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# Evaluation of the quality index of the riparian strip of three tributaries of the Ayamé 1 hydroelectric dam lake, subject to agricultural pressure (South-Comoé Region, Côte d'Ivoire)

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## Abstract

In Côte d'Ivoire, the progressive degradation of the riparian vegetation of the tributaries of the artificial lake of Ayamé 1 represents the source of the deterioration of water quality. Thus, the general objective of this study is to acquire a better understanding of the quality of the banks of the lake's tributaries in order to identify priority areas for intervention in the event of revegetation. To do this, the protocol for evaluating the riparian strip quality index consisted of delimiting segments 200 m long and 10 m wide, along the riparian vegetation of three streams that communicate directly with Lake Ayamé 1. Within these sampling areas, an inventory was conducted to assign a coverage percentage to the different components of the riparian strip, allowing for the calculation of the riparian quality index. Data analysis revealed low floristic richness with 36 plant species, distributed into 15 species of herbs, 8 species of lianas, 7 species of shrubs, 5 species of trees and 1 species of small shrub. Almost all riparian zone segments of the three streams have IQBR values classified as low and very low. This is due to the destruction of riverbanks for the benefit of crops and pastures. The results of this study could represent an awareness-raising tool for local residents and public authorities to plan revegetation actions in order to restore all the ecosystem services related to this important water resource.

**Keywords:** Riparian strip; Revegetation; Water quality; Lake Ayamé 1; Côte d'Ivoire

## 1. Introduction

Riparian strip represent a typical transitional habitat between aquatic and terrestrial environments [1]. Thanks to their layer of woody vegetation, they help maintain water quality and quantity, moderate temperature through shading, limit solar heating, and promote habitat connectivity [2]. Furthermore, riparian strips stabilize riverbanks by reducing erosion. They can also be preserved to prevent excessive runoff of nutrients and solid particles into waterways [3]. Thus, at the end of the 20th century, [4] developed the IQBR (quality index of the riparian strip) with the aim of contributing to the effective management of riparian zones to regulate water quality, stabilize banks, and maintain the ecological and economic functions of aquatic ecosystems. According to these authors, this index serves as a tool for the rapid and easily understandable assessment of the ecological condition of riparian habitats and their impact on the integrity of the aquatic environment. The IQBR index has been the subject of several studies worldwide [5, 6, 7]. In Canada, as part of a comprehensive assessment of riparian zones to ensure the conservation and sustainable management of waterways, the Ministry of Sustainable Development, Environment, and the Fight Against Climate Change has developed a mapping tool to illustrate this riparian zone quality index [8].

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In Côte d'Ivoire, the Bia River, one of the main waterways in the South Comoé region, is a vital water resource for local communities [9]. In 1959, the country's very first hydroelectric dam was built on this river in the town of Ayamé, which over time created an artificial reservoir known as Lake Ayamé 1 [10]. Since then, this lake has also become an important water resource for riparian communities, due to fishing activities and the supply of water for various uses [11]. Today, the riparian zones of the Bia River and Lake Ayamé 1 are subject to anthropogenic pressures such as urbanization and agriculture, which intensify erosion, siltation, eutrophication, and the degradation of these aquatic habitats [10, 12, 13]. Hydrochemical and sedimentological studies conducted by the aforementioned authors have shown that the lake waters are exposed to increased concentrations of suspended solids and excessive inputs of sediments and nutrients. [10] demonstrated that sediment inputs into the lake primarily originate from runoff flowing from anthropogenically altered shorelines. Furthermore, certain tributaries of the Bia River located near Lake Ayamé 1 discharge their nutrient-enriched waters directly into the lake due to degraded shorelines. In other words, the sedimentary and hydrochemical characteristics of the lake's waters are closely linked to the hydrological flows of these streams, which flow directly into the lake. Therefore, this study aims to assess the condition of the riparian zones of these lake tributaries, whose effectiveness in performing their various hydrological and biogeochemical functions depends on the level of shoreline disturbance. With a view to contributing to the sustainable management of the ecosystem services that Lake Ayamé 1 provides to the local communities through the preservation of riparian zones, we will attempt to answer the following main question: What is the quality of the banks of the Bia River's tributaries that flow directly into Lake Ayamé 1?

This work aims to be the very first study to evaluate the quality of the banks of the watercourses of the sub-watersheds of Lake Ayamé 1 using the quality index of the riparian strip (IQBR). The main objective assigned is therefore to acquire a better knowledge of the quality of the banks of the tributaries of the artificial lake of the Ayamé 1 hydroelectric dam. Specifically, the study aimed to: Specifically, the aim was to: (1) determine the floristic characteristics of the riparian strips of three tributaries of Lake Ayamé 1 and (2) assess the quality index of the riparian strip of these tributaries.

## 2. Methodology

### 2.1. Study area

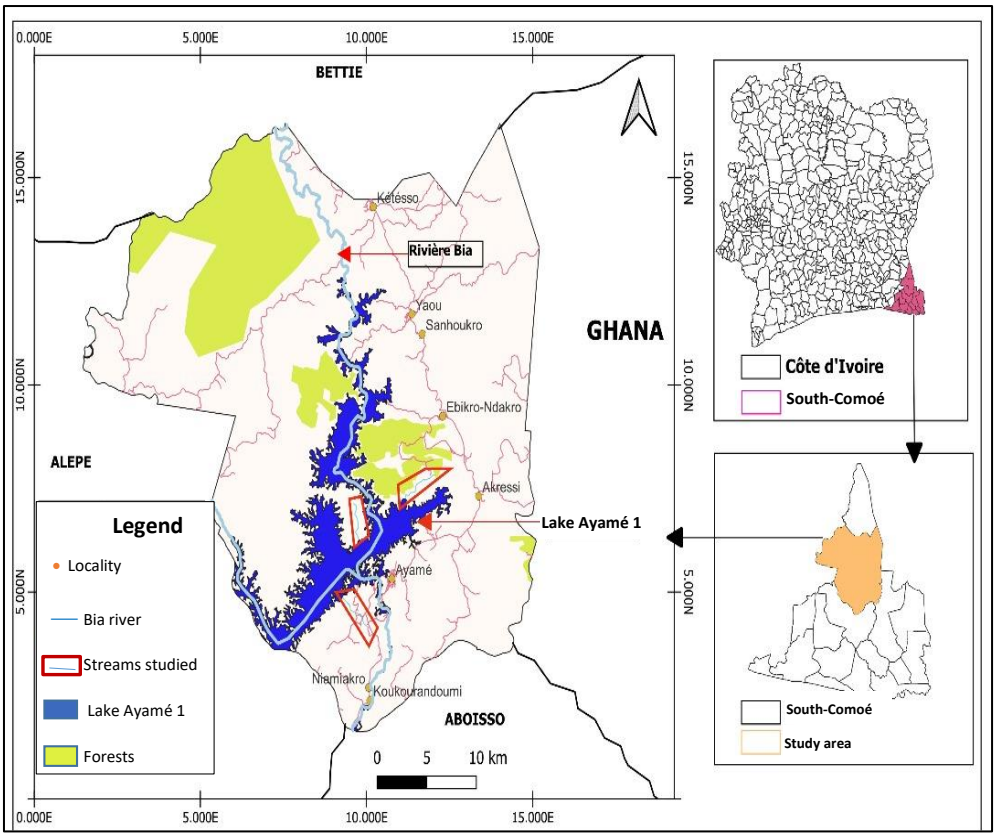


**Figure 1** Geographical location of Lake Ayamé 1 and the streams studied

Located in southeastern Côte d'Ivoire, Lake Ayamé 1 is an artificial reservoir created by the Ayamé hydroelectric dam, built on the Bia River between 5°50' and 5°85' north latitude and 3°10' and 3°25' west longitude. Lake Ayamé covers an area of 179 square kilometers and reaches a maximum depth of 30 meters [14]. It is bordered to the east by Ghana, to the south by the town of Aboisso, to the west by the town of Alepé, and to the north by the town of Bettié (Figure 1). This artificial lake is the country's primary inland fishing site. It is characterized by the presence of numerous dead tree trunks on the water's surface which is the result of rapid flooding without prior deforestation.

### 2.2. Data Collection

The entire methodology developed for this study is based on the protocol for assessing the quality index of the riparian strip (IQBR), developed by Quebec's Ministry of Sustainable Development, Environment, and the Fight Against Climate Change [8]. This protocol was inspired by the work of [4]. Data collection began with the delineation of the riparian zone's width. This is defined as the vegetation zone surrounding streams, extending from the shoreline that is, the edge of the water's surface up to 10 meters inland from the bank. Next, 1000 meters (1 km) of riparian zone were sampled along the left and right banks of each stream, subdividing them into five (5) segments or sections, each 200 m long and 10 m wide (2000 $m^2$). Within each sampling section for which the quality index of the riparian strip (IQBR) will be calculated a botanical inventory was conducted to identify all plant species encountered. Next, an inventory of land use within the riparian zone was conducted, which involved performing a visual and subjective assessment in each sampled area of the percentage of coverage occupied by each of the nine components of the riparian zone, as if viewed from a bird's-eye view (Table 1). The sum of the coverage percentages must total 100%.

**Table 1** List of riparian strip components for calculating the IQBR

| **Components of the riparian strip** | **listed items** |
|---|---|
| Tree layer | Forests, plantations |
| Shrub layer | Shrubs |
| Herbaceous layer | Herbs (*all herbs*) |
| Forest cutting | All wood cutting is considered forest cutting |
| Wasteland, pasture and gazon | Lawn, pasture (*lawn planted and maintained*) |
| Crops | Food crops, agricultural crops, forage crops |
| Bare soil | Clay, sand, and gravel |
| Bedrock | Solid rock mass |
| Infrastructure | Housing, embankments, retaining walls, road, rail, industrial and commercial infrastructure |

(Source : [4])

### 2.3. Data Analysis

#### *2.3.1. Specific richness*

In this study, species richness was determined by counting all species recorded at the site, without taking into account their frequency, abundance, or the size and productivity of the taxa encountered. The number of genera and families of the species was also counted, following the [15].

#### *2.3.2. Morphological type*

The classification of species according to their morphological type was based on the work of [16, 17]. The morphological type consisted of indicating whether the inventoried species is a herb, a liana or an arborescent species (shrub, small shrub or tree).

#### *2.3.3. Calculation of the quality index of the riparian strip (IQBR) by segment*

The IQBR is used to determine the quality of riparian buffers along a watercourse. This assessment helps determine whether the riparian zone is capable of providing the necessary ecological services [6]. The IQBR was calculated in an

Excel spreadsheet using the formula developed by [4], whose mathematical equation is as follows: $IQBR = [\Sigma (\% i \times Pi)] / 10$

*i* is the nth component (e.g., tree layer, shrub layer, etc.); *% i* = percentage of the area covered by the nth component; *Pi* = weighting factor for the nth component.

The weighting factor specific to each component reflects its ability to perform ecological functions that protect aquatic ecosystems (Table 2). The weighted calculation of the IQBR is therefore presented below:

**IQBR** = [(% tree layer*10) + (% shrub layer*8.2) + (% natural herbaceous layer*5.8) + (% forest cutting*4.3) + (% fallow land, forage, pasture, turf*3) + (% crops*1.9) + (% bare soil*1.7) + (% bedrock*3.8) + (% infrastructure*1.9)] / 10

**Table 2** List of riparian strip components and corresponding weighting factors for calculating the IQBR

| Components of the riparian strip | Weighting factors |
|---|---|
| Tree layer | 10 |
| Shrub layer | 8,2 |
| Herbaceous layer | 5,8 |
| Forest cutting | 4,3 |
| Wasteland, pasture and gazon | 3 |
| Crops | 1,9 |
| Bare soil | 1,7 |
| Bedrock | 3,8 |
| Infrastructure | 1,9 |

(Source : [4])

*2.3.4. Color representation of IQBR values*

Each sampled segment was assigned a riparian strip quality class using a color code corresponding to the resulting IQBR score. The colors range from red, indicating very poor riparian zone quality, to green, indicating excellent quality [18] (Table 3). In this study, the various percentages of the IQBR values for an entire stream were represented by colored pie charts, thereby illustrating the levels of degradation of the banks of the studied streams.

**Table 3** Different quality classes of riparian strips

| Colors | Classes | IQBR values |
|---|---|---|
| | | |
| | Excellent | 90-100 |
| | | |
| | Good | 75-89 |
| | | |
| | Intermediate | 60-74 |
| | | |
| | Low | 40-59 |
| | | |
| | Very low | 17-39 |

(Source : [18])

## 3. Results

### 3.1. Floristic characteristics of the riparian strip along the streams studied

The floristic inventory of riparian strip along the three tributaries of Lake Ayamé 1 revealed low species richness. A total of 36 plant species were recorded, distributed across 36 genera and 26 families (Table 4). The most represented families are the Euphorbiaceae and Fabaceae, with 4 species each (11.1%), and the Apocynaceae (3 species, 8.3%). The Cyperaceae and Malvaceae each have two species (5.6%). All other families are monospecific. Specifically, the Anassouè stream recorded 12 species, distributed across 12 genera and 11 families (Table 4). On the Agnouan Assouè stream, 25 species, 25 genera, and 20 families were recorded. The Koua stream recorded 8 species, 8 genera, and 7 families. When examining floristic richness by bank, the right bank of the Anassouè stream had 10 species, 10 genera, and 10 families, while the left bank had 10 species, 10 genera, and 9 families. On the Agnouan Assouè stream, the right bank is the richest with 24 species, 24 genera, and 19 families, compared to the left bank, which recorded 11 species, 11 genera, and 10 families. Finally, on the Koua stream, each of the two banks recorded 8 species, 8 genera, and 7 families. Analysis of the flora recorded along the riparian zones of the three streams revealed five morphological types. Specifically, the flora consists of 5 tree species, 7 shrub species, 1 small tree species, 8 liana species, and 15 herb species. Analysis of the morphological spectrum by stream indicates that the flora of each of the three streams is dominated by herbaceous species (Figure 2). One small tree species was recorded only on the Koua Stream.

**Table 4** List of species recorded along the riparian strips of the differents streams

| **Species** | **Family** | **Morphological Type** | **Species presence per stream** | | |
|---|---|---|---|---|---|
| | | | Anassouè | Agnouan Assouè | Koua |
| *Angylocalyx oligophyllus* | Fabaceae | shrub | | + | |
| *Baphia heudelotiana* | Fabaceae | shrub | | + | |
| *Bolboschoenus maritimus* | Cyperaceae | herb | | | + |
| *Cecropia peltata* | Urticaceae | tree | + | | |
| *Centella asiatica* | Apiaceae | liana | + | | |
| *Cissus smithiana* | Vitaceae | liana | | + | |
| *Coccinia barteri* | Cucurbitaceae | liana | + | | |
| *Coldenia procumbens* | Boraginaceae | herb | | | + |
| *Costus afer* | Costaceae | herb | + | + | |
| *Coula edulis* | Olacaceae | tree | | + | |
| *Crotonogyne preussii* | Euphorbiacae | shrub | | + | |
| *Cyperus ligularis* | Cyperaceae | herb | | + | + |
| *Dioscorea minutiflora* | Dioscoreaceae | liana | | + | |
| *Euphorbia heterophylla* | Euphorbiacae | herb | | + | |
| *Ficus sur* | Moraceae | shrub | | + | |
| *Gongronema latifolium* | Apocynaceae | liana | + | | |
| *Gonolobus patens* | Apocynaceae | liana | | + | |
| *Hevea brasiliensis* | Euphorbiacae | tree | + | + | |
| *Hypselodelphys velutina* | Marantaceae | herb | | + | |
| *Ludwigia abissinica* | Onagraceae | herb | + | + | + |
| *Manniophyton fulvum* | Euphorbiacae | liana | | + | |
| *Melanthera scandens* | Asteraceae | herb | + | | |

| | | | | | |
|---|---|---|---|---|---|
| *Nephrolepis bisserata* | Nephrolepidaceae | herb | | + | |
| *Persicaria senegalensis* | Polygonaceae | herb | | | + |
| *Phymatodes scolopendria* | Polypodiaceae | herb | | + | |
| *Pteridium aquilinum* | Dennstaedtiaceae | herb | | + | |
| *Pterocarpus santalinoides* | Fabaceae | tree | | + | |
| *Rauvolfia vomitoria* | Apocynaceae | shrub | + | | |
| *Scottelia klaineana* | Achariaceae | shrub | | + | |
| *Senna alata* | Fabaceae | tree | + | | |
| *sida acuta* | Malvaceae | Small shrub | | | + |
| *Spigelia anthelmia* | Loganiaceae | herb | + | + | |
| *Sporobolus pyramidalis* | Poaceae | herb | | + | + |
| *Stachytarpheta cayennensis* | Verbanaceae | herb | | + | + |
| *Theobroma cacao* | Malvaceae | shrub | + | + | |
| *Vanilla crenulata* | Orchidaceae | liana | | + | |

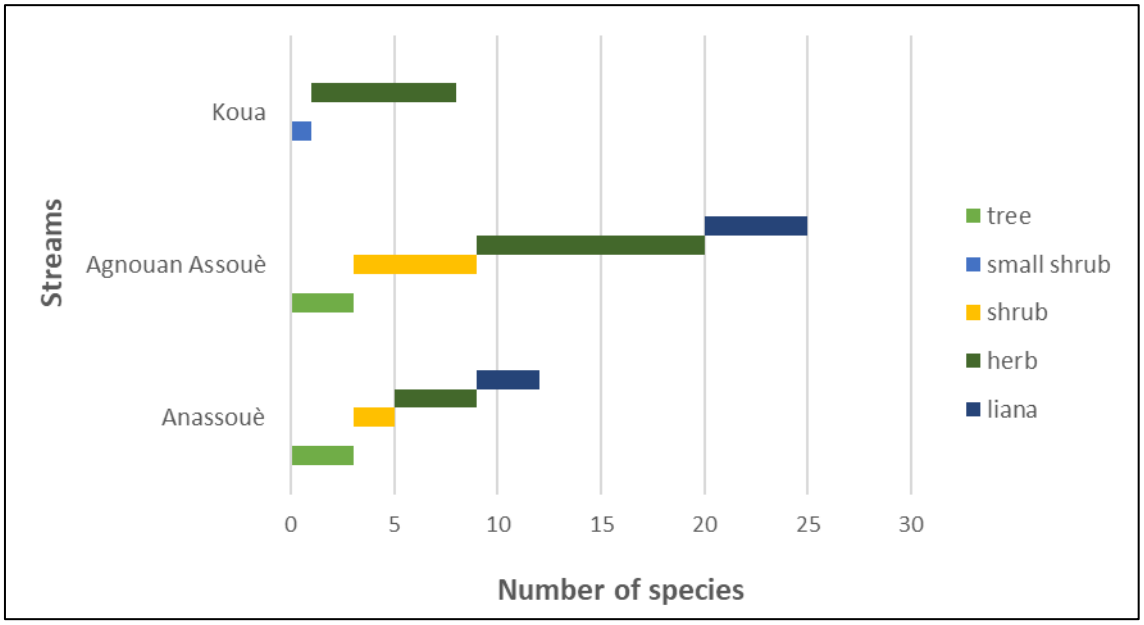


**Figure 2** Distribution spectrum of the morphological type of species for each stream

### 3.2. Quality index of the riparian strip of the streams studied

*3.2.1. Components of the riparian strip and IQBR of the Anassoue stream*

This study characterized a 1 km stretch along each bank of the Anassouè Stream. Figure 3 shows the proportions of riparian strip components across both banks. Crops constitute the dominant component, representing 25% of the studied area. They are followed by shrubs and bedrock, each occupying 21%, and then the herbaceous layer, which occupies 20%. In contrast, the forest cover is low, at around 7%. Finally, forest cutting is the least represented component, with less than 1%. Regarding the quality index of the riparian strip, all (100%) segments along both banks of the Anassouè stream have a low-class IQBR.

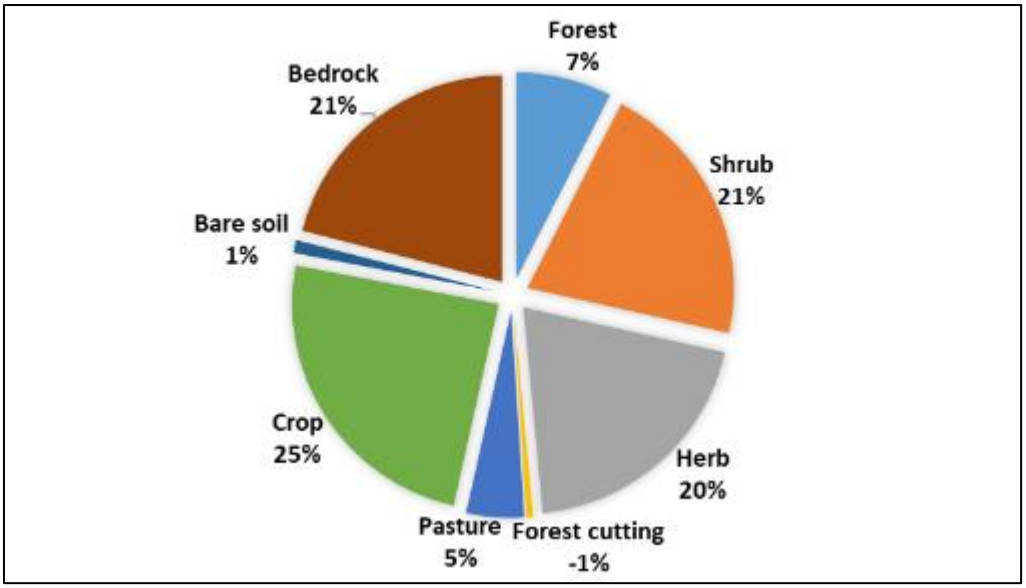


**Figure 3** Proportions of the riparian strip components along the banks of Anassouè stream

*3.2.2. Components of the riparian strip and IQBR of the Agnouan Assouè stream*

Figure 4 shows that pastures are the most dominant component, covering 25% of the study area. Next are shrubs, which cover 20%. Bedrock, herbaceous vegetation, and forest cover 18%, 17%, and 12% of the riparian strips, respectively. Bare soil (7%) and clear-cut areas (1%) are the least prevalent components. Figure 5 illustrates the distribution of all segments on both banks according to their IQBR classification. It is noted that segments in the medium class are slightly more numerous (38%) than those in the very low class (37%). Similarly, segments in the Good and Low quality classes are roughly equal in proportion, at approximately 13% and 12%, respectively.

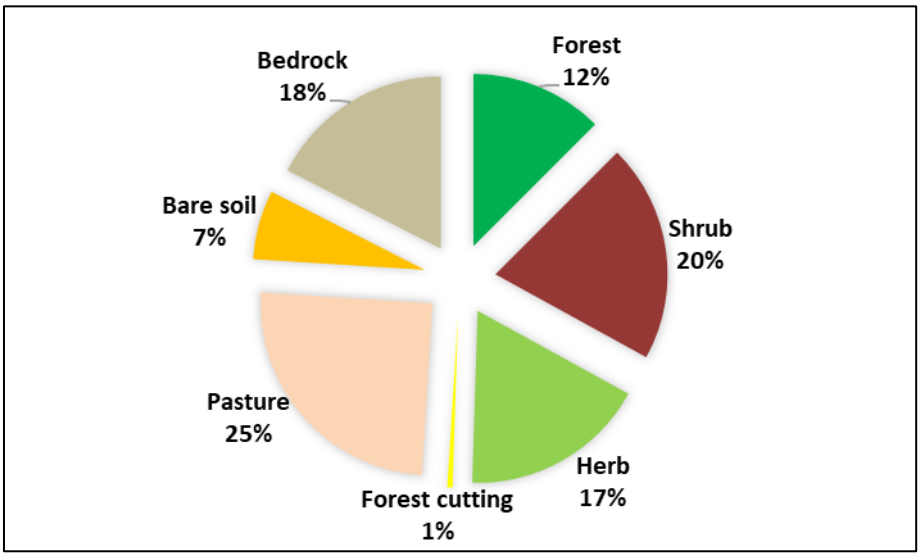


**Figure 4** Proportions of the riparian strip components along the banks of Agnouan Assouè stream

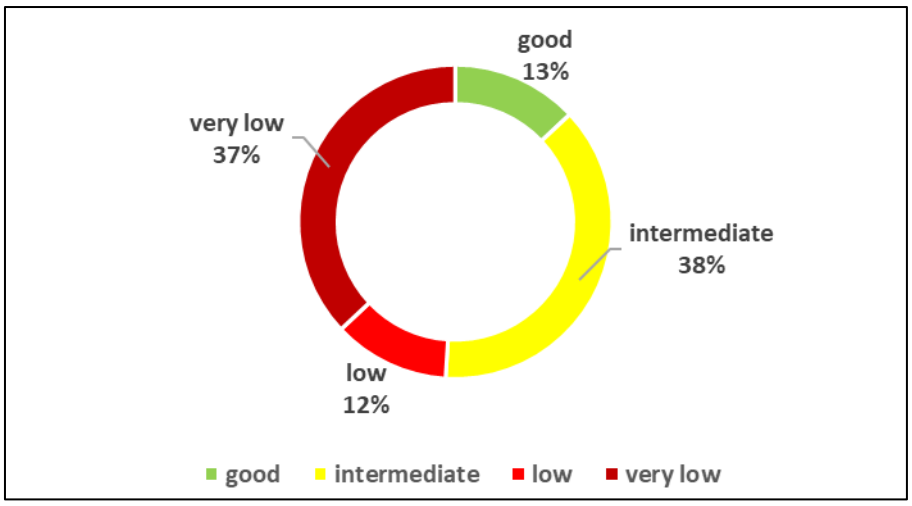


**Figure 5** IQBR of Agnouan Assouè stream

*3.2.3. Components of the riparian strip and IQBR of the Koua stream*

Along the Koua Stream, pastureland is the dominant component of the riparian strip, accounting for 74% (Figure 6). It is followed by herbaceous vegetation, which accounts for 21%. Finally, bare soil is the least represented component, accounting for only 5%. Figure 7 shows the proportion of IQBR quality classes across all segments on both banks. It reveals that more than half of the segments (80%) have a very low IQBR class. Segments in the low class account for 20%. No segment of this stream has a higher IQBR quality.

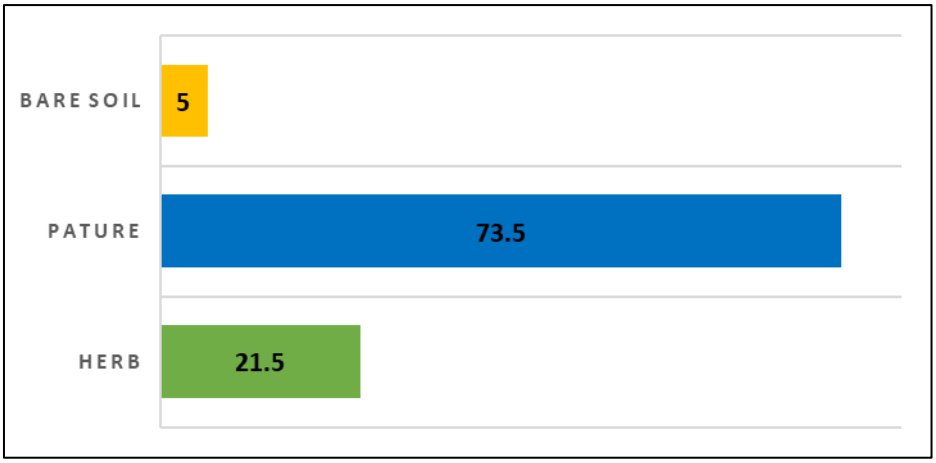


**Figure 6** Proportions of the riparian strip components along the banks of Koua stream

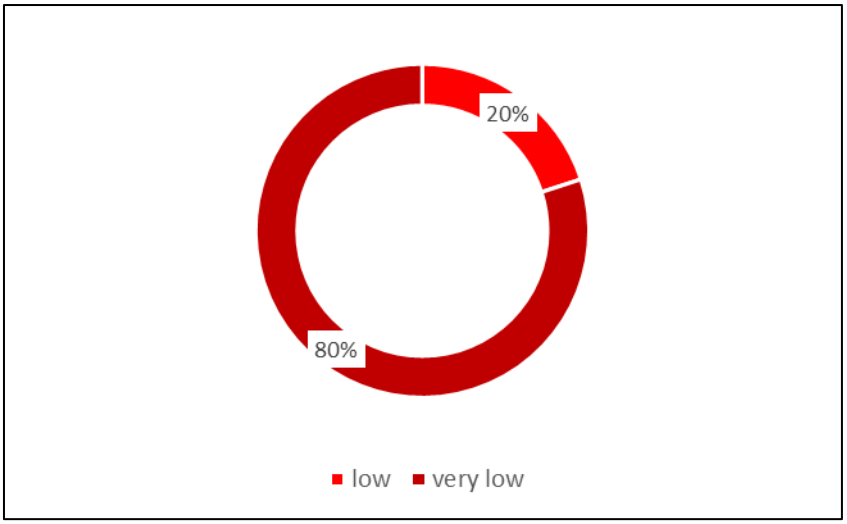


**Figure 7** IQBR of Koua stream

## 4. Discussion

This study was conducted to assess the quality of the banks of three streams that are natural tributaries of the Bia River and connect directly to the Ayamé 1 artificial reservoir. The work carried out aims to identify priority areas for revegetation efforts. Floristic analyses indicated low species richness along the riparian strips of the Anassouè, Agnoua Assouè, and Koua streams. This could be explained by the high degree of human impact on the banks. This finding corroborates the work of [19], who demonstrated that the progressive human impact on the riparian strips of the Ebrié Lagoon in the urban area of the Abidjan district has led to a decline in plant species within these biotopes. [20] similarly noted that deforestation leads to the extinction of tree species. The situation is becoming alarming along these three streams, where part of the regenerating banks is dominated by herbaceous vegetation. The abundance of this herbaceous layer in the riparian strips is consistent with the findings of [21], who revealed that forest fragmentation caused by human activities, which allows light to penetrate, is responsible for the establishment of herbaceous pioneer species. Furthermore, it should be noted that the heavy sedimentation of the riverbed which could impact the aquatic fauna of Lake Ayamé 1 was the primary motivation for this study, which aims to characterize the riparian strips of the tributaries, where the degree of bank disturbance is linked to sediment runoff into the lake. The Quality Index Riparian Strip (IQBR) was therefore used to assess the health of the banks of these tributaries of Lake Ayamé 1. The values of IQBR, divided into five quality classes, each associated with a color code, indicate that, overall, the riparian strips are in poor condition or of poor quality. All surveyed riparian strip segments along the Anassouè and Koua streams are characterized by IQBR classes of very poor and poor quality, thus demonstrating significant degradation of the shorelines. Indeed, at present, the riparian strips of these streams have been more or less deforested due to agricultural activities, particularly the cultivation of rubber and cocoa. [10, 13] also highlighted the impact of agricultural practices in the sub-basins of Lake Ayamé 1. These authors demonstrated that these uncontrolled activities contribute to increased erosion and heighten the production of various sediments. Only the Agnouan Assouè stream recorded a small portion of its length with a Good-class IQBR. [6] noted that only riparian strip sections with an Excellent or Good IQBR are considered capable of fulfilling their ecological role. Thus, the low number of trees and shrubs found along the banks indicate that the riparian strips of the three streams cannot provide the regulatory services that healthy vegetation is expected to deliver. [22] noted that, in order to adequately fulfill their function of protecting water quality, riparian strips should ideally consist of a well-preserved woody layer. According to [23], vegetated strips must be at least 30 to 50 meters wide to trap sediment and nutrients. The root systems of trees capture nutrients such as phosphorus and nitrogen, thereby largely purifying runoff water from adjacent agricultural lands [24]. When present in excessively high concentrations in the water, these nutrients cause excessive growth of aquatic plants. Lake Ayamé 1 even experienced this phenomenon of its water surface being overrun by Invasive Aquatic Plants, including water hyacinth, *Eichhornia crassipes* (Mart.) Solms-Laub (Pontederiaceae), before being cleared through biological control by releasing predatory insects onto the stands of these invasive aquatic plants [25]. The removal of vegetation from a riparian strip has numerous ecological, environmental, sociocultural, and economic consequences. Indeed, the penetration of light into the water surface in the absence of vegetation cover tends to influence variations in dissolved oxygen saturation levels, due to poor regulation of water temperature [26]. Furthermore, [10] have shown that particles from runoff can remain suspended in the water or settle to the bottom of the water column**.** Consequently, changes in certain physical and biochemical mechanisms, which disrupt environmental conditions, can prove harmful to aquatic fauna. For example,

the survival of many invertebrates that serve as food for thousands of fish species is closely linked to an optimal concentration of dissolved oxygen [24]. Thus, such a loss of fish fauna diversity could significantly impact fishing activity. Faced with a potential loss of ecosystem services from Lake Ayamé 1, linked to excessive deforestation along the banks of its tributaries, it is becoming urgent to raise awareness among local communities and public authorities about the importance of the riparian strip, as noted by [27] and [6] by emphasizing that the degradation of the riparian strip in favor of urbanized areas stems from a lack of understanding of the role of these ecosystems.

## 5. Conclusion

This study, evaluating the quality index riparian strip of the Anassouè, Agnouan Assouè, and Koua streams, highlighted the degraded state of the riverbanks. It revealed that the establishment of agricultural crops and forage crops has led to the deterioration of the riparian strips of these tributaries of the Ayamé 1 artificial reservoir. The results of this study could serve as an awareness-raising tool for local residents and public authorities, encouraging them to consider restoring the degraded riparian strips using more plant-based and environmentally friendly methods. These restored vegetation strips could then fully perform their mechanical function of purifying the lake's waters.

## Compliance with ethical standards

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*Disclosure of conflict of interest*

The authors have not declared any conflict of interest.

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