by the technical services.

- **Financing Players**

The funding bodies do not intervene directly in the field. They work in close collaboration with the ministries and the Decentralized Local Authorities. This group includes national and international funding bodies. At national level, there are two structures, namely the Ministry of Finance (MINFI) and the Fonds Spécial d'Equipement et d'Intervention Intercommunale (FEICOM). MINFI pays the amounts collected to the Urban Community to finance all public waste service operations. It also acts as liaison between the State and international bodies (IMF, WB, EU, etc.) for the receipt and distribution of subsidies obtained from these institutions.

#### I.2.8.5. Civil society and private stakeholders

- **NGOs, Associations, Cooperative societies, and Common Initiative Groups (CIGs)**

NGOs and associations are involved in educating, raising awareness, informing and training local residents and associations in waste recovery techniques.

Like NGOs, CIGs and cooperatives are involved in education, awareness-raising, information and training of local populations and associations on waste recovery and valorization techniques.

# CHAPTER II: MATERIALS AND METHODS

## II.1. MATERIAL

### II.1.1. Description of the coastal region of Kribi

### II.1.2. Physical Environment

The coastal region of Kribi is located on the edge of the Gulf of Guinea, in the South Region of Cameroon and in the Ocean Division, with GPS coordinates 02˚56’06’’N 09˚54’36’’E (Suchel et *al.*, 1987).

### II.1.3. Climate

The region experiences a tropical monsoon climate (Köppen climate classification *Am*) of Guinean type characterized by the existence of four seasons, 02 dry seasons (from December to March for the long season and from July to August for the short season) and 02 rainy seasons (from September to November for the long season and from April to June for the short season) (Suchel et *al.*, 1987). The average daily duration of sunstroke varies from 8 to 10 hours all year round (Suchel et *al.*, 1987). Average daily maximum temperatures range from 25˚C to 33˚C while average daily minimum temperatures range from 15˚C to 22˚C (Suchel et *al.*, 1987). As for rainfall, it reaches monthly values of 504 mm in September.

### II.1.4. Vegetation

The vegetation is made of marsh forests, mangrove forests and evergreen forests creating a specific environment at the beach levels, making them attractive to tourists. Here, common tree species found include *Saccoglottis gabonensis*, *Andira inermis*, *Cynometra hankei*, *Coula edulis* and *Pycnanthus angolensis* (Obiang et *al.*, 2020). The marine area surrounding this formation is rich in marine tree species such as *Termeinalia catappa*, *Syzygium guineense var. littorale*, *Phoenix reclinata*, *Chrysobalanus icaco* spp. *icaco*, *Manilkara obovata*, *Calophyllum inophyllum*, *Carapa procera* and *Cocos nucifera.*

### II.1.5. Hydrology

The hydrology is dominated by the Atlantic Ocean whose tidal range is low with small waves. The presence of the Lobé and Kiénké rivers is remarkable, as are the Ngoyè, Abondé, Wamié, Nzami, Bidou Rivers, which receive household waste and wastes from agro industrial companies like SOCAPALM and HEVECAM (Obiang et *al.*, 2020). It has an estimated population of 55,401 inhabitants as of 2021 and statistical models indicate forecasts of about 140,049 inhabitants in 2025 and 194,306 inhabitants by 2050 (BUCREP, 2010).

### II.1.6. Faunal Biodiversity

- **Fish, Crustaceans and Molluscs:**

The diversity of marine fish in the study area is comparable to that known from the coastal waters of Cameroon. Some 381 species, with a further 70 species identified as being associated with brackish estuarine environments (Fish base, 2004). The main target fish species comprise two main groups: pelagic and demersal (benthic) fish, both accounting for approximately 63% and 19% respectively of total fishing exploitation, followed by *Paneidae* (2%) and *Nematopalaemon hastatus* (16%). The crustaceans have all been identified, and 4 are of commercial value namely: *Nematopalaemon hastatus*, *Parapaeneus atlantica*, *Penaeus notialis* and *Penaeus kerathurus*; twenty-five species of molluscs, including the *Siphonaria mouret*, *Purpura collifera*, *Purpura yetus*, *Sepia officinalis*, *Mytilus tenuistratus*, *Crassostrea gasar* and *Crassostrea rufa* (Crosnier, 1964), which are of commercial value. Various fish species cannot be left out as most of them attract a lot of fishermen from far and near. Among the fish species are those found in Table IV.

### II.1.7. Socio-Environmental Aspects

Kribi as an attractive city has a very cosmopolitan population. From indigenous or local populations to people from all over the national territory, in addition to foreigners from other African countries, Europe and Asia make up the 80,000 inhabitants in the area. This number could reach 300,000 in the next 15 years according to the regional United Nations Development Program (UNDP). This is a global trend because in 2003, 41% of the world’s population lived in coastal areas and mostly in developing cities (Martínez et *al*., 2007). The socio-economic activities that are ongoing in the area range from the primary to the tertiary sector and exert serious and direct pressure on the coastal environment with the main outlet which is the ocean for their waste deposition.

Table III. Common species of marine fauna found in the coastal waters of Kribi

| **Common Name** | **FAO Name** | **Species Name** |
|---|---|---|
| Mussobo | Longneck croaker (Fr. Otolithe naka) | *Pseudotolithus typus* Blecker, 1863 |
| Cover-pot | Daisy Stingray (Fr. Pastenague) | *Dasyatis margarita* (Gunther, 1870) |
| Barracuda | Barracuda (Fr. Bécune) | *Sphraemapiscatorium sp.* |
| Sole | Senegalese tonguesole (Fr. Sole langue de sénégalaise) | *Cynoglossus senegalensis* |
| Capitaine | Lesser African threadfin (Fr. Petit capitaine) | *Galeodes decadactylus* (Bloch, 1795) |
| Machoiron | Smooth mouth sea catfish (Fr. Machoiron banderille) | *Arius heudelotii* |
| Shark | Shark (Fr. Requin) | *Carcharodon carcharias* |
| African spade fish | African spade fish (Fr. Chèvre de mer) | *Chaetodipterus goreensis* |
| Nyanga fish | West African Spanish mackerel (Fr. Thazard blanc) | *Scomberomorus tritor* (Cuvier, 1831) |
| Crab | Smooth swim crab (Fr. Etrille lisse) | *Portunus validus* (Herklots, 1851) |
| Gambas | Caramot prawn (Fr. Caramot) | *Penaeus cf. kerathurus* (Forsskal, 1775) |
| Sea Turtles | Sea Turtles (Fr. Tortue marin) | *Eretmochelys* imbricata |
| West African Manatee | Manatee (Fr. Lamantin) | *Trichechus senegalensis* |
| Estuarine prawn | Crayfish (Fr. Crevete) | *Nematopalaemon hastatus* |
| Shellfish | Shellfish (Fruits de mer) | *Siphonaria mouret* |
| Bonga | Bonga Fish | *Ethmalosa fimbriata* |
| Sardine fish | Sardine fish (Sardines) | *Sardinella maderensis* |
| Croakers | Croakers (Courbines) | *Pseudotolithus spp.* |

### II.1.8. Location of the study area (Choice and Description of Sampling Stations)

The sampling stations were chosen based on their economic and industrial importance. The following reasons contributed to the choice of these sampling stations:

- Proximity to industrial sites: stations near industrial facilities to evaluate direct impacts from pollutants, effluents, and habitat alteration.
- Fishing activity areas: locations with high fishing activity to assess the ecological impacts and potential overfishing effects on local marine populations.
- Community use areas: stations in areas where local communities engage in fishing or other marine activities to assess socio-economic impacts
- Environmental gradient: stations along a gradient (from heavily impacted to less impacted areas) to compare ecological conditions and assess the extent of impacts.

After taking into consideration the choice for the sampling stations, the following stations were chosen and their corresponding GPS coordinates noted as shown in Table VI:

Table IV. Sample stations and their GPS coordinate

| **Sampling Station** | **GPS Coordinates** | **Description** |
|---|---|---|
| Londji | N3.50912, E9.58160 | Fish market and oil pipeline |
| Mpalla | N3.01223, E9.56904 | Closeness to hotels |
| Mahale | N2.59075, E9.54939 | Closeness to hotels |
| Ngoye | N2.57797, E9.54442 | Canoe building and fishing |
| Mboamanga | N2.56610, E9.54142 | Busiest fish market |
| Palm Beach | N2.56101, E9.53991 | Presence of hotels |
| Tara Plage | N2.54391, E9.53786 | Clear view of offshore oil rigs |
| Lobe | N2.53565, E9.53589 | Estuary of the Lobe River |
| Grand Batanga | N2.52415, E9.95158 | Less impacted area |
| Basin Zone | N2.43317, E9.50288 | Seaport Zone |
| Anchorage or Mooring Zone | N2.43770, E0.45429 | Seaport Zone |
| Spoil or Excavation Zone | N2.43999, E9.28396 | Seaport Zone |
| Phase II Zone | N2.45521, E9.50882 | Seaport Zone |
| Outlet Zone | N2.72054, E9.86022 | Seaport Zone |

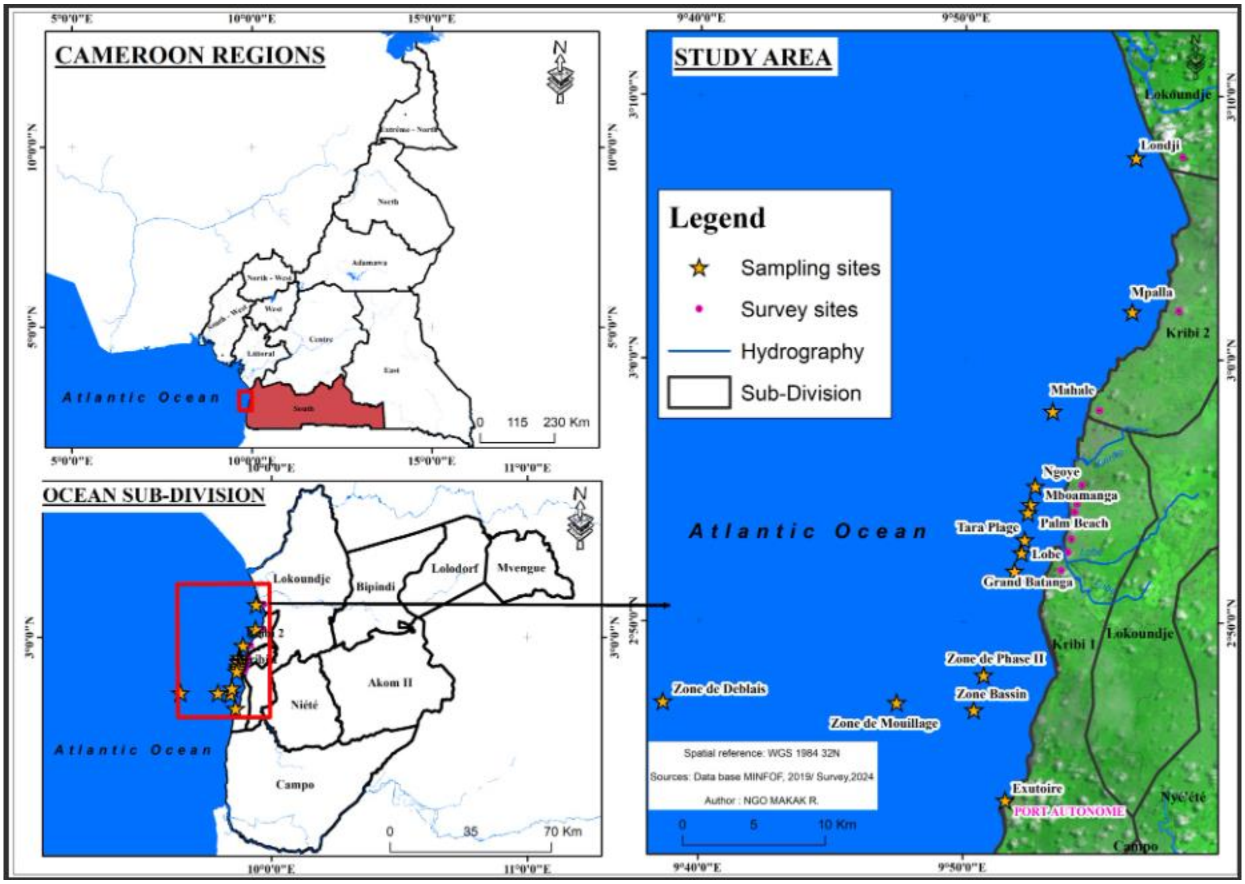


Fig. 1. Geographical location of survey sites and sampling points

### II.1.9. Equipment used in the study

The equipment used comprised of the following:

- A modern vessel of the type PILOT BOAT provided by the Port Authority for rapid and secured movements at high sea to transport personnel to the various sampling stations
- Life jackets and personal protective equipment for safety of personnel
- An access form declaring presence in the Seaport Zone
- A digital camera of the mark CANON for taking of pictures
- A GPS of the mark GARMIN for reading of GPS coordinates
- Jotters and pens for collection of information in the field
- Plankton nets
- Van Dorn Water Sampler
- Ropes
- 10L buckets

- Multi-parameter water quality analyzer
- 250ml plastic bottles
- Coolers with ice for preservation of collected samples
- Lugol solution
- Light microscope
- 10ml pipettes
- Slides and slide covers
- Sedgewick-Rafter counting cell for determination of particles per unit volume.
- A micrometer
- A laptop with Microsoft Excel, Word, PowerPoint, etc., for statistical analysis.


Fig. 2. Field equipment; (A) Fast Pilot Boat, (B) GPS, (C) Multi-parameter water quality analyzer, (D) sample collection bottles.

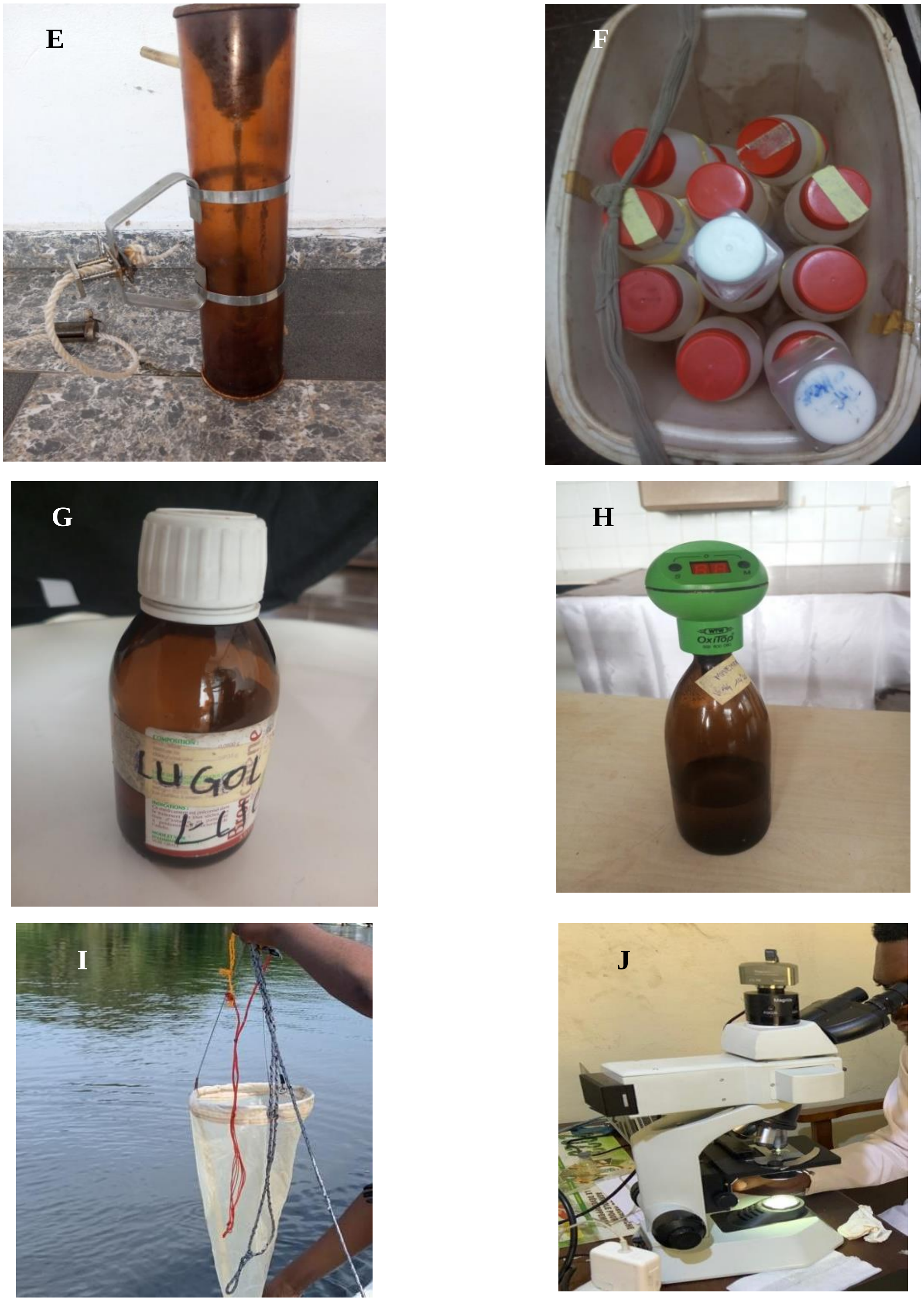


Fig. 3. Collecting equipment; (E) Van Dorn Water Sampler, (F) 250ml sampling bottles in cooler, (G) Lugol solution, (H) BOD bottle, (I) phytoplankton net, and (J) light microscope.

## II.2. METHODS

### II.2.1. Status report on the opinion of local residents and the quality of seawater

The opinion of the local residents of the study area was gotten through interviews and questionnaires. A total of 150 locals were interviewed and they gave their opinions on what they perceive as good water quality. Their age distribution was noted alongside their gender, level of education, years of inhabitation, notion about marine algae and water quality. The participants, through the interviews and questionnaire forms gave their opinion on what they perceive as good water quality, and also about waste management in the area. They also mention some industries and industrial activities known to them in the area.

### II.2.2. Identification of potential impacts on water quality and algal diversity

To be able to identify potential impacts on water quality and algal diversity, a survey was carried out in the study area. This survey was randomly carried out within the local population using questionnaires in the study area based on some important key points such as waste management practices from both industrial and fishing activities. Water sampling was then performed in the chosen sampling points for further investigations.

### II.2.3. Water sample collection

The abiotic factors considered for water analysis were: pH, temperature, conductivity, salinity, turbidity, dissolved oxygen, chlorophyll, total suspended solids (TSS), total dissolved solids (TDS), chemical oxygen demand (COD), biological oxygen demand (BOD), nitrates ($NO^{3-}$), nitrites ($NO^{2-}$), ammonium ions ($NH^{4+}$), and phosphates ($PO_4^{3-}$).

At each sampling station, samples were collected at the surface using a 10L bucket attached to a rope and at a depth of 10m using a Van Dorn Water Sampler bottle attached to a rope with a mark visible at the 10th meter. The water samples collected were put into 250ml plastic bottles (after washing and rinsing with the same water sample) with labels bearing the name of each sampling station, the collection position (surface or deep) and the date. Physical parameters such as pH, temperature, conductivity, salinity and TDS were measured in situ using a waterproof multi-parameter water quality analyzer. For nitrate and phosphate determinations, water samples were stored in 250ml polyethylene bottles, and sulfuric ($H_2SO_4$) acid was added to reach a pH < 2. Lowering the pH to <2 helps to stabilize the phosphate and nitrate species in solution, preventing their conversion to other forms that may not be detected accurately during analysis. It also prevents precipitation, reduces interference and improves detection. The amount of phosphate and nitrate were estimated using a spectrophotometer.


Fig. 4. (A) Water sampling; (B) pouring water sample into a 250ml plastic bottle

**II.2.4. Sample preparation, observation and algae identification and quantification**

To collect surface microalgae, plankton net with a mesh size of 64µm was set at a distance of 4m from the boat; this was repeated 10 times for each sampling station. The retentate was collected and stored in a plastic sampling bottle and fixed with Lugol's iodine (0, 5 mL in 100 mL of sample), and preserved for transportation to the Hydrobiology and Environment Laboratory of the University of Yaoundé I for further analysis. The analysis was going to follow the methodology used for waters sampled at depth. Lugol's solution was used as a fixative to preserve the microalgae in a state as close as possible to the living state. Color is a taxonomic characteristic of most algae, especially green algae. The colors of the microalgae included the following: green, light green, blue green, dark brown, light brown to greenish brown. The preservation of microalgae in Lugol's solution can maintain the natural color of algae for longer duration even when kept in dark condition.

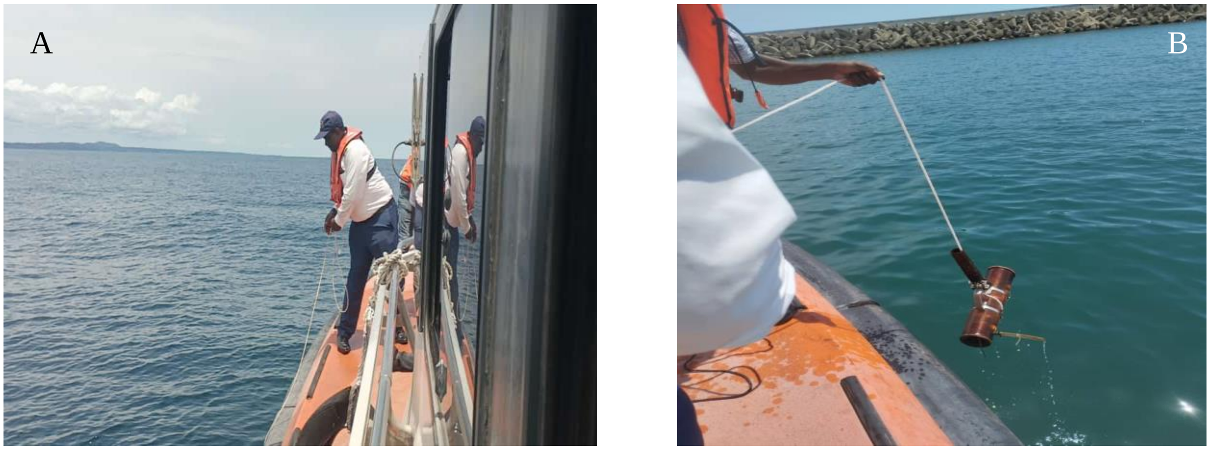


Fig. 5. (A) Seawater collection from the surface; (B) Seawater collection from a depth of 10m below using Van Dorn bottle

The collected algal samples were brought to the Hydrobiology and Environmental Science laboratory of the University of Yaoundé I and the National Herbarium at the Institute of Agricultural Research for Development for microscopic examination. In the laboratory, the samples were left for 48 hours, then the supernatant was siphoned off and the cap obtained was allowed to sediment in a 25ml sedimentation tank. After homogenization of the sediment, 1ml was pipetted and observed under a Magnus Binocular Microscope Model: MLX-B Plus LED at 10x, 20x and 40x magnification using a Sedgewick-Rafter counting cell with alternating left-right scans of the counting cell transects; images observed were photographed using the microscope's built-in camera connected to a laptop. An Olympus CH-2 Optical Microscope was also used which is equipped with a movable stage and a five-objective revolver, including an immersion objective for counting algae species.

During this identification process, algal species were identified at the phyla, genera and species level. Photo plates of algal samples were microscopically examined and identified on the basis of morphological and molecular characteristics using standard algae identification keys (Bourelly, 1984) and consultation of articles related to marine algae identification. We also made use of the help of taxonomists working with the National Herbarium of Cameroon at the Institute of Agricultural Research for Development in the identification process.

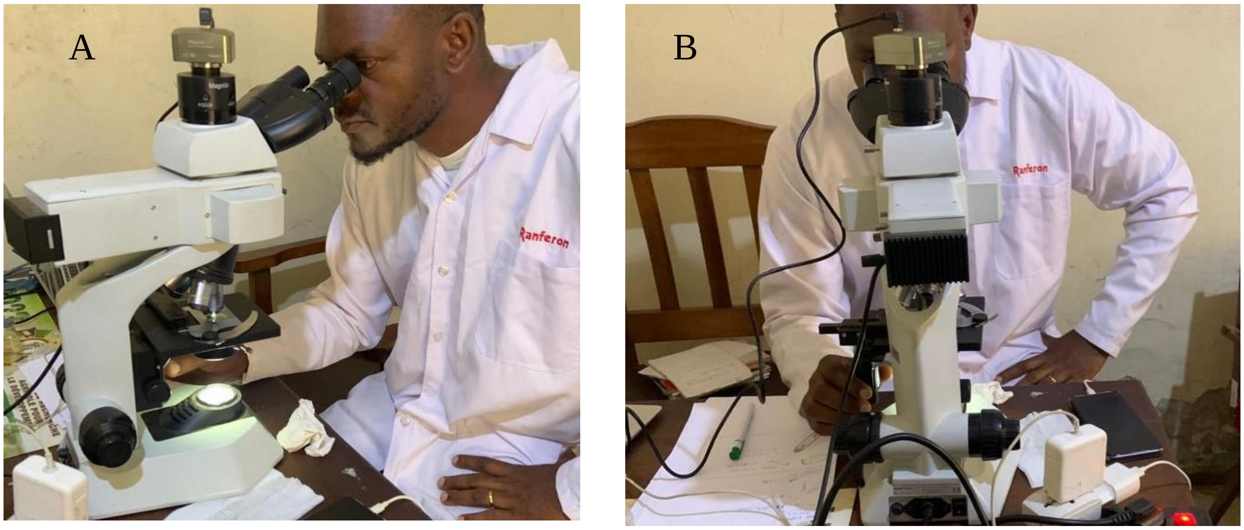


Fig. 6. (A) Microscopic observation of phytoplankton; (B) Algae counting.

### II.2.5. Physicochemical Analysis of water

Various physical parameters such as pH, temperature and DO were analyzed in situ using standard methods (using a multi-parameter water analyzer). The EC (Electrical conductivity), TDS (Total dissolved solids), TSS (Total suspended solids), BOD (Biological oxygen demand), COD (Chemical oxygen demand), acidity and alkalinity were determined by standard methods using the Rodier protocols (Rodier et *al.*, 2009).

- **Physicochemical parameters considered**

Table V shows the physicochemical parameters considered and their significance in this study. These parameters play key roles in aquatic ecosystems and understanding them is essential for water quality management and monitoring of changes that could upset the balance of the ecosystem. Their understanding also helps in initiatives aimed at restoring and protecting aquatic environments, hence notion of their individual roles is of vital importance.

Table V. Significance of the various parameters considered

| **Parameter** | **Significance** |
|---|---|
| Temperature | -Regulates metabolic rates of marine organisms<br>-Regulates dissolved oxygen levels<br>- Influences the distribution and composition of marine species<br>- Plays a role in nutrient availability and cycling within marine ecosystems<br>- Influences the proliferation of harmful algal blooms |
| pH | - Provides information on the acidic or basic nature of water.<br>- Can affect disinfection processes and metal solubility.<br>- Influences many physicochemical reactions.<br>- Influences the distribution of micro-organisms involved in degrading organic matter. |
| Electrical conductivity | - Capacity of ions present in a solution to carry electric current.<br>- Gives an idea of the overall mineralization of the water. Water with high conductivity is likely to contain high levels of dissolved inorganic solids such as nitrates, phosphates, sodium, calcium, etc. |
| Salinity | - Aquatic life health; different species of aquatic organisms have specific salinity tolerance<br>- Ecosystem functioning; salinity influences the physical and chemical properties of water, affecting nutrient availability, oxygen levels, and overall ecosystem productivity<br>Indicator of pollution; increased salinity can indicate pollution from agricultural runoff or industrial discharge, which can harm marine ecosystems. |
| Turbidity | - Indicator of water clarity; turbidity measures the cloudiness of water caused by suspended particles. Higher turbidity can reduce light penetration, affecting photosynthesis in aquatic plants.<br>- Effects on chemical reactions; suspended particles can absorb chemicals, affecting their availability and toxicity in water. This can alter nutrients dynamics and impact water quality. |
| Colour | - Indicator of contaminants; water colour can indicate the presence of dissolved organic matter, sediments, or pollutants. For example, brown or yellow water often suggests the presence of organic materials or tannins, while green may indicate algal blooms.<br>- Impact on aquatic life; colour can affect the behavior and health of aquatic organisms. For instance, darkened waters can reduce light penetration, affecting photosynthesis and disrupting food |

| | |
|---|---|
| | chains |
| Dissolved oxygen (DO) | - Vital for aquatic life; DO is essential for the survival of fish, invertebrates, and other aquatic organisms. Low DO levels can lead to hypoxia, which can stress or kill these organisms.<br>- Indicator of ecosystem health; DO levels reflect the overall health of aquatic ecosystems. High oxygen levels typically indicate a healthy, balanced ecosystem, while low levels can signify pollution or excessive organic matter decomposition.<br>- Response to environmental changes; DO levels can serve as an early warning system for environmental changes, such as increased organic pollution or climate change impacts, allowing for timely management interventions |
| Chlorophyll | - Indicator of primary production; chlorophyll concentration directly reflects the abundance of phytoplankton, which are essential for primary production in aquatic ecosystems. Higher levels indicate productive waters, while low levels may suggest nutrient limitations.<br>- Assessment of nutrient levels; elevated chlorophyll levels can indicate nutrient enrichment, often from agricultural runoff and industrial discharges leading to algal blooms. This is critical for managing nutrient pollution.<br>- Water quality implications<br>- Climate change indicators<br>- Recreational and Aesthetic concerns |
| Total Suspended Solids (TSS) | - Indicator of water clarity; this measures the concentration of particulate matter suspended in water. High levels can lead to reduced water clarity, affecting aquatic life by limiting light penetration necessary for photosynthesis.<br>- Impact on aquatic ecosystems; elevated TSS can smother habitats, interferes with fish spawning, and disrupt the feeding mechanisms of filter feeders. This can lead to decreased biodiversity and overall ecosystem health.<br>- Pollution indicator<br>- Effects on chemical reactions<br>- Erosion and sedimentation |
| Total Dissolved Solids (TDS) | - Indicator of water quality; TDS measures the concentration of all dissolved substances in water, including salts, minerals, and organic matter. High TDS levels can indicate poor water quality and affect taste and usability. |

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| | - Correlation with pollution; increased TDS often correlates with pollution, such as runoff from urban areas or agricultural lands. - Monitoring TDS helps identify potential contamination sources and assess environmental health.<br>- Impact on aquatic life<br>- Influence on chemical properties |
| Chemical Oxygen Demand | - Indicator of organic matter; COD measures the amount of oxygen required to chemically oxidize organic and inorganic substances in water. High COD values indicate high levels of organic pollutants, which can be detrimental to aquatic ecosystems.<br>- Assessment of water pollution; COD is a reliable indicator of water pollution, particularly from industrial discharges, sewage, and agricultural runoff. Monitoring COD helps identify contamination sources and assess the effectiveness of wastewater treatment processes.<br>- Research and management; understanding COD levels aids in research on pollution sources, ecosystem responses, and management strategies for water quality improvement. It supports initiatives aimed at restoring and protecting aquatic environments.<br>- Nutrient cycling; high COD levels can influence nutrient cycling in aquatic systems, affecting the availability of nitrogen and phosphorus, which are critical for plant growth. |
| Biochemical Oxygen Demand | - Indicator of organic pollutants; BOD measures the amount of oxygen consumed by microorganisms while decomposing organic matter in water. High BOD levels indicate a significant presence of biodegradable organic pollutants, which can harm aquatic ecosystems.<br>- Assessment of water quality; BOD is a key indicator of the overall health of a water body. Elevated BOD levels can signal pollution from sources such as sewage, agricultural runoff, and industrial discharges, necessitating further investigation.<br>- Impact on aquatic life; high BOD levels can lead to oxygen depletion in water, creating hypoxic conditions that stress or kill fish and other aquatic organisms.<br>- Ecosystem dynamics; changes in BOD can reflect shifts in ecosystem dynamics, including nutrient loading and microbial community composition. Understanding these changes is essential for effective water resource management. |
| Nitrates | - Indicator of nutrient pollution; elevated nitrate levels often |

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| | indicate nutrient pollution.<br>- Impact on aquatic ecosystems; high concentrations of nitrates can lead to eutrophication and hence oxygen depletion and reduction of water quality |
| Phosphates | - Indicator of nutrient pollution<br>- Eutrophication risk; high concentrations of phosphates can lead to eutrophication, which stimulates excessive algal growth. This can result in oxygen depletion, harmful algal blooms, and negative impacts on aquatic life.<br>- Research and management |
| Ammonium ions | - Indicator of organic pollution; elevated levels of ammonium ions often indicate pollution from organic matter decomposition, sewage, and agricultural runoff. Monitoring ammonium ions helps identify sources of contamination in water bodies.<br>- Nutrient dynamics<br>- Indicator of eutrophication |

### II.2.6. Impact assessment (identification and characterization) using a matrix

After physicochemical analyses of the various water parameters considered, there is need to evaluate their impacts and this can be done using a matrix.

To systematically evaluate the significance of various impacts based on their severity and likelihood, an impact assessment matrix was used. It is a matrix similar to that developed by Luna Leopold in 1971, but here the focus is on severity and likelihood of impacts from which the significance can be deduced. It is from the significance that the impacts are characterized and prioritized for management, guiding further research and management actions.

Components of the impact assessment matrix include:

**Activities:** This will constitute the various activities being assessed; in the case of this study, industrial and fishing activities.

**Impacts:** Identification of potential impacts on water quality and algal diversity

**Severity:** The severity of each impact is ranked as low, medium or high using numbers 1-3 (numbers 1 = Low, 2 = medium and 3 = high)

**Likelihood:** Assessment of the likelihood of each impact occurring using numbers also (1 = rare, 2 = possible and 3 = likely).

**Significance:** The severity and likelihood are combined to determine the overall significance of each impact.

The simple equation for this combination is: **Severity X Likelihood = Significance**

### II.2.7. Proposition of mitigation measures

To be able to propose good measures for a better management of the coastal region, the various activities exerting pressure on the marine ecosystem are considered, censored and their various weak points noted. In this study, the main activities looked upon are industrial and fishing activities. The industries involved include mining (Oil and gas exploration and exploitation), agro-industrial transformation, animal breeding, construction, seaport activities and sea transport and power generation. Fishing methods include artisanal and industrial fishing with practices such as trawling and dredging, used of uncontrolled mesh size nets, use of chemicals for fishing, dumping of fish wastes at the shores. The drainage system in the region is poor and industrial effluents always find their way into the marine environment. Fisher people have little or no knowledge on waste management and this area needs improvement. The areas to be touched therefore include:

- Regulation and monitoring
- Sustainable fishing practices
- Waste management improvements
- Habitat restoration
- Community engagement and education
- Research and development
- Policy development
- Emergency response plans

Implementing these measures can help protect water quality and algal diversity along the seacoast of Kribi, fostering a more sustainable environment for both the ecosystem and local communities.

# CHAPTER III: RESULTS AND DISCUSSION

## III.1. RESULTS

### III.1.1. Opinion of local residents on seawater quality and algal diversity

- **Educational level**

The educational attainment of participants in the study area in Kribi shows a diverse range of educational backgrounds. The majority, 48%, have completed secondary education, indicating a strong base of individuals with a relatively high level of formal education. Additionally, 40% have received primary education, reflecting a significant portion of participants with fundamental schooling. Only 7% of the respondents have attained higher education, while 5% have no formal education.

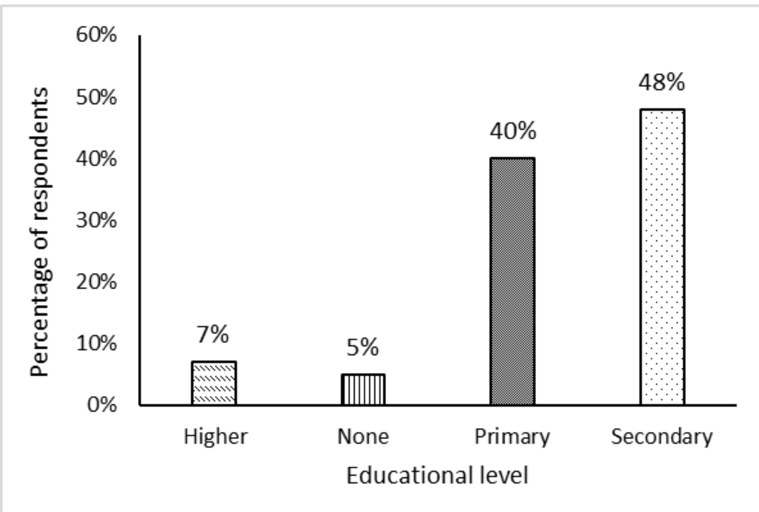



Fig. 7. Educational level of participants

- **Observations of Changes in Fish Quality or Quantity Over Time**

The majority of participants, 67%, have observed changes in fish quality or quantity over time, indicating a prevalent perception of alterations in the local fish populations or their conditions. Conversely, 33% of participants did not report any noticeable changes in fish quality or quantity, which may reflect either stable conditions or less awareness of subtle shifts in the aquatic environment.

- **Reasons for decrease in fish quality and quantity according to participants**

Participants attributed changes in fish quality or quantity to several key factors. The most frequently cited reason is water pollution, identified by 25.15% of respondents. Industrial activities were also highlighted by 23.31% of participants, suggesting that industrial processes may be contributing to adverse effects on the aquatic environment and fish stocks. Climate change was mentioned by 21.47% of respondents, reflecting concerns about how shifting climate patterns are affecting fish habitats and populations. Overfishing was cited by 14.11% of participants, indicating that excessive fishing pressure is perceived as a factor in declining fish numbers or quality. A smaller portion, 15.95%, reported that they had not identified any specific reasons for the observed changes.

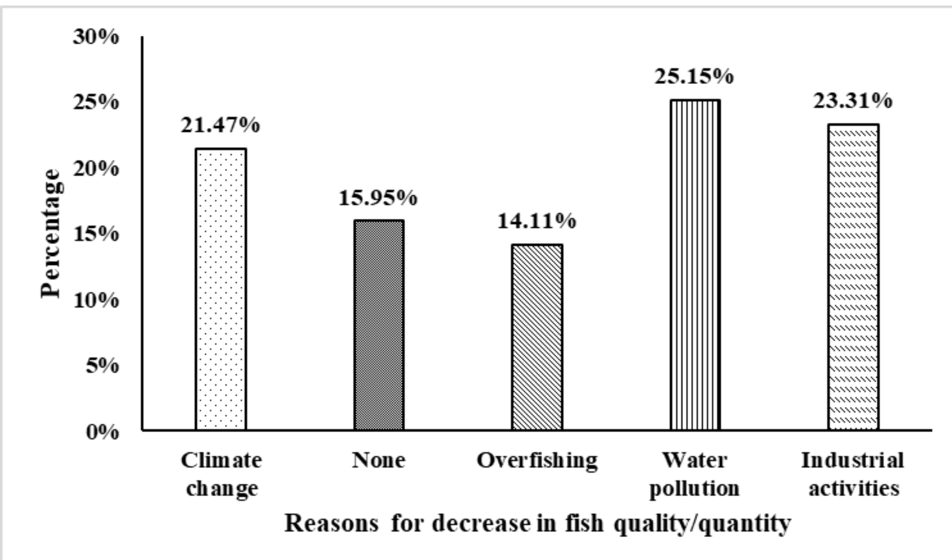



Fig. 8. Reasons for decrease in fish quality/quantity according to participants

- **Use of Marine Algae**

The survey results show that marine algae are used for a variety of purposes in the region. The most common use, reported by 46.00% of respondents, is in medicine, indicating the significant role of algae in traditional or modern medical practices. Cosmetics follow closely, with 36.00% of participants identifying algae as an ingredient in cosmetic products, highlighting its importance in the beauty and skincare industry. A part of the respondents, 14.00% revealed that algae are used as food and 4.00% shared the opinion that algae are used as ornamentals. This can be seen in the representation in fig.12.

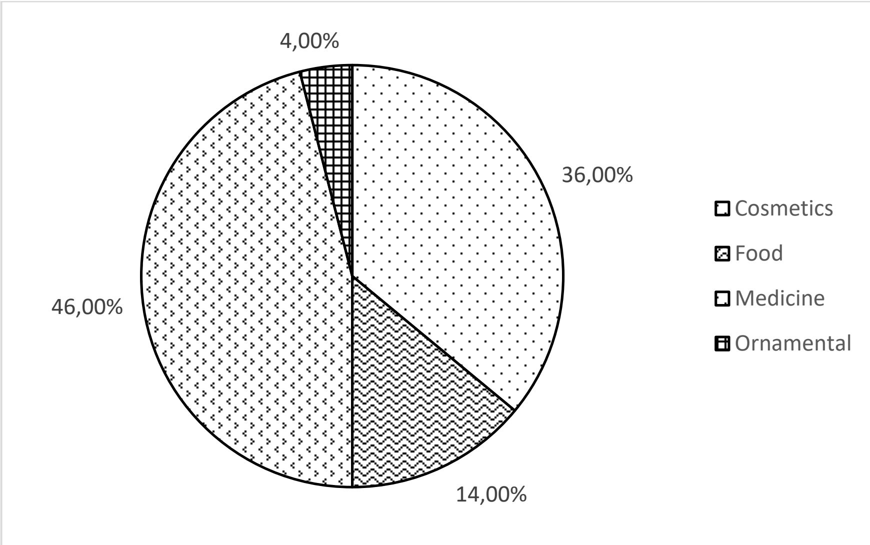



Fig. 9 . Uses of algae in the study area according to participants

### III.1.1.1. Activities impacting water quality on the seacoast of Kribi

Industrialization is identified by 20.79% of respondents as a major factor affecting water quality, reflecting concerns about pollutants and waste from industrial processes. Oil and gas exploitation is also a significant concern, cited by 16.83% of participants, indicating its considerable impact on water quality due to potential spills and contaminants (Fig. 13).

Urbanization, reported by 14.85% of respondents, suggests that the expansion of urban areas contributes to deteriorating water conditions, possibly through increased runoff and waste. Fishing with chemicals is noted by 11.88% of participants as a detrimental practice, pointing to the harmful effects of chemical use in fishing on aquatic ecosystems (Fig. 13).

Agricultural activities, identified by 12.87%, contribute to water quality issues through runoff containing fertilizers and pesticides. Pollution from household waste, mentioned by 9.90%, reflects the impact of domestic waste on local water bodies. The use of petroleum products (6.93%) and tourism (4.95%) are perceived to have a lesser but still relevant impact on water quality. Animal breeding, with only 0.99%, is considered the least significant among the listed activities (Fig. 13).

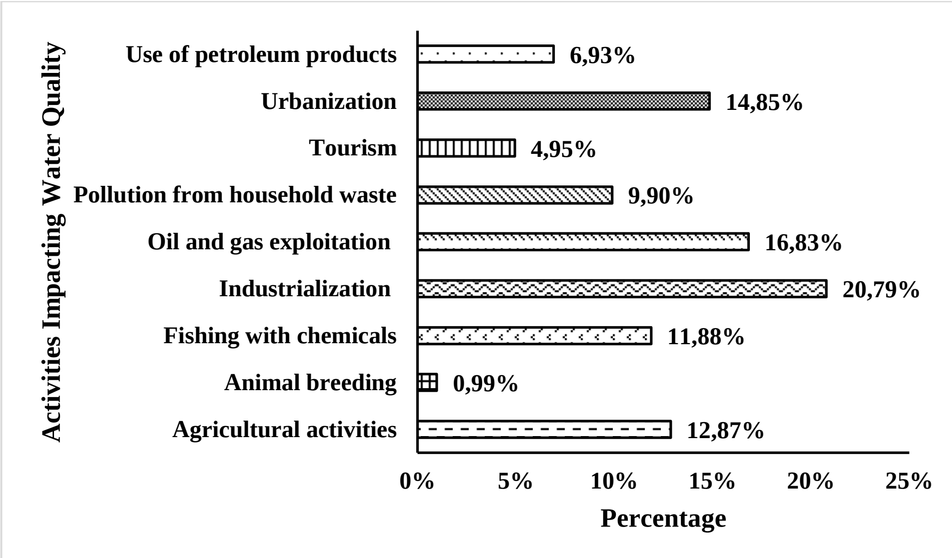



Fig. 10. Activities impacting water quality from survey reports

- **Industrial Activities**

The survey results indicate that mining is perceived as the most impactful industrial activity, accounting for 34.40% of responses. This highlights the significant role of mining operations in influencing the local environment, potentially through the release of pollutants or habitat disruption. Transport and logistics follow closely, with 31.20% of respondents citing this sector as a major contributor, likely due to its role in infrastructure development and the movement of goods, which can affect coastal ecosystems and water quality (Fig. 14).

Agriculture and transformation activities were identified by 29.20% of participants, indicating their considerable influence on the environment, likely through runoff and land use changes. Electricity and gas production, at 2.80%, and energy production, at 2.40%, are perceived as having a lesser impact compared to other industrial sectors (Fig. 14).

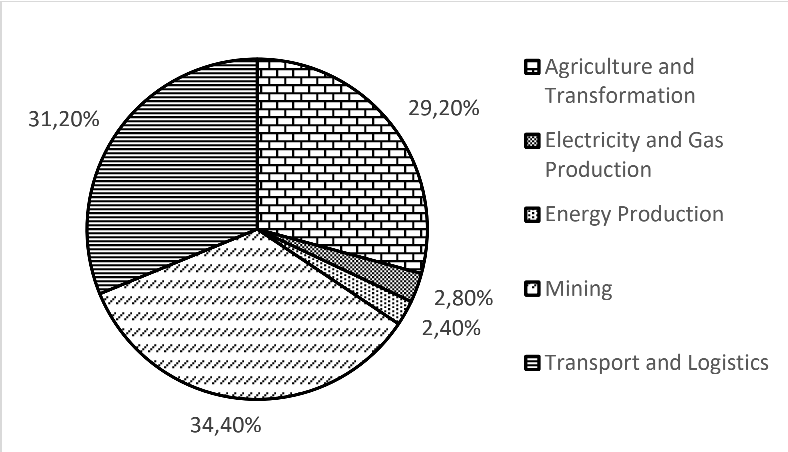



Fig. 11. Industrial activities impacting water quality and algal diversity

- **Positive Impacts of Industries**

The survey results indicate that industries around the seaport of Kribi are perceived to have several positive impacts on the local community. Employment stands out as the most significant benefit, cited by 29.68% of respondents, underscoring the crucial role of industries in providing jobs and supporting livelihoods in the region. Increased economic activities follow closely at 26.43%, reflecting the boost in commerce and trade resulting from industrial operations, which positively affects the local economy (Fig. 15).

The supply of potable water is identified by 14.46% of participants as a key positive contribution, suggesting that industries play a role in improving access to clean water for the community. Construction of health centers (12.72%) and schools (7.98%) are additional benefits, highlighting the contribution of industrial investments to social infrastructure and community well-being. Beautification of the city, noted by 8.73%, is the least reported benefit, yet it shows that industries are also recognized for their role in enhancing the urban landscape (Fig. 15).

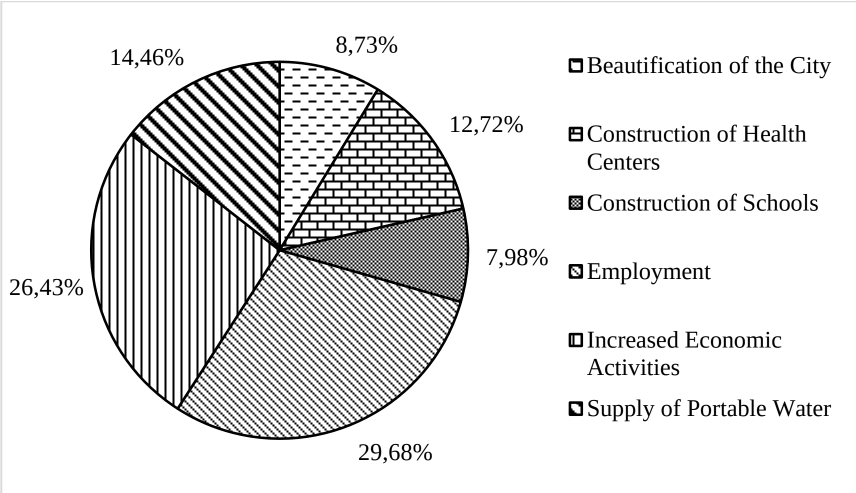



Fig. 12. Positive impacts of industrial activities

- **Negative Impacts of Industries**

The survey identifies several negative impacts of industrial activities surrounding the sea coast of Kribi. Water pollution is reported by 32.21% of respondents, making it the most significant concern, closely followed by air pollution at 31.29%. These results indicate a pressing environmental challenge, with industrial operations contributing to the degradation of essential natural resources, potentially affecting both ecosystem health and community well-being (Fig. 16).

Proliferation of diseases is noted by 25.77% of participants, suggesting that industrial activities may be linked to health risks through pollution or poor living conditions. Additionally, 5.21% of respondents cited prostitution as a social issue arising from industrial development, which could be related to increased economic activity and migration patterns (Fig. 16).

Noise pollution, at 3.68%, and traffic congestion, reported by only 1.84% of participants, are seen as lesser concerns but still reflect the broader social and infrastructural impacts of industrialization (Fig. 16).

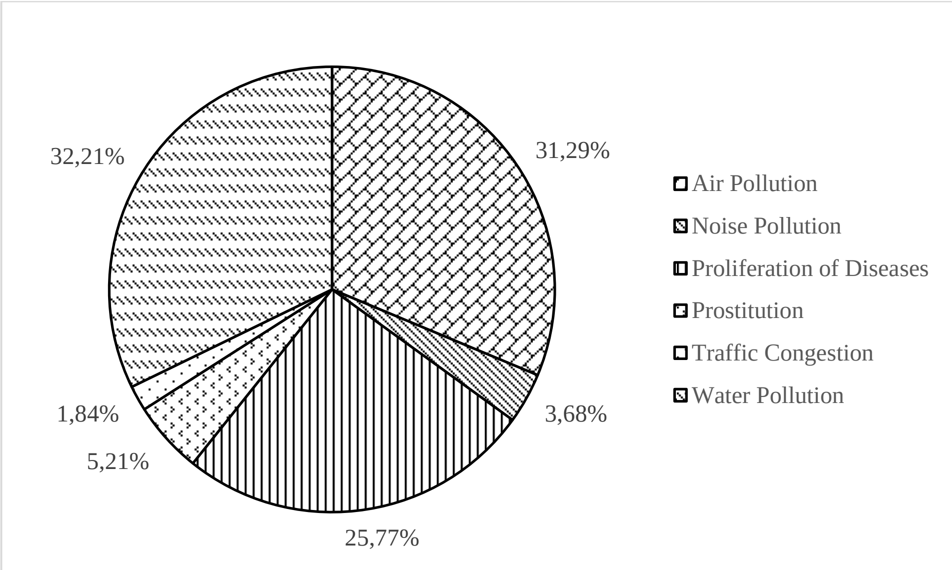



Fig. 13. Negative impacts of industrial activities

- **Identified Impacts on Fisheries**

The survey results indicate significant concerns regarding the impacts of various activities on fisheries in the region around the sea coast of Kribi. The most reported issue is the reduction in fish quantity, cited by 33.22% of respondents. Closely related is the modification of water quality, mentioned by 32.24% of participants, emphasizing the detrimental effect of water pollution on marine ecosystems, which directly affects fish health and abundance (Fig. 17).

Restricted fishing zones were identified by 31.91% of respondents, indicating that industrial expansion and the establishment of exclusion zones for various activities are limiting access to traditional fishing grounds. The malformation of some fish species was reported by 2.30% of participants. Coastal deforestation, at 0.33%, appears to be a minor concern but still represents a broader issue of habitat degradation (Fig. 17).

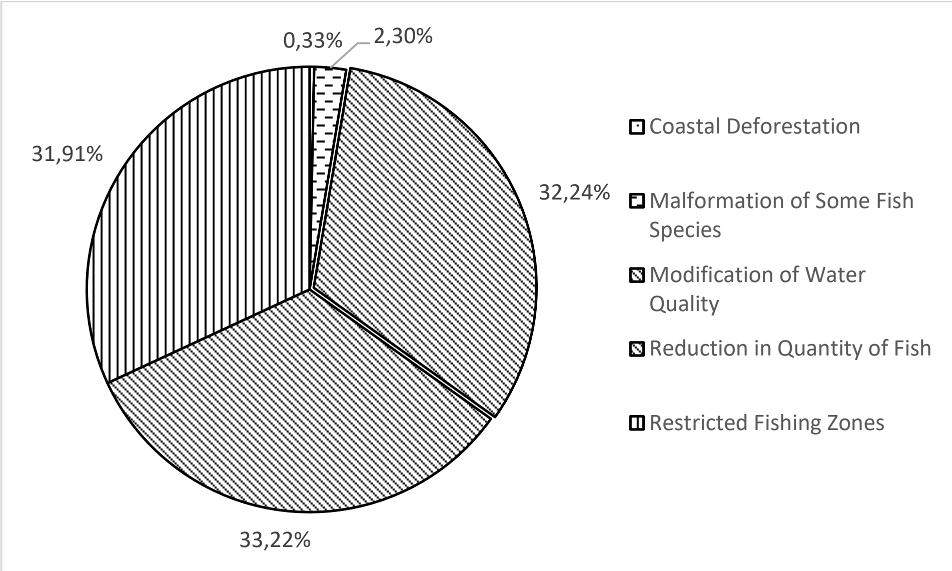



Fig. 14. Impact of anthropogenic activities on fisheries

From the study, the following impact assessment matrix was set up using some pertinent industrial and fishing activities from which the significance of the various impacts could be deduced for further actions.

### III.1.1.2. Comparison of water quality parameters in different zones in the sea coast of Kribi

Water samples were collected from fourteen (14) different sampling sites divided into two zones (Fishing/other activities, and Seaport Zone) and after analyses; the following results were obtained and compared with some International Standards (Table VIII).

The fishing and other activities Zone was made up of such sampling sites as Londji, Mpalla, Mahale, Ngoye, Mboamanga, Palm Beach, Tara Plage, Lobe and Grand Batanga; while the Seaport Zone was made up of the Basin Zone, the Anchorage Zone, the Spoil Zone, Phase II Zone and the Outlet Zone. Table VII shows the comparison between the different water quality parameters in various sampling sites.

All sites sampled have water **color** well in excess of the norm (15 Pt/Co). The water color of the Londji (87.3 Pt/Co), Mpalla (88.3 Pt/Co), Mahale (47 Pt/Co), Palm Beach (47.75 Pt/Co) and Tara Plage (48 Pt/Co) sites is significantly different ($p<0.05$) from the other sites with higher values. The Ngoye (13 Pt/Co) and Mboamanga (34.5 Pt/Co) sites are closer to the norm, but still above it.

**Total Suspended solids (TSS)** at all sampling sites were below the 25 mg/L standard, except for Palm Beach (20.50 mg/L), which was close. The Mboamanga (16.50mg/L) and Palm Beach (20.50 mg/L) sampling sites are significantly ($p<0.05$) higher, and the Tara Plage (0.00 mg/L) site is significantly lower.

**Turbidity** values at the various sites exceed the 5 NTU standards. Palm Beach (20.50 NTU) and Mboamanga (16.50 NTU) have the highest values. Tara Plage (3.25 NTU) is significantly lower than the others.

Analysis of the **alkalinity** parameter shows that only Palm Beach (228.50 mg/L) exceeds the recommended range (100-200 mg/L). Palm Beach is clearly superior to all other sites, which are broadly similar, except for Lobe (58 mg/L), which has the lowest alkalinity.

**Nitrate ($NO_3^-$)** is well below the recommended limit of 2 mg/L at all sites. Tara Plage (0.06 mg/L) and Lobe (0.08 mg/L) are slightly higher compared to Palm Beach (0.01 mg/L), which has the lowest nitrate concentration. **Nitrite ($NO_2^-$)** is below the recommended standard of 0.1 mg/L at all sites. Ngoye (0.108 mg/L) is significantly higher than any of the other sampling sites.

**Phosphate ($PO_4^{3-}$)** levels at all sites far exceed the recommended standard of 0.1 mg/L. Palm Beach (234 mg/L) is the site with the highest concentration compared to Mboamanga (46 mg/L), which is significantly lower.

Analysis of **temperature** data shows that all sites have similar values, except Lobe (24.25°C), which is significantly lower. The Lobe site is cooler than the other sites, where temperatures are uniformly around 29-30°C.

All sampling sites are within the recommended pH range (6.5-8.5). The Londji site (8.27) is significantly higher and the Tara Plage site (7.86) has the lowest pH.

**Conductivity** values at all sites are well below the upper limit of 1500 µS/cm. Tara Plage (27.52 µS/cm) has the lowest conductivity. Mahale (43.35 µS/cm) and Ngoye (43.25 µS/cm) have the highest values.

**TDS** values at all sampling sites exceed the 500 ppm standard, with Lobe (2064.50 ppm) and Grand Batanga (2167.50 ppm) having the highest values. Lobe and Grand Batanga have significantly higher TDS values.

**Dissolved oxygen** levels at the various sites are above the recommended minimum standard of 5 mg/L. The Mahale site (6.48 mg/L) has the lowest value, close to the critical threshold.

The Tara Plage (1422.50µm³/mL) and Lobe (1418 µm³/mL) sampling sites have significantly ($p<0.05$) lower algae values. Palm Beach (2159.50 µm³/mL) and Londji (2119 µm³/mL) have higher values.

**Chlorophyll** levels at Lobe (2.01 µg/L) and Tara Plage (1.86 µg/L) were significantly higher than at Mahale (1.07 µg/L), which had the lowest concentration.

The Mahale (26.40µS/cm), Ngoye (26.25µS/cm) and Grand batabnga (26.40µS/cm) sampling sites have high salinity levels, with significantly higher averages than the other Lobe and Tara plage sampling areas.

All **calcium** levels are well below the 100 mg/L standard, showing little significant variation between sampling sites. The Mahale site (1.92 mg/L) has the highest calcium content, while the Palm Beach site (1.56 mg/L) has the lowest.

**Magnesium** concentrations are all within the normal range; with Mboamanga (1.48 mg/L) having the highest concentration and the lowest being from the Grand Batanga site (1.05 mg/L).

**Ammonium** levels at the Mboamanga site (7.51 mg/L) are significantly higher than the other sites, while the Lobe site (1.96 mg/L) has the lowest concentrations.

**COD (Chemical Oxygen Demand)** values at the various sampling sites are high, especially at the Mpalla site (122 mg/L) compared to the standard of 20 mg/L, indicating greater organic pollution at several sites, with the lowest values at Tara Plage (40.75 mg/L) and Lobe (61.50 mg/L).

**Biochemical Oxygen Demand (BOD)** values varied widely, with the highest at Tara Plage (45 mg/L) and the lowest at Grand Batanga (5 mg/L), indicating significantly different levels of organic pollution in these areas. Table 8 below shows the comparison between the different water quality parameters in various sampling sites in the Seaport zone.

Table VI. Comparing the different water quality parameter values in the various sampling sites

**Legend**: a,b,c represents values with different letters for the same parameter which are significantly different at 5% probability level.

| Parameters | **Londji** | **Mpalla** | **Mahale** | **Ngoye** | **Mboa manga** | **Palm beach** | **Tara plage** | **Lobe** | **Grand Batabnga** | **Standards** |
|---|---|---|---|---|---|---|---|---|---|---|
| Colour (Pt/Co) | 87.3±7.36 **e** | 88.3±9.09 **e** | 47±4.04 **c** | 13±2.31 **a** | 34.5±1.44 **bc** | 47.75±3.61 **c** | 48±5.77 **c** | 67.3±7.94 **d** | 27±5.20 **ab** | **15 Pt/Co** (WHO,2017) |
| Total Suspended Solids (mg/L) | 6.75±1.30 **b** | 3±0.58 **ab** | 6.75±1.30 **b** | 13.50±2.60 **c** | 16.50±2.02 **cd** | 20.50±3.75 **d** | 0.00±0.00 **a** | 3.75±0.72 **ab** | 4.50±0.29 **ab** | **25mg/L** (European Commission, 2019) |
| Turbidity (NTU) | 12.25±1.59**bcd** | 15±2.89 **bcde** | 9.33±0.33 **abc** | 13.50±2.60 **bcd** | 16.50±2.02 **de** | 20.50±3.75 **e** | 3.25±0.43 **a** | 8.50±0.29 **ab** | 15.50±0.87**cde** | **5 NTU** (WHO, 2017) |
| Alkalinity (mg/L) | 74±3.46 **ab** | 98±2.31 **b** | 82±1.16 **ab** | 71±2.89 **ab** | 80±0.00 **ab** | 228,50±29.73 **c** | 63±9.81 **ab** | 58±6.93 **a** | 80±3.45 **ab** | **100 et 200 mg/L** (Boyd, 2020) |
| Nitrates **($NO_3^-$)** (mg/L) | 0.04±0.003 **ab** | 0.04±0.01 **ab** | 0.05±0.014 **abc** | 0.03±0.006 **ab** | 0.04±0.012 **ab** | 0.01±0.00 **a** | 0.06±0.029 **bc** | 0.08±0.006 **c** | 0.04±0.003 **ab** | < 2 mg/L (WHO, 2017) |
| Nitrites **($NO_2^-$)** (mg/L) | 0.010±0.004 **a** | 0,016±0.002 **a** | 0,016±0.007 **a** | 0,108±0.59 **b** | 0,013±0.0003 **a** | 0.015±0.001 **a** | 0.014±0.0012 **a** | 0.014±0.001 **a** | 0.014±0.001 **a** | **0.1 mg/L** (WHO, 2017) |
| Phosphate **($PO_4^{3-}$)** (mg/L) | 179±19.05 **d** | 115.50±13.57 **bc** | 76.50±11.84 **ab** | 126.25±14.29 **bcd** | 46.00±2.31 **a** | 234±30.02 **e** | 134±2.31 **cd** | 60.50±11.26 **b** | 172.75±26.13 **d** | **0.1 mg/L** (EPA, 2020) |
| Température **(°C)** | 30.45±0.375 **b** | 29.35±0.029 **b** | 29.35±0.029 **b** | 29.30±0.00 **b** | 29.30±0.058 **b** | 29.50±0.00 **b** | 29.75±0.087 **b** | 24,25±2.858 **a** | 29,55±0.029 **b** | – |
| pH | 8.27±0,014 **d** | 7.97±0.043 **ab** | 8.05±0.058 **bc** | 8.12±0.075 **c** | 8.09±0.026 **bc** | 7.97±0.040 **ab** | 7.86±0.023 **a** | 8.07±0.009 **bc** | 8.08±0.026 **bc** | **6.5 et 8.5** (WHO, 2017) |
| Conductivity **(µS/cm)** | 38.05±0.32 **bc** | 40.40±0.06 **bc** | 43.35±0.03 **c** | 43.25±0.09 **c** | 36.25±3.49 **bc** | 42.50±0.12 **c** | 27.52±6.75 **a** | 32.09±3.12 **ab** | 43.35±0.14 **c** | **50 et 1500 µS/cm** (Wetzel, 2021) |
| TDS (ppm) | 1612±27.14 **a** | 1701.50±24.54 **ab** | 1695±28,29 **ab** | 1619.50±73.04 **a** | 1772±39.26 **ab** | 1847±0,00 **b** | 2064.50±74.19 **c** | 1668±103.35 **a** | 2167.50±14.72 **c** | **500ppm** (WHO, 2017) |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Dissolved Oxygen(mg/L) | 6.79±0.01 **b** | 6.73±0.01 **b** | 6.48±0.13 **a** | 6.78±0,00 **b** | 6.67±0.02 **b** | 6.50±0.10 **a** | 6.70±0.03**b** | 6.72±0.00 **b** | 6.71±0.01 **b** | **5mg/L** (EPA, 2020) |
| BG Algae | 2119±51.96 **b** | 2009±28.88 **b** | 1932.50±53.41 **b** | 2042±44.46 **b** | 1820±3.46 **ab** | 2159.50±231.81 **b** | 1422.50±131.35 **a** | 1418±28.87 **a** | 2053.50±335.73 **b** | |
| Chlorophyll | 1.84±0.009 **c** | 1.74±0.009 **bc** | 1.07±0.110 **a** | 1.20±0.009 **ab** | 1.73±0.401 **bc** | 1.12±0.023 **ab** | 1.86±0.283 **c** | 2.01±0.283 **c** | 1.45±0.014 **abc** | |
| Salinity | 23.15±0.20 **bcd** | 23.80±0.23 **cd** | 26.40±0.06 **d** | 26.25±0.03 **d** | 21.70±2.31**abc** | 25.90±0.06 **d** | 19.83±2.12 **ab** | 18.93±1.95 **a** | 26.40±0.12 **d** | |
| Calcium (mg/L) | 1.91±0.07 **b** | 1.58±0.03 **ab** | 1.92±0.02 **b** | 1.77±0.01 **b** | 1.17±0.23**a** | 1.56±0.03 **ab** | 1.77±0.36 **b** | 1.66±0.02 **b** | 1.65±0.09 **b** | 100mg/L (EPA, 2020) |
| Magnesium (mg/L) | 1.25±0.09 **ab** | 1.25±0.20 **ab** | 1.20±0.06 **ab** | 1.13±0.03 **a** | 1.48±0.15 **b** | 1.29±0.04 **ab** | 1.16±0.09 **ab** | 1.15±0.02 **ab** | 1.05±0.09 **a** | 1-20 mg/L (EPA, 2020) |
| Ammonium (mg/L) | 4.41±0.27 **d** | 2.35±0.10 **ab** | 2.53±0.12 **abc** | 4.26±0.04 **d** | 7.51±0.75 **e** | 3.66±0.60 **cd** | 3.48±0.45 **bcd** | 1.96±0.28 **a** | 2.27±0.10 **ab** | |
| COD (mg/L) | 101.50±3.18 **bcd** | 122±8.08 **d** | 111±1.16 **cd** | 165±16.17 **e** | 73.50±30.31 **abc** | 112±12.12 **cd** | 40.75±4.19 **a** | 61.50±8.95 **ab** | 90±12.12 **bcd** | **20mg/L** (WHO, 2017) |
| BOD (mg/L) | 17.50±1.44 **c** | 15±2.89 **bc** | 11.25±2.17 **abc** | 15±2.89 **bc** | 8.75±0.72 **ab** | 30±2.89 **d** | 45±2.89 **e** | 12.50±1.44 **bc** | 5±0.00 **a** | |

Table IX shows a comparison of the different water quality parameters of the various sampling sites of the seaport zone.

The results for the water color vary according to the sampling zones, and show that the Spoil Zone is significantly ($p<0.05$) higher and has an extremely high color (77 Pt/Co), indicating a strong presence of organic matter or other colored substances. The Outlet Zone (Exutoire) is also higher (42.50 Pt/Co), but lower than the Spoil Zone. It is important to note that the Anchorage zone (Zone de Mouillage) is statistically distinct and the lowest (13 Pt/Co). Color values in the Basin (Zone de Bassin) and Anchorage zones are relatively low, but still above WHO standards.

The Spoil Zone is statistically different ($p<0.05$) from the other zones, with a higher concentration of suspended solids. The highest concentrations within the TSS parameter are found in this zone (19 mg/L), while the other zones, such as Mooring or Anchorage zone, Basin zone (Zone Bassin), Phase II Zone and Outlet zone, have values ranging from 8.50 ± 0.87 mg/L to 12.50 ± 2.03 mg/L, showing no statistically significant differences ($p>0.05$).

The Spoil Zone is statistically different ($p<0.05$) and has a lower turbidity (7.25 NTU) than the other zones. The Anchorage (16.50 NTU) and Outlet (18.75 NTU) zones have higher turbidity, which is consistent with the other zones having more dispersed particles.

The Outlet Zone has significantly ($p<0.05$) higher alkalinity (96 mg/L) than all other zones. The Spoil Zone (92 mg/L) also stands out statistically, but remains closer to the other zones, such as the Phase II Zone (82 mg/L), the Anchorage Zone (80 mg/L), and the Basin Zone (76 mg/L), which each show decreasing alkalinity.

The nitrate concentrations obtained in this study are not significantly different ($p>0.05$) and are very low, well below established standards. The highest value (0.003 mg/L) was obtained in the Outlet Zone, and the lowest concentrations were obtained in the Phase II Zone and Anchorage Zone, with an average nitrate value of 0.001 mg/L. Such low nitrate levels are favorable and should not contribute to eutrophication.

The nitrite concentrations obtained are significantly different ($p<0.05$) and are very low, well below established standards. The Anchorage Zone (0.0017 mg/L) has a slightly higher concentration and is statistically different from the other zones (Basin Zone, Spoil Zone, Phase II Zone and the Outlet Zone) whose values fluctuate around 0.001 mg/L. Nitrites are often an indication of recent pollution, as they are unstable and rapidly transform into nitrates.

Phosphate concentrations are extremely high in all zones, exceeding established standards by several orders of magnitude. The Basin Zone has the highest concentration (241.25 mg/L), indicating a major source of pollution, and possibly related to industrial wastewater and runoff. The Outlet Zone has a very low phosphate concentration (43.75 mg/L) compared to the other study sites.

The Basin (33.90°C) and Anchorage (33.55°C) zones have higher temperatures than the other study zones, possibly due to the discharge of industrial cooling water or shipping activities. The lowest temperatures were recorded in the Phase II Zone (30.15°C) and Spoil Zone (30.30°C).

All zones have a slightly alkaline pH, within the normal range for marine waters. The Outlet Zone has a significantly more alkaline pH (8.40) than the other zones, and the Phase II Zone (8.18) shows the lowest pH, although still slightly alkaline. The Outlet and Bassin Zones are at the upper threshold, but remain within acceptable limits.

The **conductivity** of the Outlet Zone (38.15 µS/cm) and the Basin Zone (38.55 µS/cm) are statistically similar and the lowest compared to the Spoil Zone (43.10 µS/cm) and the Phase II Zone (42.75 µS/cm) which have significantly higher conductivities, suggesting an increased concentration of dissolved salts.

The Phase II Zone has an extremely high **Total Dissolved Solids** (TDS) value (178.55 ppm) compared to the other zones, far exceeding the salinity of seawater, which may indicate concentrated saline contamination. The lowest TDS values were found in the Anchorage Zone (2.195 ppm), the Outlet Zone (1.906 ppm), and the Spoil Zones (1.837 ppm).

**Dissolved oxygen** levels varied between 6.33 and 6.69 mg/L in the different sampling zones, with slightly lower values in the Anchorage Zone. Lower dissolved oxygen levels may indicate increased biological degradation of organic matter.

The algal measurements taken in the Anchorage (5958.5$\mu m^3$/mL) and Phase 2 (5619.8 $\mu m^3$/mL) zones showed the highest averages, indicating a high potential for algal blooms. The Outlet showed the lowest average (2178 $\mu m^3$/mL) compared with the other zones.

The Anchorage Zone shows relatively low chlorophyll levels (179µg/L), while the Outlet Zone records much higher values (477µg/L), which may indicate greater phytoplankton activity. The Spoil Zone (1.37µg/L) shows the lowest chlorophyll concentration.

**Salinity** measurements at the different sites showed a significant difference. The Spoil Zone (26.60 mg/L) and phase 2 zones (26.45 mg/L) are significantly more saline than the Anchorage Zone (22.50 mg/L) and the Outlet Zone (22.75 mg/L).

**Calcium** measurements in the Outlet Zone (2.25 mg/L) are significantly higher than those in the Basin Zone (1.60 mg/L), Anchorage zone (1.74 mg/L) and Phase 2 Zone (1.44 mg/L).

**Magnesium** measurement values are higher and statistically distinct in the Outlet Zone (1.36 mg/L), the Spoil Zone (1.34 mg/L), and the Phase II Zone (1.22 mg/L). The lowest value was obtained in the Anchorage Zone (1.03 mg/L).

The **average ammonium concentration** in each zone is a key indicator for assessing organic loading. The Anchorage Zone has the highest average ammonium concentration (4.58 mg/L), while the Outlet Zone has the lowest (3.23 mg/L).

**Chemical oxygen demand (COD)** is relatively high in the Phase II Zone (128 mg/L) and Outlet Zone (111 mg/L), reflecting a high organic load, while the Spoil Zone (64.5 mg/L) has a significantly lower COD. As for the BOD measurements, the Phase II Zone (95 mg/L) is the highest and the Outlet Zone (3.75 mg/L) the lowest, while the other zones showed no significant differences.

Table VII. Comparing the different water quality parameters in various sampling sites in the Seaport zone

| Parameters | Basin Zone | Anchorage Zone | Spoil Zone | Phase II Zone | Outlet Zone | Standards |
|---|---|---|---|---|---|---|
| Colour (Pt/Co) | 15.00 ± 0.58 **ab** | 13.00 ± 1.16 **a** | 77.00 ± 5.20 **d** | 25.00 ± 5.20 **b** | 42.50 ± 2.60 **c** | **15Pt/Co** (WHO, 2017) |
| Total Suspended Solids (mg/L) | 9.50 ± 0.87 **a** | 12.50 ± 2.03 **a** | 19.00 ± 2.89 **b** | 8.50 ± 0.87 **a** | 8.50 ± 1.45 **a** | **25mg/L** (European Commission, 2019) |
| Turbidity (NTU) | 15.75 ± 2.45 **b** | 16.50 ± 2.02 **b** | 7.25 ± 1.01 **a** | 9.00 ± 0.58 **a** | 18.75 ± 1.88 **b** | **5NTU** (WHO, 2017) |
| Alkalinity (mg/L) | 76.00 ± 2.31 **a** | 80.00 ± 0.00 **ab** | 92.00 ± 4.62 **bc** | 82.00 ± 4.62 **ab** | 96.00 ± 5.78 **c** | **100 et 200 mg/L** (Boyd, 2020) |
| Nitrates (**$NO_3^-$**) (mg/L) | 0.02 ± 0.01 **a** | 0.01 ± 0.01 **a** | 0.02 ± 0.003 **a** | 0.01 ± 0.01 **a** | 0.03 ± 0.003 **a** | **<2mg/L** (WHO, 2017) |
| Nitrites (**$NO_2^-$**) (mg/L) | 0.014 ± 0.001 **c** | 0.017 ± 0.001 **d** | 0.01 ± 0.0003 **a** | 0.01 ± 0.0003 **a** | 0.01 ± 0.0003 **b** | <0.06mg/L (WHO, 2017) |
| Phosphates (**$PO_4^{3-}$**) (mg/L) | 241.25 ± 24.1 **c** | 83.50 ± 10.1 **b** | 117.00 ± 16.7 **b** | 57.50 ± 11.8 **a** | 43.75 ± 4.76 **a** | **0.1mg/L** (EPA, 2020) |
| Temperature **(°C)** | 33.90 ± 0.00 **b** | 33.55 ± 0.38 **b** | 30.30 ± 0.00 **b** | 30.15 ± 0.09 **a** | 33.45 ± 0.14 **a** | _ |
| pH | 8.42 ± 0.02 **c** | 8.29 ± 0.06 **b** | 8.21 ± 0.04 **ab** | 8.18 ± 0.02 **a** | 8.40 ± 0.01 **c** | **6.5 et 8.5** (WHO, 2017) |
| Conductivity **(µS/cm)** | 38.55 ± 0.72 **a** | 39.95 ± 0.43 **b** | 43,10 ± 0,12 **c** | 42.75 ± 0.43 **c** | 38.15 ± 0.14 **a** | **50 et 1500 µS/cm** (Wetzel, 2021) |
| TDS (ppm) | 2019.5 ±71.88 **a** | 2029 ± 148.96 **a** | 1837 ± 0.00 **a** | 1785.50 ± 30.89 **a** | 1906 ± 58.31 **a** | **500 ppm** (WHO, 2017) |
| Dissloved Oxygen (mg/L) | 6.69 ± 0.02 **b** | 6.33 ± 0.19 **a** | 6.50 ± 0.08 **ab** | 6.53 ± 0.04 **ab** | 6.61 ± 0.006 **ab** | **5mg/L** (EPA, 2020) |
| BG Algae | 4882 ± 509.2 **bc** | 5958.5 ± 470.3 **c** | 2562.5± 1387.1 **ab** | 5619.8 ± 566.5 **c** | 2178 ± 264.4 **a** | |
| Chlorophyll | 2.22 ± 0.02 **ab** | 1.79 ± 0.09 **a** | 1.37 ± 0.77 **a** | 1.70 ± 0.32 **a** | 4.77 ± 1.61 **b** | |
| Salinity | 26.25 ± 0.03 **b** | 22.50 ± 0.58 **a** | 26.60 ± 0.06 **b** | 26.45 ± 0.09 **b** | 22.75 ± 0.03 **a** | |
| Calcium (mg/L) | 1.60 ± 0.16 **a** | 1.74 ± 0.17 **a** | 1.83 ± 0.18 **ab** | 1.44 ± 0.01 **a** | 2.25 ± 0.12 **b** | **100mg/L** (EPA, 2020) |
| Magnesium (mg/L) | 1.1800 ± 0.06 **ab** | 1.03 ± 0.04 **a** | 1.34 ± 0.03 **b** | 1.22 ± 0.08 **b** | 1.36 ± 0.03 **b** | **1-20mg/L** (EPA, 2020) |
| Ammonium (mg/L) | 3.94 ± 0.39 **a** | 4.58 ± 0.17 **a** | 3.53 ± 0.49 **a** | 4.27 ± 0.71 **a** | 3.23 ± 0.11 **a** | |
| COD (mg/L) | 118.50 ± 3.75 **b** | 98.50 ± 3.75 **b** | 64.50 ± 9.53 **a** | 128.00 ± 7.51 **b** | 111.00 ± 16.17 **b** | **20mg/L** (WHO, 2017) |
| BOD (mg/L) | 20.00 ± 0.0 **a** | 18.75 ± 3.61 **a** | 11.25 ± 2.17 **a** | 95.00 ± 17.32 **b** | 3.75 ± 0.72 **a** | |

Legend: a,b,c represents values with different letters for the same parameter which are significantly different at 5% probability level.

### III.1.1.3. Identification and quantification of algal species and diversity in the different sampling sites.

The investigation of algal diversity across various sampling points revealed notable variations in species composition and abundance. At Londji, the algal community was sparse, with only *Licmophora ehrenbergii* recorded with 1 count. In contrast, Mpalla exhibited moderate diversity, with *Chlorella sp.* being the most abundant species with 15 counts, alongside *Licmophora ehrenbergii* (1 count), *Licmophora colosalis* (3 counts), and *Ceratium furca* (1 count). This suggests that Mpalla has more favorable conditions for a range of algal species. Mahalle displayed a diverse algal community with significant counts of *Licmophora colosalis* (3 counts) and *Chaetoceros peruvianus* (6 counts), along with lower counts of *Ceratium fusus* (2 counts) and *Navicula sp.2* (2 counts). Ngoye was characterized by higher diversity, prominently featuring *Ceratium macroceros* with 28 counts and *Ceratium furca* with 2 counts, along with additional species such as *Gloeocystis ampla* (2 counts) and *Pleurosigma majus* (4 counts). This indicates that Ngoye supports a rich algal community.

At Mboamanga, the diversity was also notable, with high counts of *Pleurosigma majus* (4 counts) and a significant presence of *Ceratium macroceros* (11 counts). Other species such as *Licmophora abbreviata* (1 count) and *Rhizosolenia robusta* (8 counts) were also observed, suggesting a range of environmental conditions that support diverse algal species. Palm Beach followed with diverse species, including *Pleurosigma majus* (5 counts) and *Ceratium macroceros* (22 counts), and the presence of *Licmophora ehrenbergii* (2 counts) and *Nitzschia paradoxa* (2 counts). Tara Plage showed significant diversity with notable counts of *Pleurosigma majus* (6 counts), *Ceratium macroceros* (1 count), and *Chlorella sp.* (8 counts). This indicates a varied algal community at this location. Grand Batanga also demonstrated diversity, highlighted by *Pleurosigma majus* (6 counts) and *Navicula sp.2* (2 counts), along with other species such as *Ceratium macroceros* (1 count) and *Gloeocystis ampla* (2 counts).

Finally, Lobe exhibited a diverse algal community, with a prominent presence of *Ceratium macroceros* (21 counts) and *Licmophora abbreviata* (1 count), along with the less abundant *Rhizosolenia robusta* (0 counts).

Table VIII. Various algae identified in the other sampling sites out of the seaport zone of the study zone

| **Family** | **Genus** | **Species name** | **Londji** | **Mpalla** | **Mahalle** | **Ngoye** | **Mboa manga** | **Palm beach** | **Tara plage** | **Grand batanga** | **Lobe** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Gonyaulacaceae | Alexandrium | *Alexandrium catenella* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |
| Fragilariaceae | Asteronellopsis | *Asteronellopsis glacialis* | 0 | 0 | 0 | 0 | 0 | 3 | 2 | 0 | 0 |
| Ceratiaceae | Ceratium | *Ceratium contortum* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 5 |
| | | *Ceratium breve* | 0 | 0 | 0 | 3 | 0 | 0 | 0 | 0 | 0 |
| | | *Ceratium furca* | 0 | 0 | 1 | 2 | 0 | 0 | 0 | 0 | 0 |
| | | *Ceratium fusus* | 0 | 1 | 2 | 2 | 6 | 2 | 0 | 0 | 1 |
| | | *Ceratium macroceros* | 0 | 0 | 0 | 28 | 11 | 22 | 1 | 0 | 21 |
| | | *Ceratium massiliens* | 0 | 0 | 6 | 4 | 0 | 3 | 0 | 0 | 0 |
| | | *Ceratium symetricum* | 0 | 1 | 1 | 2 | 0 | 0 | 0 | 0 | 1 |
| | | *Ceratium horridum* | 0 | 0 | 0 | 7 | 0 | 0 | 0 | 0 | 0 |
| Chaetocerotaceae | Chaetoceros | *Chaetoceros damicus* | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| | | *Chaetoceros peruvianus* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 6 | 0 |
| | | *Chaetoceros soltans* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Chlorellaceae | Chlorella | *Chlorella* sp. | 0 | 15 | 1 | 6 | 0 | 1 | 8 | 0 | 0 |
| Cymatosiraceae | Climacodium | *Climacodium frauenfeldianum* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| Climacospheniaceae | Climacosphenia | *Climacosphenia* sp. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Cocconeidaceae | Cocconeis | *Cocconeis littoralis* | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 |
| Coscinodiscaceae | Coscinodiscus | *Coscinodiscus granii* | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Coscinodiscus jonesianus* | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| | | *Coscinodiscus* sp.1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 2 | 0 |
| | | *Coscinodiscus* sp.2 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| Oocystaceae | Gloeocystis | *Gloeocystis ampla* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 |
| Scenedesmaceae | Crucigenia | *Crucigenia qudrata* | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| Hemidiscaceae | Hemidiscus | *Hermidiscus ovalis* | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Licmophoraceae | Licmophora | *Licmophora abbreviata* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| | | *Licmophora ehrenbergii* | 0 | 1 | 0 | 1 | 0 | 2 | 0 | 0 | 0 |
| | | *Licmophora colosalis* | 0 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 0 |
| Mastogloiaceae | Mastogloia | *Mastogloia* sp. | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| Naviculaceae | Navicula | *Navicula* sp.1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| | | *Navicula* sp.2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 |
| | Caloneis | *Caloneis crassa* | | | | 2 | | | | | |
| Bacillariaceae | Nitzschia | *Nitzschia closterium* | 4 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| | | *Nitzschia hybrida* | 7 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Nitzschia paradoxa* | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 |
| Noctilucaceae | Noctiluca | *Noctiluca scintillans* | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| Hydrodictyaceae | Pediastrum | *Pediastrum clathratum* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 |
| Pleurosigmataceae | Pleurosigma | *Pleurosigma directum* | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 |
| | | *Pleurosigma angulatum* | 6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Pleurosigma majus* | 0 | 2 | 0 | 0 | 0 | 5 | 4 | 6 | 3 |
| | | *Pleurosigma normanii* | 4 | 0 | 0 | 0 | 4 | 0 | 0 | 0 | 0 |
| Volvocaceae | Pandorina | *Pondorina morum* | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| Prorocentraceae | Prorocentrum | *Prorocentrum micams* | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Rhizosoleniaceae | Rhizosolenia | *Rhizosolenia robusta* | 0 | 0 | 0 | 0 | 0 | 8 | 0 | 0 | 0 |
| Stephanodiscaceae | Stephanodiscus | *Stephanodiscus astraea* | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 |
| Bacillariaceae | Thalassiotrix | *Thalassiotrix frauenfeldii* | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

In the Seaport zone, the following types of algae were identified and classified as shown in Table XI below. During the course of the study, several areas were sampled to identify and quantify the phytoplankton species present. The phytoplanktons identified were classified into different families, genera and species. The following is an analysis of the main findings based on the data: A number of distinct species were identified across the areas studied, belonging to various genera such as *Ceratium*, *Chaetoceros*, *Navicula*, *Nitzschia*, and others. The greatest species diversity was observed within the *Ceratium* genus, particularly in the Spoil Zone and the Phase II Zone, with species such as *Ceratium macroceros* and *Ceratium declinatum* being more predominant. This suggests that the *Ceratium* genus thrives in environments with transient or disturbed conditions. In the Spoil Zone, a large number of species were observed, notably *Chaetoceros peruvianus* (140 counts) and *Ceratium macroceros* (82 counts), indicating favorable conditions for species of the Chaetoceros and Ceratium genera. In the Phase II Zone, *Ceratium declinatum* was particularly abundant with 114 counts, suggesting that this zone may be conducive to the growth of this species. In the Outlet Zone, *Climacosphenia* sp. was only present with 26 counts, which may indicate a preference for environmental conditions specific to this zone, such as water discharge characteristics. The Bassin Zone showed a more balanced distribution of species, with moderate counts across several genera, including *Ceratium* and *Chaetoceros*. In the Anchorage Zone, fewer species were recorded, with *Chaetoceros* peruvianus showing a significant presence (70 counts), suggesting a less diverse but specialized community.

Comparative analysis revealed that areas such as the Spoil Zone and the Phase II Zone were distinguished by the greatest diversity and abundance of species, particularly those of the *Ceratium* genus. The presence of *Chaetoceros peruvianus* in both the Spoil Zone and the Anchorage Zone suggests a wide adaptability of this species to the different environmental conditions within these zones. In contrast, the Outlet Zone and Anchorage Zone showed lower species counts, which could be attributed to specific environmental stressors or the unique nature of these areas.

Table IX. List of algal species identified in the Kribi Seaport Zone.

| Family | Genus | Species name | Spoil Zone | Phase II Zone | Outlet Zone | Basin Zone | Anchorage Zone |
|---|---|---|---|---|---|---|---|
| Biddulphiaceae | Biddulphia | *Bidulphia* sp. | 2 | 0 | 0 | 0 | 0 |
| Ceratiaceae | Ceratium | *Ceratium contortum* | 0 | 0 | 0 | 0 | 0 |
| | | *Ceratium declinatum* | 11 | 114 | 0 | 2 | 1 |
| | | *Ceratium* sp. | 0 | 0 | 0 | 0 | 3 |
| | | *Ceratium breve* | 6 | 0 | 0 | 0 | 0 |
| | | *Ceratium furca* | 2 | 0 | 0 | 1 | 1 |
| | | *Ceratium fusus* | 1 | 0 | 0 | 0 | 0 |
| | | *Ceratium macroceros* | 82 | 0 | 0 | 0 | 12 |
| | | *Ceratium massiliens* | 0 | 0 | 0 | 0 | 0 |
| | | *Ceratium symetricum* | 1 | 0 | 0 | 0 | 0 |
| | | *Ceratium horridum* | 0 | 0 | 0 | 0 | 0 |
| Chaetocerotaceae | Chaetocerus | *Chaetoceros damicus* | 0 | 0 | 0 | 0 | 0 |
| | | *Chaetoceros peruviamus* | 140 | 0 | 0 | 0 | 70 |
| | | *Chaetoceros decipiens* | 0 | 1 | 0 | 0 | 0 |
| Chlorellaceae | Chlorella | *Chlorella* sp. | 2 | 0 | 0 | 0 | 3 |
| Climacospheniaceae | Climacosphenia | *Climacosphenia* sp. | 0 | 0 | 26 | 0 | 0 |
| Coscinodiscaceae | Coscinodiscus | *Coscinodiscus kurzii* | 0 | 0 | 0 | 0 | 1 |
| | | *Coscinodiscus* sp.1 | 0 | 0 | 0 | 0 | 1 |
| | | *Coscinodiscus* sp.2 | 0 | 0 | 0 | 0 | 0 |
| Fragilariaceae | Fragilaria | *Fragilaria* sp. | 3 | 0 | 0 | 8 | 0 |
| Scenedesmaceae | Crucigenia | *Crucigenia quadrata* | 0 | 0 | 0 | 0 | 0 |
| Hemiaulaceae | Hemiaulus | *Hermiaulus sinensis* | 1 | 0 | 0 | 0 | 0 |
| Naviculaceae | Navicula | *Navicula elegans* | 0 | 0 | 3 | 0 | 0 |
| Bacillariaceae | Nitzschia | *Nitzschia sigma* | 0 | 0 | 0 | 1 | 0 |
| | | *Nitzschia longissima* | 0 | 0 | 13 | 0 | 0 |
| Noctilucaceae | Noctiluca | *Noctiluca scintillans* | 0 | 0 | 0 | 0 | 0 |
| Oscillatoriaceae | Lyngbia | *Lyngbia* sp. | | 2 | 0 | 21 | |
| | Oscillatoria | *Oscilatoria* sp.1 | 0 | 0 | 0 | 3 | 0 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | *Oscillatoria* sp.2 | 0 | 0 | 0 | 0 | 4 |
| Pleurosigmataceae | Pleurosigma | *Pleurosigma sp.* | 0 | 0 | 0 | 0 | 1 |
| Hemiaulaceae | Eucampia | *Eucampia cornuta* | 16 | 0 | 0 | 0 | 0 |
| Grammatophoraceae | Grammatophora | *Grammatophora* sp. | 1 | 0 | 1 | 0 | 0 |
| Tabellariaceae | Tabellaria | *Tabellaria flocculosa* | 0 | 0 | 1 | 0 | 0 |
| Chlamydomonadaceae | Chlamydomonas | *Chlamydomonas* sp. | 0 | 2 | 0 | 0 | 0 |
| Licmophoraceae | Licmophora | *Licmophora* sp. | 0 | 0 | 3 | 0 | 0 |
| Protoperidiniaceae | Protoperidinium | *Protoperidinium* sp. | 0 | 0 | 1 | 0 | 0 |

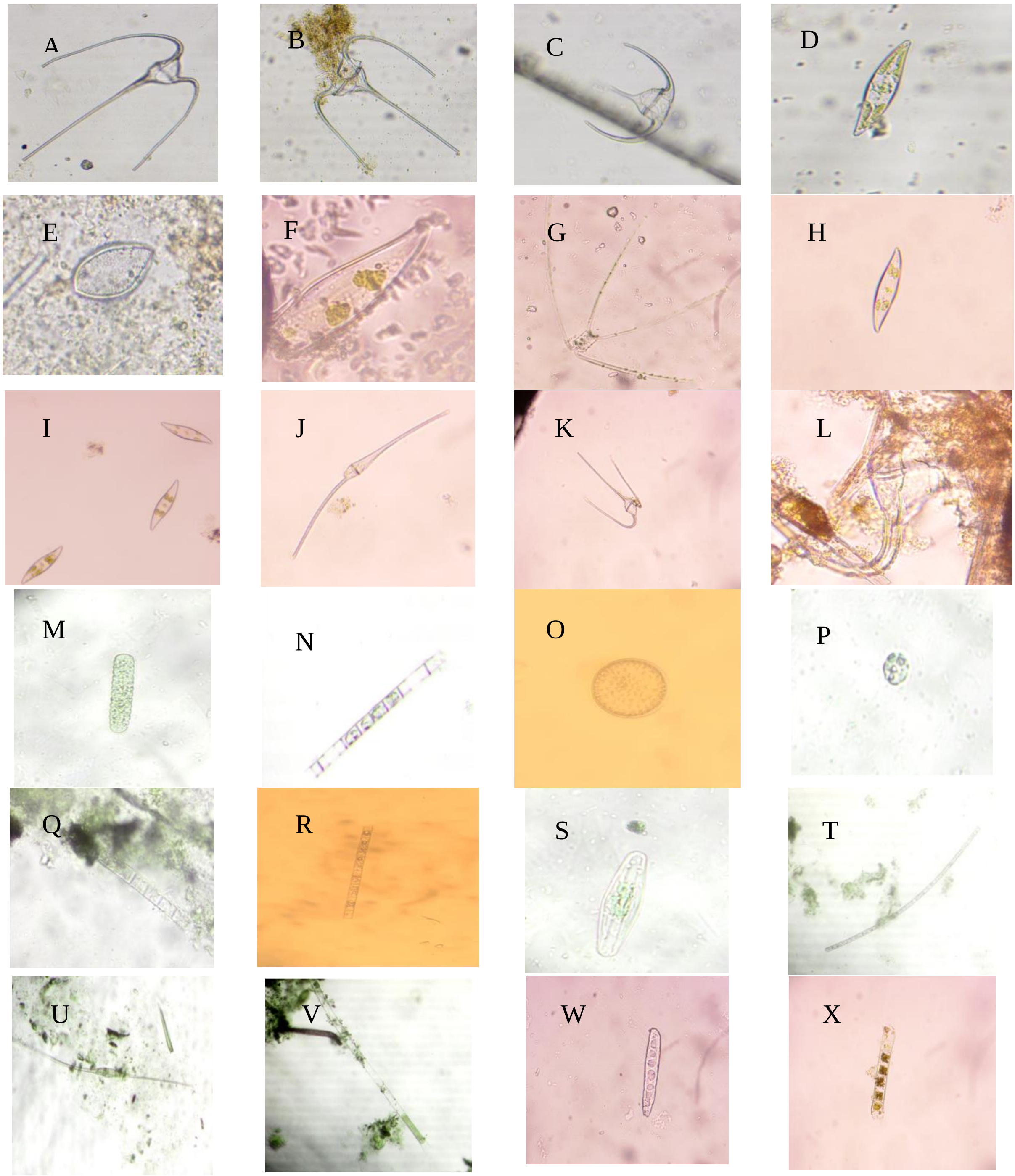



Fig. 15. List of various algae inventoried in the study area : *Ceratium macroceros* var. *gallicum* (A), *Ceratium horridum* var. *molle* (B), Ceratium tripos (C), *Navicula* sp.1 (D), *Prorocentrum micans* (E), *Pleurosigma* cf. *elongatum* (F), *Chaetocerus peruvianus* (G), *Pleurosigma directum* (H), *Pleurosigma angulatum* (I), *Ceratium fusus* (J&L), *Ceratium macroceros* (Ehrenb.) Vanhoffen (K), *Oscillatoria* sp. (M), *Hermiaulus sinensis* (N&R), *Coscinodiscus granii* (O), *Chlorella salina* (P), *Chaetoceros decipiens* (Q), *Closterium* sp. (S), *Lyngbia* sp.1 (T), *Nitzschia* sp. (U), *Lyngbia* sp.2 (V), *Grammatophora* sp. (W), *Caloneis crassa* (X).

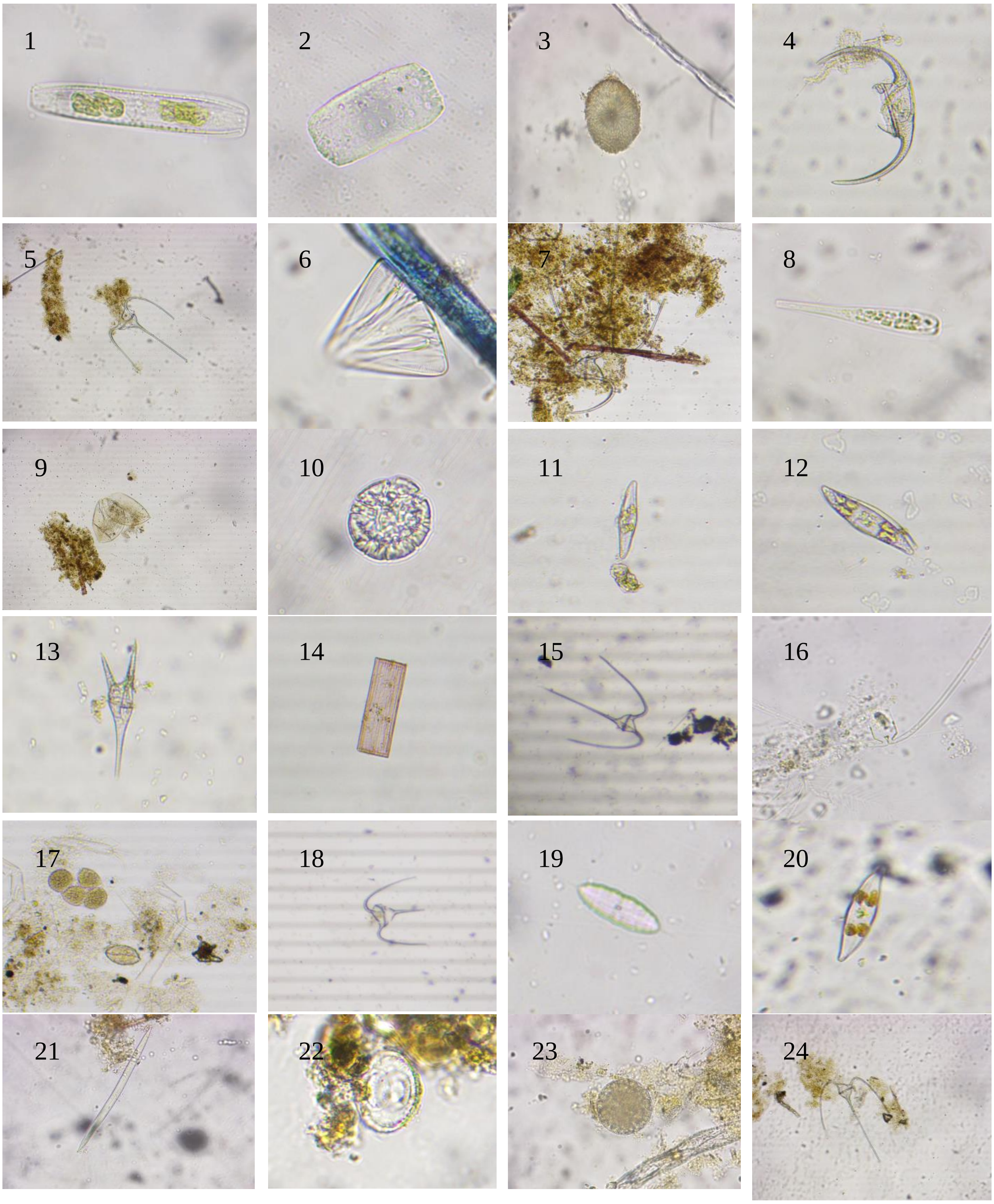
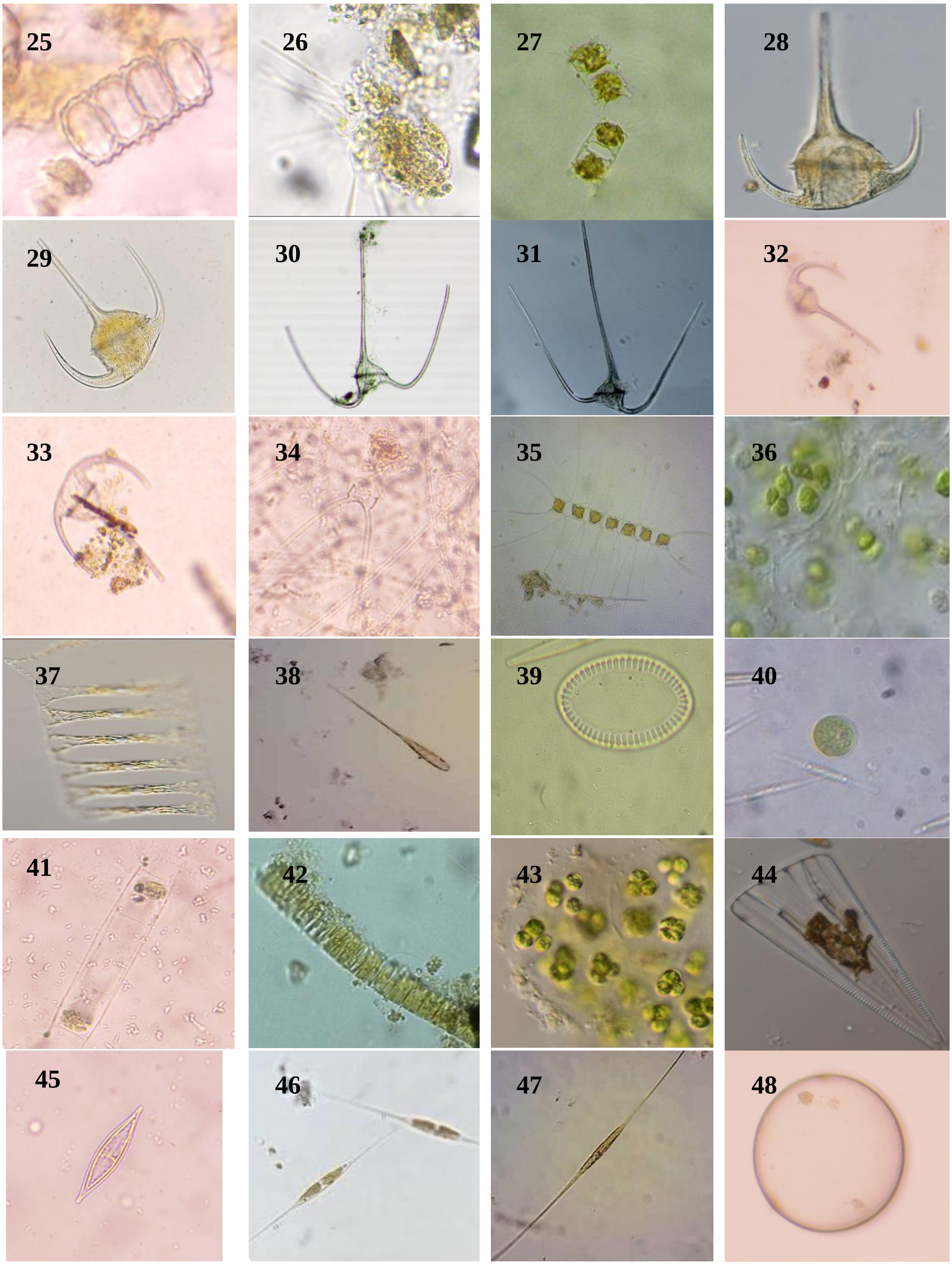



Fig. 16. List of various algae inventoried in the study area : *Nitzschia paradoxa* (1), *Tabellaria* sp.1 (2), *Stephanodiscus astraea* (3), *Ceratium declinatum* (4), *Ceratium* sp.1(5), *Licmophora abbreviata* (6), *Ceratium* sp.2 (7), *Licmophora colosalis* (8), *Preperidinium meunieri* (9), *Chlorella* sp. (10), *Mastogloia* sp. (11), *Navicula* sp.2 (12)., *Ceratium furca* (13), *Tabellaria* sp.2 (14), *Ceratium* sp.3 (15), *Chaetoceros* sp. (16), *Crucigenia quadrata* (17), *Ceratium* sp.4 (18), *Nitzschia hybrid* (19), *Navicula* sp. (20), *Nitzschia sigma* (21), Coscinodiscus sp.1 (22), *Coscinodiscus jonesianus*(23) , *Ceratium macroceros* var (Ehrenberg) Vanhoffen 1897 (24)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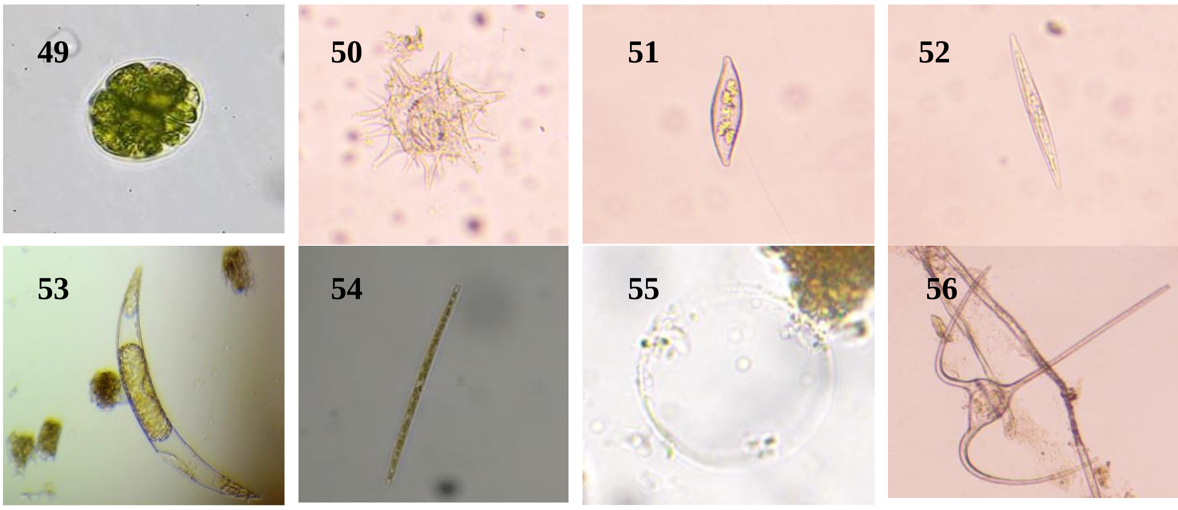


Fig. 17. List of various algae inventoried in the study area: *Alexandrium catenella* (25), *Asteronellopsis glacialis* (26), *Biddulphia* sp. (27), *Ceratium breve* (28), *Ceratium declinatum* (29), *Ceratium macroceros* (Ehrenb.) Vanhoffen (30), *Ceratium massiliense* (31), *Ceratium* sp.1 (32), *Ceratium symmetricum* (33), *Chaetoceros danicus* (34), *Chaetoceros soltans* (35), *Chlamydomonas* sp. (36), *Climacodium frauenfeldianum* (37), *Climacosphenia* sp. (38), *Cocconeis littoralis* (39), *Coscidiscus* sp.1 (40), *Eucampia cornuta* (41), *Flagilaria* sp. (42), *Gloeocystis ampla* (43), *Licmophora ehrenbergii* (44), *Navicula elegans* (45), *Nitzschia closterium* (46), *Nitzschia longissima* (47), *Noctiluca scintillans* (48), *Pandorina morum* (49), *Pediastrum clathratum* (50), *Pleurosigma majus* (51), *Pleurosigma normanii* (52), *Rhizosolenia robusta* (53), *Thalassiotrix frauenfeldii* (54), *Coscinodiscus* sp.2 (55), *Ceratium* sp.2 (56).

Table X. Role and importance of identified algae in the marine ecosystem

| **Algal Species** | **Role/Importance in the marine ecosystem** |
|---|---|
| *Alexandrium catenella* | A species that produces toxins that cause paralytic shellfish poisoning, and is a cause of red tides. |
| *Asteronellopsis glacialis* | Primary producer, supports biodiversity, provides habitat, and contributes to the overall health and stability of marine environments |
| *Bidulphia* sp. | Essential components of coastal marine ecosystems, contributing to primary production, nutrient cycling, habitat complexity, and serving as indicators of environmental health. Their presence is vital for maintaining the balance and productivity of these ecosystems |
| *Caloneis crassa* | A type of diatom whose presence is a good indicator of ecological health and biodiversity.<br>Contributes in primary production in coastal waters.<br>An indicator of environmental change; *C. crassa* can indicate changes in environmental conditions, such as nutrient levels and water quality. Monitoring its populations can provide insights into the health of coastal ecosystems |
| *Ceratium breve* | Vital for coastal marine ecosystems due to its roles in primary production, nutrient cycling, and as food source. Its potential to form harmful algal blooms also makes it an important species for monitoring environmental health. |
| *Ceratium contortum, C. furca, C. fusus.* | These species of dinoflagellates play the roles of primary producers, nutrient cycling, food sources, indicators of environmental conditions, habitat for marine life and potential to form harmful algal blooms. |
| *Ceratium macroceros, C. massiliens, C. symmetricum, C. horridum* | This species of dinoflagellates play the roles of primary production, nutrient cycling, food source, and environmental indicators. Its presence also provides valuable insights into environmental health, making it a key species foe monitoring and understanding coastal ecosystem dynamics. |
| *Chaetocerus damicus* | This photosynthetic diatom plays the roles of primary production, nutrient cycling, and food source for zooplankton, environmental indicators and the potential to form harmful algal blooms. |
| *Chaetocerus peruvianus* | A photosynthetic diatom significant in coastal marine ecosystems due to its roles in primary production, nutrient cycling, and as a food source. Its ability to adapt to environmental stressors and its function as an ecological indicator further underscore its importance in maintaining the health and dynamics of marine ecosystems. |
| *Chaetocerus soltans* | This photosynthetic diatom plays a vital role in the ecosystem through its contributions to primary production, nutrient cycling, and as a food source for various marine organisms. Its presence enhances biodiversity and serves as an ecological indicator, providing insights into the health of marine environments. Additionally, its impact on biogeochemical cycles underscores its importance in regulating carbon levels in the atmosphere. |
| *Chlamydomonas* sp. | These unicellular green algae play the role of primary production, nutrient cycling, and biodiversity. Their role in biogeochemical cycles further underscores their importance in regulating environmental conditions and supporting marine life. |
| *Chlorella* sp. | This green microalga is integral to the health and sustainability of coastal marine ecosystems. Its roles in primary production, nutrient cycling, carbon sequestration, water quality improvement, and support for biodiversity |

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| | highlight its ecological importance Additionally, its applications in aquaculture and environmental management underscores its economic and environmental benefits. |
| *Climacodium frauenfeldianum*, *Climacodium* sp. | This is a photosynthetic diatom that contributes to nitrogen fixation, primary production, biodiversity, carbon sequestration and nutrient cycling. Its ecological roles underscore the importance of preserving such diatoms in maintaining the health and sustainability of marine environments. |
| *Coccineis littoralis* | An essential component of coastal marine ecosystems, contributing to primary production, nutrient cycling, habitat formation, and biodiversity. Its role as a food source, indicator of water quality and nutrient levels, and silica utilization further underscores its ecological importance. |
| *Coscinodiscus granii* | An essential component of marine ecosystems, contributing to primary production, nutrient cycling, habitat formation, and biodiversity. Its role in red tide formation and as an indicator of environmental change further underscores its ecological importance. |
| *Coscinodiscus jonesianus* | This is not just a single species but a vital component of the ecological web, affecting everything from food chains to global carbon cycles, making it important for both ecological health and climate regulation. |
| *Coscinodiscus* sp.1, *Coscinodiscus* sp.2 | Primary production, ecological indicators, nutrient cycling, carbon sequestration, commercially important in the formation of diatomaceous earth and fossil fuel indication, research and monitoring. |
| *Crucigenia quadrata* | This is an important species in the study of green algae, contributing to taxonomic clarity, ecological health, and genetic research. Its role as a primary producer and indicator of environmental conditions underscores its significance in aquatic ecosystems. |
| *Eucampia cornuta* | This is more than just a diatom; it is integral to maintaining the health and functionality of aquatic ecosystems, influencing both ecological dynamics and environmental monitoring efforts. Its role in primary production, as a food source, silica production, and scientific studies related to climate change, pollution, and habitat restoration underscores its importance in supporting marine life and biodiversity. |
| *Fragilaria curta* | This species of diatom is a key player in aquatic ecosystems, contributing to primary production, food web dynamics, and environmental monitoring. Its role as an indicator species, research applications, water quality indicator and its involvement in biogeochemical cycles make it essential for understanding ecosystem health and resilience. |
| *Gloeocystis ampla* | This green alga contributes to primary production, nutrient cycling, and biodiversity. Its role as a food source and indicator of water quality makes it significant for both ecological research and environmental monitoring. |
| *Grammatophora* sp. | This species of diatoms are important components of aquatic ecosystems, contributing to primary production, nutrient cycling, and food web dynamics. Their role as indicator species further emphasizes their importance in monitoring environmental health and understanding ecological processes. |
| *Hermidiscus ovalis* | This is an important organism in aquatic ecosystems, contributing to primary production, nutrient cycling, food web dynamics, ecological studies, ecosystem stability, and water quality monitoring. |
| *Hermiaulus sinensis* | This species of diatoms is an essential component of aquatic ecosystems playing the role of primary producer, nutrient cycling, and food web dynamics. Its role as an indicator species highlights its significance in environmental |

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| | monitoring and ecological research. |
| *Licmophora abbreviate, Licmophora chrenbergii,* | This photosynthetic diatom is an essential component of aquatic ecosystems, contributing to primary production, nutrient cycling, biodiversity, ecosystem stability, habitat formation and food web dynamics. Its significance as an indicator species and its role in enhancing biodiversity underscores its importance in maintaining healthy aquatic environments. |
| *Licmophora colosalis* | This specie of diatoms plays the of primary production, nutrient cycling, food source, habitat formation, indicator species, response to environmental changes such as temperature and nutrient loading; biodiversity contribution and research applications. |
| *Lyngbia* sp. | Filamentous cyanobacteria that play the role of primary production, nutrient cycling, habitat formation, food source, chemical diversity and bioactive compounds, indicator species for environmental monitoring, impact on Coral Reefs and response to environmental changes. However, their potential to dominate and alter community dynamics, particularly in coral reefs, highlights the need for careful monitoring and management of these organisms in the face of environmental change. |
| *Mustogloia campechiana* | This is diatom species play the role of primary production, nutrient cycling, food source, habitat formation, indicator species, biodiversity contribution, and research applications. |
| *Navicula spp.1, Navicula* sp. 2, *Navicula elegans* | These species are significant not only for their ecological roles but also for their applications in research, environmental monitoring, and potential commercial uses. Their study aids in understanding the dynamics of aquatic ecosystems and the impacts of human activities on these environments. |
| *Nitzschia closterium, N. hybrida, N. paradoxa, N. sigma* | This species of diatoms plays the role of primary production, foundation of food webs, water quality monitoring, eutrophication indicator, biogeochemical cycling, research applications, and potential commercial uses like biotechnology. |
| *Noctiluca scintillans* | This species of marine dinoflagellates also known as Sea Sparkle plays a vital role in marine ecosystems through its ecological functions, bioluminescence, and significance as an indicator of environmental health. Its contributions to food webs and ongoing research into biology underscore its importance in marine science and ecology. |
| *Nygmophora* sp. | While specific studies on this species may be limited, their role as primary producers, contributors to nutrient cycling, and potential indicators of environmental health underline their ecological significance. Ongoing research into microalgae continues to reveal their importance in both natural ecosystems and potential biotechnological applications. |
| *Oscillatoria* sp.1, *Oscillatoria* sp.2 | This is a genus of filamentous cyanobacteria (blue-green algae) that plays crucial role in various ecosystems. They are vital components of aquatic ecosystems, contributing to primary production, nutrient cycling, and environmental monitoring. Their roles in nitrogen fixation and potential applications in biotechnology further emphasize their ecological and scientific importance. They also have traditional uses such as food or medicine in certain cultures, highlighting their historical significance. |
| *Pediastrum clathratum* | This species of green algae contributes to primary production, nutrient cycling, indicator of environmental health, food source, and ecological studies. Its roles and potential applications in research and biotechnology underscore its significance in both natural and applied sciences. |

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| *Pleurosigma directum* | *P. directum* plays a vital role in aquatic ecosystems through its contributions to primary production, nutrient cycling, and as an indicator of environmental health. Its significance in research and potential biotechnological applications further underscores its ecological and scientific importance. |
| *Pleurosigma majus, P. normanii* | Primary production, base of the food web, indicator of environmental health, nutrient cycling, research significance (ecological studies, paleoclimatology), and biotechnological potential. |
| *Pondorina norum* | Primary production, food source, indicator of water quality (environmental monitoring), nutrient cycling, research importance (ecological studies), and potential applications (biotechnology) |
| *Prorocentrum micans* | This is a species of dinoflagellates that significant roles such as primary production, contribution to nutrient cycling, bioluminescent properties, indicator of environmental health (water quality monitoring), potential for harmful blooms, research importance (ecological studies) and applications in biotechnology. |
| *Protoperidinium* sp. | They are primary producers, oxygen producers, food source, nutrient cycling, toxin producers, toxic red tide producers, water quality monitoring, research importance and applications in biotechnology. |
| *Rhizosolenia robusta* | This is a species of diatom that plays the role of primary production, food source (base of food web), indicator of environmental health (water quality monitoring), nutrient cycling, and carbon sequestration. Its significance in research and potential applications in biotechnology further underscore its ecological and scientific importance. |
| *Stephanodiscus astraea* | This is a species of diatom that plays significant role in aquatic ecosystems, such as: primary production, food source, indicator of environmental health, nutrient cycling, ecological studies, biotechnological applications and role in carbon sequestration. |
| *Tabellaria flocculosa* | This is a species of diatom that plays a vital role in aquatic ecosystems through its contributions to primary production, nutrient cycling, biofilm formation, habitat formation, indicator of environmental health, food source, and potential applications including bioremediation and the production of bioactive compounds. |
| *Thalassiotrix frauenfeldii (Grunow)* | This species of diatom is an important component of marine ecosystems, contributing to primary production, nutrient cycling, carbon sequestration, biotechnological research applications, ecological studies, and water quality monitoring. |

Table VI shows that four (04) industrial and fishing activities impacting water quality and algal diversity in the coastal region of Kribi have high significance (9) and should be prioritize for management. These were followed by three other industrial and fishing activities with significance level of 6, two (02) activities with a significance level of 4 and finally three activities with a significance level of 3. According to the Impact Assessment Matrix, the impacts with highest significance should be top on the priority table for management actions, followed by the others in order of their significance value. Looking at the impact assessment matrix, industrial discharges need close monitoring; all industries around the Kribi coastal region should have a well-structured waste management system that ensures proper treatment of their waste before discharging into the environment. They should keep manifests of traceability that can easily be controlled by competent authorities that handle environmental issues (in the case of Cameroon, The Divisional Delegation, The Regional Delegation and The Ministry of the Environment, Protection of Nature and Sustainable Development). The manifest of traceability will provide information about the kind of waste produced and the way it is handled until its final disposal. Proper treatment of this kind of waste will prevent nutrient loading that negatively impacts marine ecosystems.

The next activity that needs monitoring and proper management is the release of ballast water from ships into the sea around the port area. This activity has as impact the introduction of invasive species that will cause an imbalance and disturbance in marine ecosystems. The primary legislation that controls the discharge of ballast water from ships into the sea is the International Convention for the Control and Management of Ships' Ballast Water and Sediments (BWM Convention). It was adopted on February13, 2004, and entered into force on September 8, 2017. The convention aims to prevent the spread of harmful aquatic organisms and pathogens through the management of ships' ballast water and sediments, which are significant pathways for invasive species. This convention was developed by the IMO of which Cameroon has been a member State since 1961.

Discarding of unwanted fish catch and bycatch is another activity that brings about a negative impact on the marine ecosystem, organic pollution. Regulation has to be placed on this with the help of competent authorities and the collaboration of interested parties.

The use of nets with uncontrolled mesh size is yet another activity in the fishing sector impacting water quality and algal diversity that needs monitoring and proper management. The other activities and their impacts on the impact assessment matrix follow this hierarchical order of significance for proper management plans to be set up.

Table XI. Impact assessment matrix

| Activity | Impact | Severity (1-3) | Likelihood (1-3) | Significance |
|---|---|---|---|---|
| **Industrial Activities** | | | | |
| Industrial discharge | Nutrient loading | 3 | 3 | 9 |
| Runoff from industrial sites | Chemical combination | 2 | 2 | 4 |
| Leak or spills of industrial chemicals | Toxicity to aquatic organisms | 3 | 1 | 3 |
| Ballast water from ships | Introduction of invasive species | 3 | 3 | 9 |
| Oil and gas exploitation and exploration | Alteration of water temperature<br>Introduction of hydrocarbons | 3 | 2 | 6 |
| Coastal construction | Habitat destruction | 3 | 1 | 3 |
| **Fishing Activities** | | | | |
| Discarding of unwanted fish catch and bycatch | Organic pollution | 3 | 3 | 9 |
| Cleaning and maintenance of fishing boats near shore | Debris and litter | 2 | 3 | 6 |
| Improper disposal of fish processing waste | Altered water chemistry and reduced water clarity | 2 | 3 | 6 |
| Resuspension of bottom sediments from trawling and dredging | Economic consequences | 2 | 2 | 4 |
| Use of chemical additives or preservatives in fishing operations | Bioaccumulation of chemicals | 3 | 1 | 3 |
| Use of nets with uncontrolled mesh size | Overfishing | 3 | 3 | 9 |

**Legend: Severity:** 1 = Low, 2 = Medium, 3 = High **Likelihood**: 1 = Rare, 2 = Possible, 3 = Likely

From the survey reports and information gotten from interviews in the study area and from the impact assessment matrix in Table XI, a problem matrix that identified the various problems related to the study topic, their possible causes and effects, and necessary measures for their mitigation was developed. These problems were taken into consideration from the economic, environmental and social points of view. This was summarized in tabular form and presented in Table XII.

Table XII. Problem analyses matrix of the industrial and fishing sector in the sea coast of Kribi.

| Problems | **Causes** | **Effects** | **Proposed measures** |
|---|---|---|---|
| **1. Economic Aspects** | | | |
| Fluctuations in the availability of fishing products | - Use of inappropriate tools and inappropriate fishing methods<br>- Fishing in spawning areas | -Reduction in fish production<br>-Food poisoning and illness linked to the use of chemical products for fishing. | - Human capacity building for the application of BRD and TED<br>- Revision of fisheries legislation<br>- Destruction of suspected products by MINEPIA |
| Post catch losses | - The use of traditional ovens<br>- The lack of infrastructure and conservation techniques | -Decrease in fish production<br>-Poverty | - Raising awareness of the use of improved ovens<br>-installation of improved ovens in fishing villages |
| Overfishing | - High demand for fishing products<br>- Ineffective regulations | - Declining fish populations<br>- Economic losses; communities that rely on fishing for their livelihoods face economic instability as fish become scarce | - Implementing quotas; establishing catch limits based on scientific assessments can help restore populations |
| Bycatch | - Non-selective fishing gear; many fishing methods unintentionally capture non-targeted species, leading to high bycatch rates | - Wastage of resources; bycatch represents a significant loss of potential catch, impacting the overall economy of fishing communities<br>- Threat to endangered species; many non-target species, including endangered ones, suffer population decline due to bycatch. | - Improved fishing technology; developing and implementing more selective fishing gear can minimize bycatch<br>- Bycatch reduction programs; training fishermen on best practices to reduce bycatch can help protect marine biodiversity |
| Illegal, Unreported, and Unregulated Fishing (IUU) | - Weak enforcement; lack of resources to effectively monitor and enforce fishing regulations<br>- Economic Incentives; the potential for high profits from illegal catches encourages IUU fishing activities | - Economic losses<br>- Undermining legitimate fisheries; IUU fishing reduces the availability of fish for legal fishermen, threatening their livelihoods | - Community engagement; involving local communities in monitoring and reporting illegal activities can improve enforcement<br>- Strengthening regulations |
| **2. Environmental Aspects** | | | |
| Habitat Degradation | - Destructive fishing practices; techniques like bottom trawling cause significant damage to marine habitats<br>- Pollution; runoff from industries, agriculture and urban areas can degrade water quality and habitats | - Loss of biodiversity; habitat destruction leads to declines in marine species and ecosystems<br>- Nutrient loading which might lead to harmful algal blooms | - Habitat restoration projects; initiatives aimed at restoring damaged marine habitats can help recover fish populations.<br>- Enforcement of legislation on proper waste management |

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|---|---|---|---|
| Pollution | - Dumping of petroleum waste from the refinery and other coastal industries<br>- Discarding of fishing gear such as nets, lines, which can entangle marine life (plastic waste)<br>- Sewage from urban settlement<br>- Discharge of effluents from industries<br>- Oil spills from Oil and Gas exploitation<br>- Runoff from agro-industries and other industrial facilities that end up in the marine environment | - Marine life threats; death of marine animals, disruption of reproductive systems, and long-term health issues in marine species<br>- Eutrophication; excess nutrients can cause algal blooms that deplete oxygen in water, creating "dead zones" where marine life cannot survive.<br>- Nutrient loading<br>- Introduction of organic wastes which depletes oxygen levels<br>- Nutrient loading that favors harmful algal blooms | - Monitoring and regulation; strengthening regulations on petroleum waste, agricultural runoff and improving waste management practices can reduce pollution entering marine environments<br>- Reducing plastic use; implementing policies to reduce plastic waste and promote biodegradable alternatives can help mitigate pollution.<br>- Encourage the proper management of sewage, e.g., collection and deposition in treatment sites<br>- Proper treatment of industrial waste before disposal<br>- Putting in place of appropriate emergency action plans to handle spills |
| Climate change | - Operation of fishing vessels often relies on fossil fuels<br>- Ships rely on fossil fuels<br>- Processing and transportation<br>- Industrial processes release greenhouse gases | - The use of fossil fuels contribute to carbon dioxide emissions, increasing greenhouse gases<br>- The processing of fish and transportation to markets also emit greenhouse gases<br>- Acid rain formation, ocean acidification<br>- Air pollution and hence water pollution | - Sustainable fishing practices should be enforced and the adoption of renewable energy in the fishing industry is essential<br>- Effective management of fish stocks is essential<br>- Renewable energy in industrial processes<br>- Control of gases released into the atmosphere by industries |
| **Social Aspects** | | | |
| Conflict between small-scale fishing and industrial fishing | - Destruction of fishing nets and juvenile fish by Chinese fishing boat | - Decrease in fish production<br>- Abandonment of fishing by some fishermen<br>- Poverty | - Enforcement of legislation fishing practices<br>- A text from MINEPIA prohibits the use of TCA trawls |
| Poor knowledge on fishing | - Lack of training | - The irrational exploitation of resources | - Sensitize and train interested parties |
| Lack of adequate data for predictive modelling | -Inadequate research into fish stocks<br>-Inadequate funding<br>Insufficient human capacity in fisheries science | - The irrational exploitation of stocks and reducing production | - Encourage and finance research programs in this domain |
| Socioeconomic inequity | - Access to resources; disparities in access to fishing grounds and technology<br>- Market control; large corporations dominate small-scale fishermen. | - Poverty; many small-scale fishermen struggle to make a living.<br>- Conflict; competition for resources can lead to tensions between communities or nations. | - Fair trade practices; promoting equitable market access for small-scale fishermen.<br>- Community support programs; providing education, training, and financial assistance (MINEPIA Loan scheme). |

### III.1.2. Management plan for the control and reduction of the impacts of industrial and fishing activities in the seacoast of Kribi.

The impact assessment and problem identification matrices presented in Tables VI and VII respectively, paved the way for a management plan to be developed. This management plan, if well implemented will go a long way to sustainably protect the marine environment in the seacoast of Kribi and beyond from the impacts of industrial and fishing activities on water quality and the diversity of algal species. The presentation of the management plan took the form of a set of goals, and under each goal, an action to be taken, the contractor involved, stakeholders, duration (short, medium or long-term), financial aspect and then observations. Table XIII shows the proposed management plan with a budget of one billion eighty-five million francs CFA francs (1,085,000,000FCFA).

The main objective of this management plan is to enable concrete measures and actions to be taken to significantly reduce the negative impacts of industrial and fishing activities on water quality and the conservation of various algal species.

It also aims to establish a systematic and collaborative approach to improving water quality and protecting marine ecosystems. By involving all stakeholders and adopting a long-term vision, this management plan will ensure a sustainable future for the environment (especially the marine environment) while promoting socio-economic development.

Table XIII. Proposed management plan for industrial and fisheries activities in the Seacoast of Kribi to limit water pollution

| **Goal G1: Raising awareness on waste management and pollution control** | | | | | | |
|---|---|---|---|---|---|---|
| **Objective** | **Action** | **Contractor** | **Stakeholders** | **Duration (Medium, Long-term)** | **Financial Aspect (x1000FCFA)** | **Observation** |
| 1.1. Making sure industrial discharges do not attain water bodies. | 1. Survey waste generating activities and various types of waste<br>2. Creation of controlled dumping sites<br>3. Building of canals that link liquid wastes to a treatment unit | MINEPDED<br>MINDHU | MINFI, MINRESI<br>Local population | Medium term | 100,000 | Already in legislation |
| 1.2. Awareness on the uncontrolled dumping of waste and impacts on water quality | 1. Form socio-professional groups<br>2. Introduce individual quotas (IQ) or group quotas of waste generation by sector.<br>3. Sensitization campaigns<br>4. Provision of garbage bins | MINEPDED | MINFI MINRESI<br>Local population<br>Fishermen | Long-term | 25,000 | Legislation exist and should be enforced |
| 1.3. Control of shipping activities | 1. Monitoring of ship discharges (sewage, ballast water and bilge water from tankers)<br>2. Port decongestion | MINEPDED | PAK, IMO, EPA | Long-term | 150,000 | Mentioned in the legislation |
| 1.4. Control the use of mesh size of nets | 1. Restriction of nets with uncontrolled mesh size in fishing<br>2. Limit waste generation in the fishing industry | MINEPIA<br>MINEPDED | MINRESI, MINFI, MINEPAT, Fishermen | Long-term | 45,000 | No measures yet. The fishing is currently free access |
| **Goal G 2: Improve technical conditions for industrial processes and the processing and marketing of fish** | | | | | | |
| 2.1. Promote capacity building and disseminate existing technologies | 1. Study of existing industrial processes and processing and marketing of fish<br>2. Create socio-professional groups<br>3. Raise awareness of and provide | MINRESI<br>MINMIDT | MINEPIA<br>MINEPAT<br>Industries and fishing community | Short-term | 155,000 | IRAD has improved oven technologies and isothermal chests and |

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|---|---|---|---|---|---|---|
| | training in improved processing and packaging technologies (Chorkor ovens, etc.)<br>4. Popularize improved technologies that value waste minimization and valorization | | | | | offers training. |
| **Goal G3: Proper management of potential polluting activities in order to mitigate their impacts on the coastal environment** | | | | | | |
| 3.1. Put in place waste management and pollution control measures | 1. Study of existing waste management infrastructure<br>2. Make decision-makers aware of the need to improve infrastructure (garbage bins, trash cans, collection points, etc.)<br>3. Seek national and international funding<br>4. Prevent the cleaning and maintenance of fishing boats near shore | MINEPDED, MINEPAT | MINTRANS<br>MINEPIA Local population | Medium-term | 250,000 | The waste management infrastructure in the study area needs improvement |
| **Goal G 4: Reduce degradation of the marine and coastal environment** | | | | | | |
| 4.1. Controlling pollutant discharges and exploitation of marine and coastal resources | 1. Study of existing sources of pollution<br>2. Technical inspection of waste discharged<br>3. Make ESIAs compulsory<br>4. Assessing pollution levels<br>5. Implement the use of clean technologies<br>6. Survey of degraded areas<br>7. Rehabilitation of degraded areas<br>8. Installation of monitoring measures. | MINEPDED | MINRESI<br>MINEPDED<br>MINMIDT<br>MINEPAT<br>MINEPIA<br>Fishermen | Medium-term | 300,000 | Provision of reports, field surveys and materials |

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|---|---|---|---|---|---|---|
| **Goal G5: Reduce conflicts between small-scale and industrial fishing** | | | | | | |
| 5.1. Strengthening the Executive Committee | 1. Revision of the Fisheries Code<br>2. Make control and monitoring systems operational<br>3. Impose heavy penalties on offenders | MINEPIA | MINRESI MINDEF MINT/Fishermen | Short-term | 45,000 | The SCS is in place but lacks equipment and staff |
| **Goal G6: Improve the industrial discharge and fisheries codes and strengthen the response capacity of staff** | | | | | | |
| 6.1. Improve and implement existing industrial and fisheries legislation | 1. Review the current law and identify any gaps<br>2. Create a mechanism to deal with problems related to industries and fishing.<br>4. Train stakeholders and raise their awareness on industrial and fisheries legislations | MINEPIA | MINRESI MINEP MINMIDT Fishermen | Medium-term | 15,000 | The Project for the new fishing code is due to be finalized |
| **TOTAL** | | | | | **1,085,000,000** | |

## III.2. DISCUSSION

### III.2.1. **Opinion of the local residents**

A sample size of 150 individuals was considered during this study and the majority was males representing 98.00% and just 2.00% females. A majority of the respondents were between the age group 20 – 40, representing 62.89%, followed by the age group 40 – 60, representing 35.05% and the age group 60 and above representing 2.06%. This results show that youths make the most active part of the population. The level of education showed that 7% of the respondents have attained higher education, 48% have attained secondary education, 40% have attained primary education and finally 5% percent had no formal education. The results also highlights that 48% of the respondents have been living in the region for 15 years and above while 52% have been living there for a period of time below 15 years.

The results obtained during the survey phase of this study after sampling the opinion of the local residents, show that many anthropogenic activities negatively affect the quality of seawater in the region. Among other activities, they pointed out industrialization, urbanization and oil and gas exploitation, where wastes are dumped into water courses which later end up in the sea. Most or all of these wastes are poorly treated or not treated at all. Clarke (2022) shares the same opinion about nutrient pollution due to wastes discharged into water bodies. It is also noted that the use of petroleum products, waste from agricultural activities, animal breeding, fishing with chemicals and dumping of fish wastes into the sea impacts water quality and algal diversity. According to the local residents, the water quality is not the same as some years back because they have noticed a reduction in fish quantity as well as dead zones. The environmental problems identified, such as changes in water color and temperature, as well as the development of new species and the proliferation of diseases, underlines the direct impact of human activities on the marine ecosystem. Changes in water color and unpleasant odors are clear indicators of degraded water quality, which can have serious consequences for public health and marine biodiversity. Comparative analysis of the main water quality parameters at different sites in this region highlights the significant impacts of human activities on aquatic ecosystems. Comparison with the water quality standards recommended by the World Health Organization (WHO) and the US Environmental Protection Agency (EPA) enables us to assess the level of degradation of these environments and the potential risks to the environment and public health.

### III.2.2. Physicochemical Variables

- **Physical parameters**

Physical parameters such as color, suspended solids (SS) and turbidity show particularly high levels in the most fishing areas, such as Londji, Mpalla, Mahale, Ngoye and Mboamanga. These sites far exceed WHO recommended standards, with values of up to 88.3 Pt-Co for color (standard: 15 Pt-Co), 20.5 mg/L for TSS (standard: 25 mg/L) and 20.5 NTU for turbidity (standard: 5 NTU). Total dissolved solids (TDS) values were also alarmingly higher in all the sampling sites. This high particulate pollution probably reflects the discharge of waste and intense human activity in these areas.

- **Chemical parameters**

Analysis of chemical parameters also reveals worrying results. Nutrient levels, particularly phosphates, are extremely high, in some sampling sites, more than 2,000 times higher than the EPA standard of 0.1 mg/L. These excessive levels of phosphates in all the sampling sites, can lead to eutrophication. Excessive phosphate inputs, particularly at more rural sites and the seaport area such as Palm Beach, Tara Plage, Lobe, Basin Zone, Anchorage Zone, Spoil Zone, Phase II Zone and the Outlet Zone can lead to marked eutrophication of aquatic environments, with risks of asphyxiation for flora and fauna. Nitrite concentrations, although still within WHO standards (0.1 mg/L), are also a cause for concern, as they are potentially toxic for aquatic organisms.

The impact of this physico-chemical pollution is reflected in the biological quality of water, with high values of biochemical oxygen demand (BOD) and chlorophyll, particularly in fishing areas. These indicators point to high levels of organic pollution and trophic enrichment, which can threaten the survival and equilibrium of aquatic ecosystems. The most affected sites are Palm Beach, Tara plage and Lobe, where BOD values reach 45 mg/L, that is, almost 5 times the WHO standard of 20 mg/L.

The results of our study highlight the multiple impacts of industrial and fishing activities on water quality and algal biodiversity along the Kribi coast. These impacts concern water physico-chemical parameters, algal community dynamics and ecological balances.

**III.2.3. Biological Variables**

A total of 35 families, 38 genera and 64 species were inventoried during this study. The algae

Identified in the 35 families include 11 belonging to the genus *Ceratium*, 5 to the genus *Coscinodiscus*, 5 to the genus *Pleurosigma*, 4 to the genera *Licmophora* and *Nitzschia* respectively, 3 to the genus Chaetocerus, and 2 to the genera *Caloneis*, *Crucigenia*, *Noctilica* and *Oscillatoria* respectively, the remaining taxa identified had a representation of 1 genus to 1 species each. This diversity was low compared to the results of the work of Lakkis in Lebanese marine waters and the Levantine basin where 54 species of *Ceratium* and 32 species of *Protoperidinium* have been identified (Lakkis, S., 2018); Okolodkov (1996) in the Sistema Arrecifal Veracruzano Park, in the southern Gulf of Mexico, recorded 33 species belonging to the genus *Ceratium* in similar studies. Koéme (2010) identified 21 species of *Ceratium* and 04 species of *Protoperidinium* in the Grand-Lahou lagoon complex in Côte d'Ivoire. This difference of diversity observed could be related to the duration of each study, the specific characteristics and the climatic conditions prevailing in the study areas. The spatio-temporal variation in the context of this work could also be justified by the specific characteristics of each sampling point, the climatic conditions specific to each season and the geographical distribution of species. Species such as *Ceratium fusus* and *Ceratium tripos* although generally incidental and rare in the context of this work have been recognized by several works as a harmful species. Indeed, according to Schmidt and Schaechter (2012), the species belonging to this genus *Ceratium*, specifically *Ceratium tripos*, *Ceratium furca*, and *Ceratium fusus* were able to produce the largest flowers of dinoflagellates due to their large sizes resulting in red tides which had significant impacts in the ecosystem. The red-brown flowers of these species (especially *Ceratium furca*) have been known to damage fish gills and to create anoxic conditions by depleting dissolved oxygen from the environment, which can suffocate various animals in the area (Encyclopedia Britanica, 2012).

The specific composition and the dynamics of the algal populations during this study would be influenced by innumerable physico-chemical factors caused by industrial and fishing activities and by the biological interactions like chattering by zooplankton and inter and intraspecific competition. The spatial and seasonal distribution of species in the section studied showed overall dominance of the genus *Ceratium*. The number of species identified for this genus was greater than the number of the other genera. Some species of the genus *Proroperidinium* may survive for a longer period of time, for example, *Protoperidinium depressum* may survive up to 71 days in states of starvation or low food availability (Gribble et *al*., 2007). Smaller to larger diatoms and dinoflagellates are the primary food source for *Protoperidinium*, and their proliferation can cause a red tide of *Protoperidinium* (Sathishkumar et *al*., 2021).

Unlike the diversity that was dominated by the genus *Ceratium*, the densities were dominated by the species belonging to the genus *Chaetocerus* especially in the Spoil Zone sampling site of the Kribi deep seaport area. *Chaetocerus peruvianus* in particular showed a density of 140 counts in the Spoil Zone and this can be attributed to favorable conditions for their growth and wellbeing in this zone. Looking at the results obtained, there was nutrient availability; phosphate levels were high in this zone which promotes diatom growth. Eutrophic conditions often enhance the proliferation of *Chaetocerus peruvianus*. Optimal water temperatures for growth typically range from 15-25˚C. Warmer temperatures can accelerate metabolic processes, leading to increased growth rates which are reflective of this zone with recorded temperatures of 30.30˚C. This diatom species can tolerate a range of salinity levels but typically prefers brackish conditions found in coastal areas where freshwater mixes with seawater. A pH range of about 7.0-9.0 is generally favorable for diatom growth, as extreme acidity or alkalinity can be detrimental. The pH of this zone was recorded as 8.21 which favor the growth of *Chaetocerus peruvianus*. Moderate water movement can help distribute nutrients and prevent the settling of cells, promoting higher growth rates. However, excessive turbulence may inhibit growth. Since this zone is characterized by shipping activities, there is bound to be water movements, thus favoring higher growth rates.

# CHAPTER IV: CONCLUSION, RECOMMENDATIONS AND PERSPECTIVES

## IV.1. CONCLUSION

This study was carried out in view of assessing the potential impacts that industrial and fishing activities can have on water quality and the diversity of algal species in coastal regions and to contribute to a better management of coastal areas. To this effect, using field observations and documentary research, supplemented by interviews with officials in charge of industrial facilities, the fishing sector and the local population, it was found out that there are many practices in these sectors that can potentially alter water quality. These alterations will not only affect algal diversity and marine ecosystems but will also result to environmental degradation and human health issues.

Analyses were carried out on various physicochemical parameters and compared with some standard norms and the results presented in tables VII and VIII showed alterations in some parameters especially total dissolved solids and phosphate ions which were far above WHO standards in all of the sampling sites of the study area indicating pollution.

To further verify the quality of water in the study area, algae species were inventoried and the various species identified and their abundance in the various sampling sites could be used to support the findings related to pollution as shown by the physicochemical parameters analyzed.

The studies showed that the zones in the coastal region of Kribi that are exposed to industrial and fishing activities have some level of pollution while those away from these activities showed very little or no pollution at all. This therefore means that industrial and fishing activities have an impact on water quality and algal diversity in the seacoast of Kribi.

The industrial sector was examined to have an idea of the kind of wastes they generate and possible ways by which these wastes attained the marine environment. The same was done with the fishing sector and from the information gotten; impact assessment and problem analysis matrices were developed which gave the means to come up with a management plan. The management plan has a number of set goals, parties involved and how they are going to be attained and with a proposed budget of 1.085.000.000FCFA (One billion eighty-five million CFA francs).

## IV.2. RECOMMENDATIONS

In order to improve and put into practice the proposed management plan and consequently the management of the impacts of industrial and fishing activities on water quality in the seacoast of Kribi, the following recommendations are to be taken into consideration by interested parties involved in the various activities of concern in this study area:

- Strengthening regulations on petroleum waste, agricultural runoff and improving waste management practices can reduce pollutants entering marine environments;
- Implementing policies on industries to reduce plastic waste and promote biodegradable alternatives can help mitigate pollution.
- Carry out surveys in industrial facilities to find out the kind of wastes generated, how these wastes are treated and disposal methods;
- Sensitize industries on the need to carry out appropriate Environmental and Social Impact Assessments;
- All ships entering the Seaport must have a ship-specific ballast water management plan approved by the relevant authorities and there should competent experts to ensure this;
- Reduce degradation of the marine and coastal environment;
- Contribute to achieving a sustainable balance between fisheries resources and their exploitation;
- Improve the fisheries code and strengthen the response capacity of staff;
- Creation of Marine Protected Areas;
- Improve technical conditions for processing and marketing fish;

- Sustainable fishing practices should be enforced and the adoption of renewable energy in the fishing industry is essential.
- A real program for Integration and Management of Coastal Cities (IMC) from Kribi to Campo should be put in place as soon as possible.
- Ngoran & Xue (2017) highlights that IMC is a dynamic process which aims, through a set of actions and inter-sectoral participation, to improve the quality of life of the people living in the coastal zone, and promote sustainable development by protecting ecosystems and coastal resources.

## IV.3. PERSPECTIVES

The proposed management plan could be implemented, but first a study of the scope and scale of the project is required. This would involve an analysis of alternatives to determine the scope and limitations of the project, and whether there are issues or objectives that could be addressed by other projects. The plan could also be extended to the management not only of the impacts of industrial and fishing activities on water quality and algal diversity but also on all other aspects of environmental concerns in the seacoast of Kribi. With a view to the outcome of this work, this study can be completed by:

- Further research into the long-term impacts of human activities on algal community dynamics and ecological balances.
- Study the potential effects of climate change on water quality and marine biodiversity in the Kribi region.
- Develop models for sustainable coastal zone management, drawing on best practices implemented in other regions.
- Establish partnerships between public and private players and non-governmental organizations for integrated and concerted management of the marine environment.
- Evaluate the effectiveness of measures to protect and restore marine ecosystems, and adjust where necessary.

- Study the potential for sustainable economic development of marine resources (responsible fishing, cosmetics, etc.).
- Identify best practices in wastewater treatment and reuse in a coastal context.
- Assess the economic, social and environmental costs and benefits of sustainable management of the Kribi marine environment.
- Explore possibilities for diversifying economic activities while preserving the integrity of marine ecosystems.

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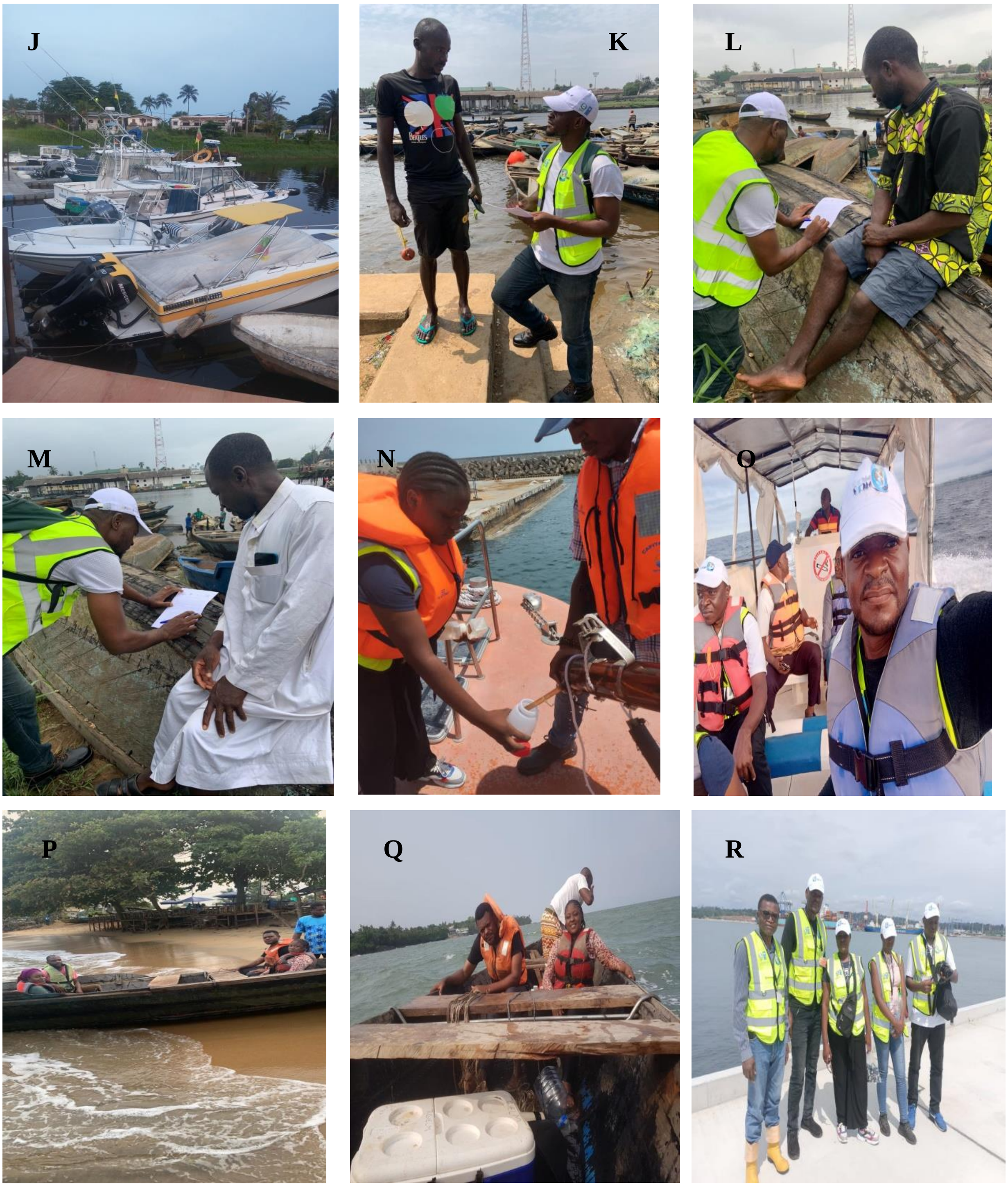
# ANNEX

**Annex 1**:


Fig.21. A- Mboamanga landing zone, B- Lobe beach with waste, C- Waste net at Lobe beach, D to G- Foamy substance at Lobe beach, H- Foamy substance at the dyke area of the Seaport, I- Sand mining Mahale beach, the root cause of erosion.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**Annex 2*:*** Survey Sheet

**QUESTIONNAIRE**

**Assessment of the impacts of human (anthropogenic) activities on water quality and some algal species on the sea coast of Kribi, Cameroon.**

**Date:** ..................................**Time:** ............................**Place:** ....................................................

I am a professional Masters student in Environmental Sciences, Specialty Environmental Sanitation and Restoration at the University of Yaoundé I. I am carrying out a study on the assessment of the impacts of human activities on water quality and some algal species on the sea coast of Kribi. This information is basically for academic purpose. I assure you that any information you give in this questionnaire will be kept confidential. Your corporation will be highly appreciated.

**Section I: General Information**

| | | |
|---|---|---|
| Q: 1 | Sex | 1. Male<br>2. Female |
| Q: 2 | Age or date of birth | |
| Q: 3 | What is your Division of origin? | |
| Q: 4 | For how long have you been in this area? | |
| Q: 5 | Do you still attend school? | 1. Yes<br>2. No |
| Q: 6 | What is your highest level of education? | 1. Never attended school;<br>2. Primary level completed;<br>3. Primary level uncompleted;<br>4. Secondary first cycle;<br>5. Secondary second cycle;<br>6. Higher education. |
| Q:7 | What is your main occupation? | 1. Farmer;<br>2. Trader;<br>3. Apprentice;<br>4. Retired;<br>5. Brick layer;<br>6. Student;<br>7. Housewife;<br>8. Unemployed;<br>9. House help;<br>10. Other……………………………………… |
| Q:8 | Do you belong to any group or association in the village? | 1. Yes<br>2. No |
| Q:9 | If yes, which type of association | 1. Farming CIG;<br>2. Health CIG; |

| | | |
|---|---|---|
| | | 3. Religious group;<br>4. Njangi group;<br>5. Village council;<br>6. Women's association;<br>7. Youth association |

**Section II: General Awareness on the impacts of human activities on water quality and some algal species in the sea coast of Kribi**

| | | |
|---|---|---|
| Q: 1 | Do you have any knowledge or experience in water quality assessment? | 1. Yes<br>2. No |
| Q: 2 | Are you aware of any anthropogenic activities that can impact water quality in Kribi? | 1. Yes<br>2. No |
| Q: 3 | What are the major anthropogenic activities that could be a potential source of impact on water quality? List them under the following headings: | 1. Tourism<br>2. Industry<br>3. Fishing<br>4. Agriculture<br>5. Other |
| Q: 4 | Have you noticed any visible changes in water quality in the coastal region of Kribi? | 1. Yes<br>2. No |
| Q: 5 | Have you noticed any reduction/increease in the quantity of fish caught over time? | 1. Increasing;<br>2. Decreasing |
| Q: 6 | How can you attempt to explain this increase or decrease? | 1. Over fishing<br>2. Water pollution<br>3. Industrial activities<br>4. Climate change |

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| Q: 7 | What kind of fishing methods are practiced in Kribi? | 1. Local<br>2. Industrial |
| Q: 8 | In which areas do you have good catch and in which areas do you notice less catch no matter the efforts made? | 1. Close to the shore<br>2. Away from human settlement |
| Q: 9 | Are you familiar with the different algal species present in the coastal waters of Kribi? | 1. Yes<br>2. No |
| Q: 10 | If yes, about how many of them | |
| Q: 11 | Have you observed any unusual growth or proliferation of algal species in the coastal waters of Kribi? | 1. Yes<br>2. No |
| Q: 12 | Have you observed a decline in the population or maybe the disappearance of some algal species in areas closest to human activities? | 1. Yes<br>2. No |
| Q: 13 | In your opinion, what are the major human activities affecting marine water quality in the coast of Kribi? | |

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| Q: 14 | What measures do you think should be implemented to mitigate the impacts of these activities on water quality in Kribi? | |
| Q: 15 | How do think the proliferation of algal species in the coastal waters of Kribi can impact aquatic ecosystems? | |
| Q: 16 | Do you think that measures should be taken to regulate the activities that affect water quality and the proliferation of algal species in the coastal region of Kribi? If so, what measures do you suggests | |
| Q: 17 | Do farmers in this region use a lot of pesticides in agriculture? | 1. Yes<br>2. No |

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| Q: 18 | In your opinion does the water quality change with changes in seasons? | 1. Yes<br>2. No |
| Q: 19 | Do you think a change in water quality implies a change in the diversity of algal species? | 1. Yes<br>2. No<br>3. Don't know |
| Q: 20 | With the installation of the deep sea port, do you think the water quality will be affected the more? | 1. Yes<br>2. No<br>3. Don't know |
| Q: 21 | How is waste disposed of in Kribi municipality? Do people empty their wastes in water bodies? | 1. Yes<br>2. No<br>3. Don't know |
| Q: 22 | Do you know that human activities can have negative impacts on water quality and that of some algal species? | 1. Yes<br>2. No |
| Q: 23 | Will you be willing to talk to your community about their activities and its impacts on water quality and algal species? | 1. Yes<br>2. No |

**THANK YOU FOR YOUR PATIENCE AND COOPERATION.**