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Contribution to the sustainable management of water and soil resources in North-West Benin: characterization of the watershed heads of the Ouémé and Pendjari rivers in the commune of Copargo

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Abstract

Due to their potential in ecosystem services, their wetlands and due to their lack of knowledge and their failure to take into account in the development and management plans of water and soil resources, the heads of watersheds for some time years undergo unprecedented anthropogenic pressure despite their fundamental role in determining the quantity and quality of the downstream watercourse. The present study was interested in shedding light on the characteristics as well as the issues associated with the watershed heads of the Ouémé and Pendjari rivers in the commune of Copargo. To achieve this objective, cartographic characterization techniques were implemented using mapping tools and the digital terrain model, followed by several exploratory analyzes using R software which made it possible to describe the variability of these areas. In Copargo, 25 watershed heads with similar operations and management issues were identified and delimited, including 14 in the Pendjari watershed and 11 in the Ouémé watershed. They occupy 59.4% of the surface area of the Pendjari watershed and 69% of the Ouémé watershed. Their surface area varies from 710ha to 4440ha with a compactness index of between 1.2 and 1.5. The slope varies from 1.5% to 4.5% and is more marked on the heads of small watershed areas. The headwater streams in the Copargo catchment represent 83.5% of the Ouémé river network and 85.7% of the Pendjari river network. Classifications based on morphology and land use profiles highlight groups characterized by vulnerability. This study will be followed by a physicochemical and bacteriological characterization study of water resources in the study area with a view to assessing the impact of anthropogenic pressure on them.

Keywords: Characterization, watershed head, Ouémé-Pendjari, integrated management, water-soil

Introduction

Watershed head (WSH) are the areas drained by the first streams in the hydrographic networks and correspond to the upstream zones of streams located at the interface between terrestrial and aquatic environments (Agence de l'Eau Loir Bretagne, 2020; Maman, 2007). Rich in small streams, ponds and wetlands, they support ecosystem services that are essential to the proper functioning of hydrosystems and are essential areas in the functioning of the water cycle (Henner, 2013; Kagan, 2017; LE Bihan, 2017). They are spread throughout a catchment area and represent a significant proportion of the territory: 60 to 80% of the length of the hydrographical network and 70 to 80% of the surface area of the catchment area, and are responsible for 60%

of the water quality of higher-ranking streams (Agence de l'Eau Loir Bretagne, 2020; Agence de l'eau Loire-Bretagne, 2018; Kagan, 2017; Maman, 2007). Catchment headwaters are a major challenge for water management. The integrity of these headwaters is crucial to the functioning of downstream rivers, in terms of both quantity and quality. So if these upstream rivers are in poor condition or polluted, they risk having a negative impact on the condition of the rivers downstream. The condition of these watercourses is therefore crucial to the state of a catchment area. Unfortunately, the headwaters of catchment areas are generally little known and are subject to anthropogenic pressure. Dispersed and small in size, with an intermittent regime and high density, headwater streams are often overlooked in inventories and in the preparation of planning documents and water resource development and management schemes. Yet they are crucial to the proper functioning of hydrosystems and strategic for the management of aquatic environments. At the same time, they are subject to heavy human pressure and their condition is rarely assessed (Barnaud, 2013; Meyer & Wallace, 2001). The decline in soil fertility, linked to over-exploitation of the land and the after-effects of climate change, is leading to a significant drop in productivity and crop yields, forcing people to look for new fertile land. Believed to be fertile, the wetlands at the head of catchment areas are being exploited day by day for a variety of purposes, particularly agricultural (Agbanou, 2018).

In northern Benin, where agriculture is the main activity, the headwaters are not spared from human pressure. With their source in Copargo, the Ouémé and Pendjari rivers are, respectively, watercourses of national and international importance that offer areas suitable for agriculture through their catchment headwaters, which are exploited day by day for agricultural purposes. Farming and livestock breeding are actively practiced and have intensified over the years in response not only to the demand for agricultural food products but also to the impoverishment and scarcity of arable land in the valleys. These activities at the head of catchment areas compromise not only the integrity of water and soil resources through pollution, but also the state of biodiversity, which continues to deteriorate (Gouv, 2021). The importance and role of the headwaters are unknown to stakeholders from all socio-professional categories, and local populations do not see the point of protecting and preserving an area whose potential is best exploited to satisfy immediate but legitimate interests (Dourotimy Rachel et al., 2020). In the light of these many observations, WSH are the subject of recent and growing concern because they have only been taken into account in water management relatively recently (Agence de l'Eau Loir Bretagne, 2020; CREDEL, 2019; Henner, 2013; Kagan, 2017; LE Bihan, 2017). In Benin, this resulted in the pilot initiative for integrated management of the head of the Mékrou river basin, in 2012, led by PNE-Benin. With this in mind, Dourotimy in 2020 has been working on identifying WSH to improve the sustainable management of water resources in the Mékrou River. The present study is therefore the second to address the issue of WSH in Benin. The original character of this study lies in the combination of several approaches enabling not only the identification but also the characterization of WSH according to several criteria, enabling the establishment of a database for subsequent consideration in the planning and management of water and soil resources. Today, it is essential to take account of catchment headlands in order to improve the planning and sustainable management of water and soil resources. In order for these measures to be effective, it is essential that the WSH, which are often unknown about their existence and condition and ignored by socio-professional stakeholders and local populations alike, are made aware not only of their functions, issues and importance, but also of their location and vulnerability to human pressure.

In view of the above, the aim of this study is to characterize the headwaters of the Ouémé and Pendjari catchment basins in the commune of Copargo in north-west Benin, with a view to contributing to the sustainable management of the water and soil resources of the Ouémé and Pendjari rivers, which are watercourses of national and international importance.

Materials and methods

Study area

Located between latitudes 9°40'50" and 10°4'31" north and between longitudes 1°20' and 1°45' east, the municipality of Copargo covers an area of 876 km^2 and has a population of 71,000. It is bordered to the north-west by Boukombé, to the north and north-east by Kouandé, to the south-west by Ouaké, to the south-east and east by Djougou and to the west by the Republic of Togo (Figure 1).

It is under the influence of the Sudano-Guinean climate, tempered by the Atacorien relief. The Harmattan, a cool, dry wind, blows during the dry season. The area has two seasons: a dry season running from mid-October to mid-April and a rainy season covering the period from mid-April to mid-October. Rainfall in the commune is unevenly distributed, ranging from 800 mm to 1,300 mm. August and September are the wettest months of the year (Mathieu & Bernard, 2020).

The highest average monthly maximum temperature is recorded in March, at around 36°C, while the lowest average monthly minimum is 32°C in August.

The vegetation consists of wooded and grassy savannahs that characterize the area. The following shrub species can be found everywhere:

Shea, néré, mango and caïlcédrat. There is a classified forest covering 1,091 ha (Republique du Bénin, 2019). There are also gallery forests.

The commune's topography is characterized by a mountainous area dominated by the Atacora range, with its highest point reaching 654 m at Tanéka-Koko in the west of the commune. The rest of the area is made up of vast wooded plains alternating with valleys and basins that are often wet and favorable to crops. These wetlands are concentrated in the north-western part of the commune at altitudes of between 329 and 396 m (Mathieu & Bernard, 2020).

The municipality of Copargo has a dense hydrographic network. It is crossed and watered by several rivers, the main ones being the Ouémé and the Pendjari, giving rise to two catchment areas in its district. The Pendjari has a seasonal regime, while the Ouémé flows permanently towards the Atlantic Ocean (Republique du Bénin, 2019).

Unconcretioned and indurated tropical ferruginous leached soils are found mainly on the summits and slopes of Copargo. Light soils with low water retention capacity, found mainly in the arrondissements of Anandana and Singré (Gnonhoue, 2020; Mathieu & Bernard, 2020).

Geologically, the formations encountered range from the Atacorien series (extending into Togo and Ghana) to the first outcrops of the Dahomean or Benino-Togolese basement formed of very ancient eruptive rocks, followed by the series formed of quartzites, schists, micaschists and the deposits of the Buem series (UNEP/GEF/Volta/NR Benin, 2010). The water resources used are groundwater and surface water.

The commune's economy is based mainly on agriculture, fishing, hunting, trade, manufacturing and other industries. The population is predominantly agricultural, and farming is the main activity in the commune, employing over 90% of the working population. Three sectors contribute most to local Gross Domestic Product (GDP) in the commune of Copargo: yam (80.12%), maize (14.95%) and cashew nuts (7.43%). Other crops that could contribute to local growth are chili peppers, rice and cotton.

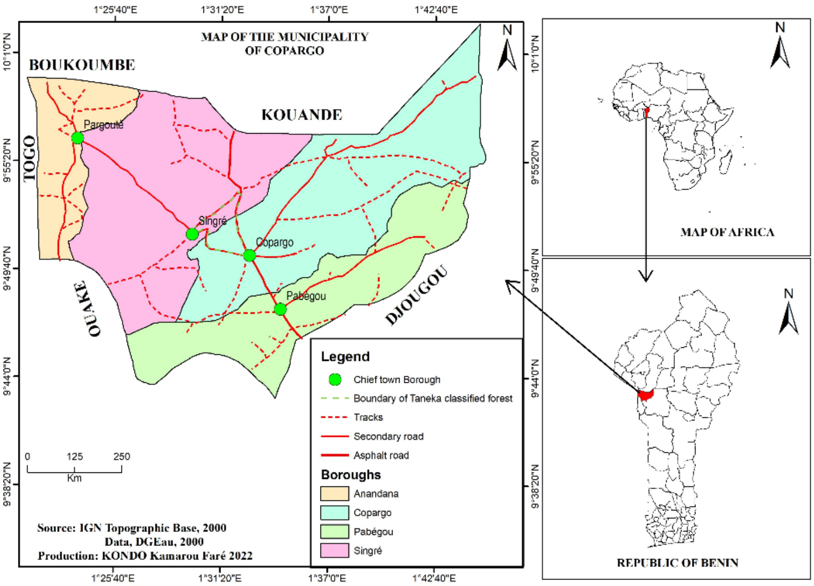

Figure 1: Geographical location of the study area

Watershed Heads (Catchment headwaters)

Definition

The definition of watershed heads varies from one approach to another and from one region of the world to another. Nonetheless, most definitions of WSH refer to Strahler's classification or ordering (1957) applied to the hydrographic network. Strahler's classification or method consists of ordering watercourses according to their importance from source to outlet in a catchment area, assigning them a rank that increases from upstream to downstream. This method stipulates that: a) the source watercourse takes the number 1 (rank 1), b) any watercourse with no tributary is of order 1, c) the confluence of two watercourses of order n gives a watercourse of order n+1, d) any watercourse that receives a tributary of lower order keeps its order (Figure 2). Thus, the WSH correspond to the watershed delimited by the Strahler rank 1 and 2 streams (Clarke et al., 2008; Freeman et al., 2007; Rasmussen et al., 2013). For some authors, the WSH extends to rank 3 (Wallace & Eggert, 2009) and for others it is limited to rank 1 (Krecek & Haigh, 2006). Some authors define them according to their streams, their width and their flow or by considering them as upstream zones devoid of fish (Wipfli et al., 2007). According to the Loire-Bretagne Water Agency in its Water Development and Management Master Plan (SDAGE 2016-2021), the WSH are the "watershed delimited by streams of lower Strahler rank or equal to 2 and whose slope is greater than 1%. This slope criterion can be adapted locally for streams with low specific power presenting a risk of non-achievement of environmental objectives. (Figure 3).

In Benin, Dourotimy (2020), in his study on the identification of the WSH of the Mékrou, defines them as the catchment areas of rivers with a Strahler rank of less than or equal to 2 and a slope greater than 1%. The slope criterion is often questioned in the delimitation of a catchment head for several reasons (Henner, 2013; LE Bihan, 2009).

In this study, the slope criterion was not used for the following reasons: a) taking the slope criterion into account leads to the exclusion of fragile streams in the WSH, b) the 1% criterion is not justified in the scientific literature, c) its application leads to the exclusion of meandering streams, d) taking the slope criterion into account leads to inconsistencies where, within the same WSH slopes are greater and less than 1%, e) the use of the slope criterion is not relevant and, conversely, counter-productive since it means not taking into account environments vulnerable to pressures and does not give sufficient consideration to lowland and plateau catchment areas and f) the fact that the mapping of rivers using Strahler's ordination method shows that headwater rivers are not necessarily located at the upstream end of a catchment area(Bihan, 2023) (Agence de l'eau Loire-Bretagne, 2018; Bihan, 2023; LE Bihan, 2009).

In the present study, it was therefore a question of defining and delimiting the WSH areas of rivers of Strahler rank 1 and 2. Thus, the WSH in the present study are the basins drained by Strahler 1 and 2 streams.

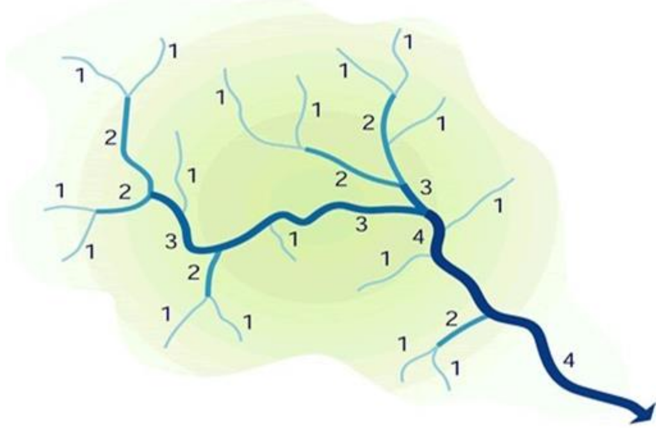

Figure 2: Strahler hydrographic network classification
(Agence de l'eau Loire-Bretagne, 2020)

Figure 3: Watershed heads (Agence de l'eau Loire-Bretagne, 2020)

Cartographic and it tools

The delimitation of WSH requires a cartographic approach (Cirou, 2017; Dourotimy Rachel et al., 2020). Excel and R software (Rcmdr and FactoMineR packages) were used to set up databases and carry out statistical analyses.

Delineation of catchment headlands

The delimitation of the WSH by cartographic approach required the use of a Digital Elevattion Model (DEM) and a hydrographic network. The DEM used has a resolution of 30 meters and was obtained from the DGEau Benin. The hydrographic network used is that resulting from the inventory of watercourses.

a. **Inventory of streams**

This consisted of various operations carried out to identify the hydrographic network from the main watercourses to the creeks and streams in the Copargo commune. From the DEM, raster layers are obtained and following their vectorisation, linear layers representing the hydrographic networks of the rivers Ouémé and Pendjari in Copargo are obtained (Dourotimy Rachel et al., 2020). The discretization threshold chosen was 350, which provided as much detail as possible on the hydrographic networks. Additional field work was also carried out to validate the hydrographic network obtained.

b. Pre-processing of the hydrographic network and ordering using Strahler's method

Pre-processing consisted of correcting topological errors (disconnections between two sections of watercourse, direction of each section, cutting of each section at each intersection, incorrect alignment) after checking the digitization of the network. The most commonly used method for defining watercourses in order of importance is the Strahler classification (1957). This method enabled each branch of Copargo's hydrographic networks to be labelled according to their order of importance. From this ordered network, all the nodes at the intersection of the sections are recovered and Strahler's order 2 streams are retained.

c. Delimitation of watershed heads according to their outlet

The delimitation of WSH consists of locating them in a given area. Thus, from each of the outlets of the Strahler order 2 watercourses previously defined, the WSH were generated by aggregating all the unitary catchment areas present upstream (Fig3)

Watershed head characterization

The aim of the characterization was to describe the WSH on the basis of a certain number of criteria in the context of improving knowledge of their condition. It is therefore informative in nature and provides a database for the preparation of master plans for the development and management of water and soil resources.

a. Criteria relating to the physical and geographical context

✓ **Index of general morphology or morphometric characteristics**

The main objectives of the morphological study are to characterize the physical data of the WSH delimited. It consisted of determining:

- the surface area, the perimeter, the linear length of the watercourse in WSH
- the Gravelius compactness index (KG), the density of inventoried beds, the density of the low point network and the time of concentration, obtained by calculation using the formulae summarized in table 1 below

Table 1: Criteria for morphometric

Criteria	**Formula/description**
Surface area of WSH	Surface de la TBV en hectare
Gravelius compactness index	Compactness or KG = $\frac{\text{(Perimeter of WSH)}}{(2\sqrt{(\pi(\text{Area of the WSH}))})}$
Density of inventoried hair	Dens_CEI = $\frac{\text{(Linear of the watercourse (m))}}{\text{(Surface of the WSH (ha))}}$
Low point network density	Dens_Pt_Bas = $\frac{\text{(Linear of the low point network (m)))}}{\text{Surface of the BV (ha))}}$
Average slope of the WSH	From a slope raster of each of the TBV via the DEM. The value obtained corresponds to the average.
Concentration time	Ccntr_Time =0,108 $\frac{\sqrt[3]{(\text{surface BV (km2)} \times \text{length of longest path of water (km))}}}{\sqrt{\sqrt{(\text{slope of longest path of water)}}}}$ (hour)

- The compactness index provides information on the shape of the WSH and gives an idea of its reactivity following a downpour. If KG is close to 1 then the WSH has an effusive form, and therefore the hydrological response is strong. If KG >1 then the WSH has an elongated shape and therefore the hydrological response of the WSH is weak.
- The density of inventoried hairs makes it possible to estimate the importance of the surface area at the interface with terrestrial environments, where potential functional hyporheic zones for self-purification can be found (Meyer et al., 2007).
- The density of the network of low points informs the density of thalwegs marked on the WSH. A high value reflects a favorable context for runoff.
- The average slope can give clues about the type of valley, more or less rugged, of the watershed. A steep slope can also correspond to greater runoff.

✓ The altitude at the crest and downstream,

✓ The specific height difference whose value obtained makes it possible to classify the relief of the WSH as follows (table 2).

Table 2: Classification of watershed relief (DGEAU, 2013)

Altitude difference	**<10**	**10-25**	**25-50**	**50-100**	**100-250**	**250-500**	**>500**
Class	R1	R2	R3	R4	R5	R6	R7
Relief	Very weak	Weak	Somewhat weak	Moderate	Somewhat strong	Strong	Very strong

b. Risk criteria and issues

The risk and issue criteria used in this study are land use and occupation criteria and wetland criteria.

➢ **Land use and occupancy criteria**

This involved determining the percentage of land by typology and the proportion of agricultural land (table 3).

Table 3: Land cover criteria

Criteria	Description/Formula
Percentage of soil per typology	$\%\text{OccSoil x} = \frac{\text{Typlogic surface area}}{\text{WSH surface area}} \times 100$
Rate of agricultural surface area	Rate of agricultural surface area = %(crops + temporary + and permanent grassland + market gardening and arboriculture)

➢ **Wetland criteria**

The density of wetlands at the WSH scale is given by the following formula:

Wetland density = (Wetland surface area)/ (WSH surface area) ×100 (Cirou, 2017).

Land use and occupancy profile

The study of land use in the catchment heads was carried out by remote sensing using Google Earth Engine through a supervised classification of each of the catchment heads using the ESA WorldCover classifier (Zanaga et al., 2022).

Statistical analysis

Using the database compiled with all the characterization criteria, exploratory analyses were carried out to group and differentiate the WSH according to their functioning and issues. A Principal Component Analysis (PCA) was carried out to explain the distribution of individuals according to the morphological characteristics described. A Hierarchical Ascending Classification (HAC) based on the principal component representation was used to distinguish groups of WSH with similar morphology. The morphology criteria were used to describe each of these modalities: the aim was to test whether, for each criterion, the mean of the modality differed from the population (ANOVA, 0.1% risk, under the assumption of homoscedasticity) (Husson et al., 2010; Lê et al., 2008).

Results

Inventory of watercourses

Figure 4 below illustrates the results of the inventory of streams in the municipality of Copargo. The Copargo hydrographic network is made up of the main watercourses, streams and headwaters.

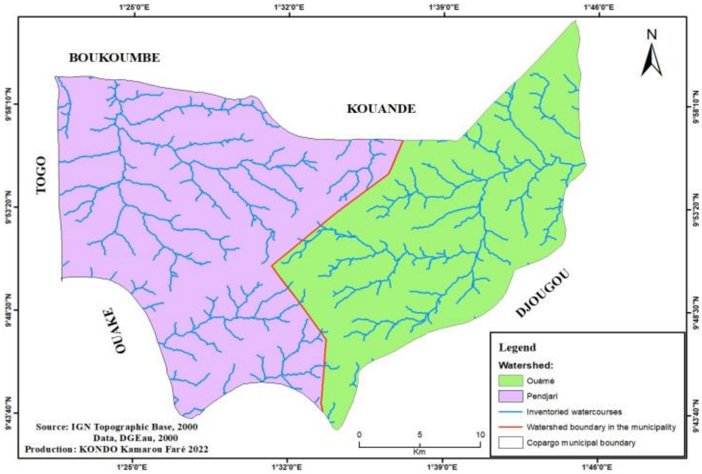

Figure 4: Hydrographic map of the Ouémé and Pendjari rivers in the commune of Copargo

Ordination of the hydrographic network and identification of catchment heads

The Strahler method applied to Copargo's hydrographic networks produced a hydrographic map with four (4) Strahler ranks (Figure 5). In the present study, the WSH identified have as their outlet the point of confluence between a watercourse of order 2 and one of order greater than 2.

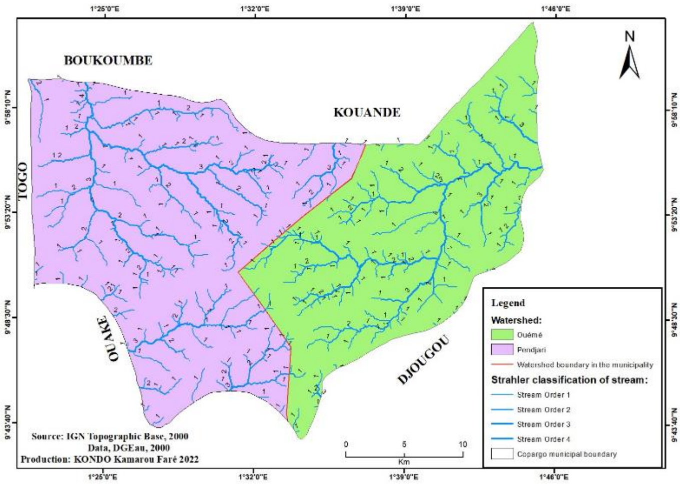

Figure 5: Ordering of the Copargo hydrographic network using the Strahler method

Delimitation obtained on the Ouémé and Pendjari rivers

The delimitation of the WSH in this study required watercourses of order 1 and 2. Strahler order 1 and 2 watercourses were therefore extracted. In total, twenty-five (25) WSH were counted in Copargo, including 11 WSH in the Ouémé watershed and 14 WSH in the Pendjari Watershed.

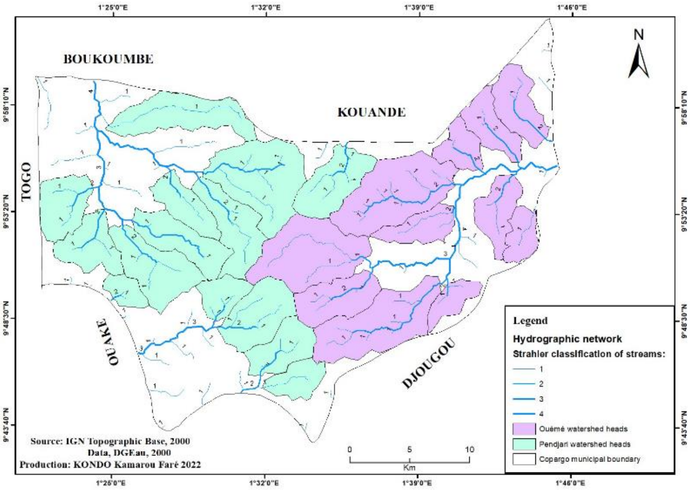

Figure 6: Demarcation of the Pendjari and Ouémé head watersheds in the commune of Copargo

Characteristics of the headwaters

Morphometric characteristics

- ✓ **Surface area**

At Copargo, the WSH of the Ouémé occupy a surface area of 259.4 km^2 or 69.4% of the surface area of the Ouémé catchment basin, with a minimum surface area of 9.3 km2 or 930 ha and a maximum surface area of 44.4 km^2 or 4440 ha; and those of the Pendjari occupy 293.7 km2 or 59.4% of the Pendjari watershed, with a minimum surface area of 7.1 km^2 or 710 ha and a maximum surface area of 42 km^2 or 42000 ha (Figure 7).

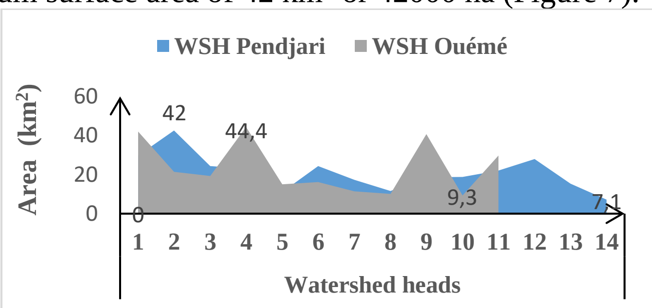

Figure 7: Surface area of the Pendjari and Ouémé watershed heads in Copargo

✓ **Perimeter**

The largest perimeter of the WSH delimited is 31 km. It varies between 14.8 and 31.7 km in the Ouémé watershed and between 11.3 and 31 km in the Pendjari watershed (Figure 8).

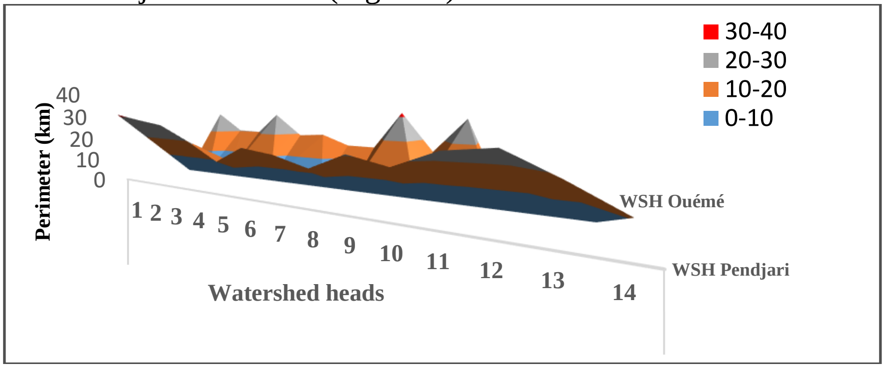

Figure 8: Perimeter of the Pendjari and Ouémé watershed heads in Copargo

✓ **Gravelius compactness index (KG)**

Each Copargo's WSH have the Gravelius compactness index greater than 1 and which varies from 1.2 to 1.5 in the Ouémé watershed and from 1.1 to 1.6 in the Pendjari watershed.

✓ **Linear of watercourses at the watershed heads**

In Copargo, the watercourses of Ouémé WSH are 132 km long, or 83.5% of the length of the Ouémé hydrographic network, and those of Pendjari WSH are 293.7 km long, or 59. 4% of the length of the Pendjari hydrographic network.

✓ **Average slope and area of watershed heads**

According to Figure 9 below, it is the WSH of small size (surface area) which have a higher average slope.

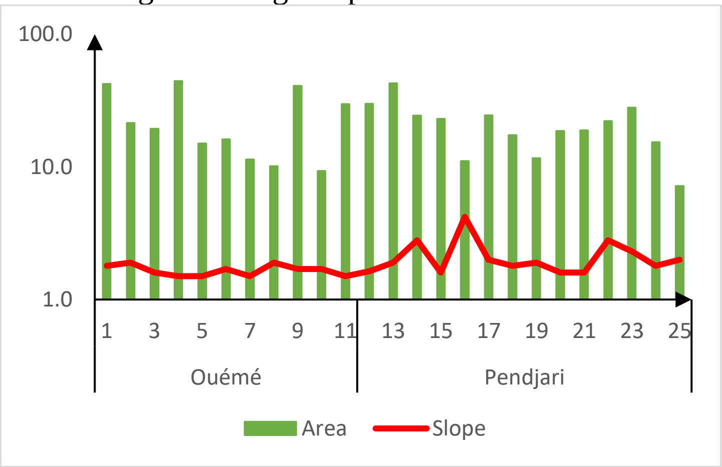

Figure 9: Area and average slope of watershed heads

- ✓ **Altitude at the crest and downstream**

The altitude at the crest and downstream of the WSH varies respectively from 432 to 543 m and from 375 to 453 m in the Ouémé watershed, from 431 to 644 m and from 342 to 432 m in the Pendjari watershed (Figure 10).

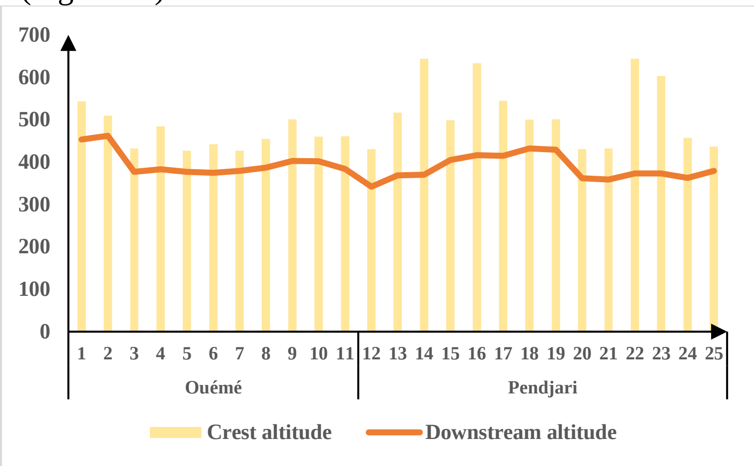

Figure 10: Elevation at the crest and downstream of the Copargo watershed heads

- ✓ **Specific height difference and average slope of the watershed heads**

The specific height difference of the WSH varies from 47 to 274 m across all the WSH. As for the average slope per WSH, it varies from 0.5% to 4.5% across all WSH (Figure 11). According to Figure 11, the variation in the specific height difference of the WSH is not a function of that of the average slope.

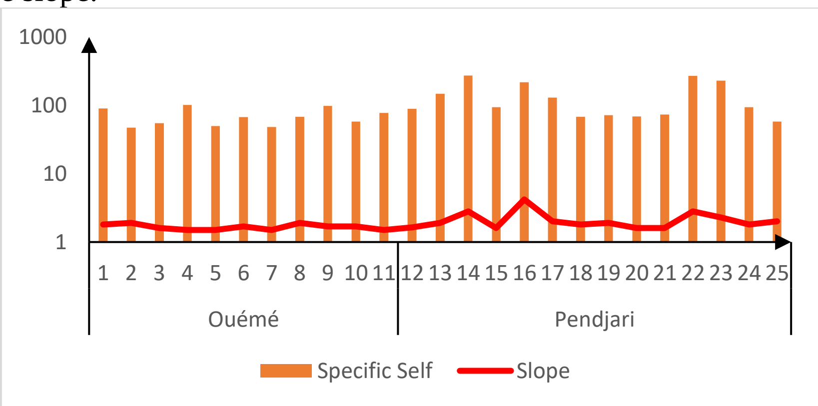

Figure 11: Specific height difference and average slope of the watershed heads

The values of the specific height difference made it possible to classify the relief of the WSH into four (4) classes (R3, R4, R5 and R6). Thus, 64% of Copargo's WSH have moderate relief (R4) compared to 8% which have strong relief (R6) and 20% have fairly strong relief (R5) compared to 8% which have fairly weak relief (R3) (Figure 12).

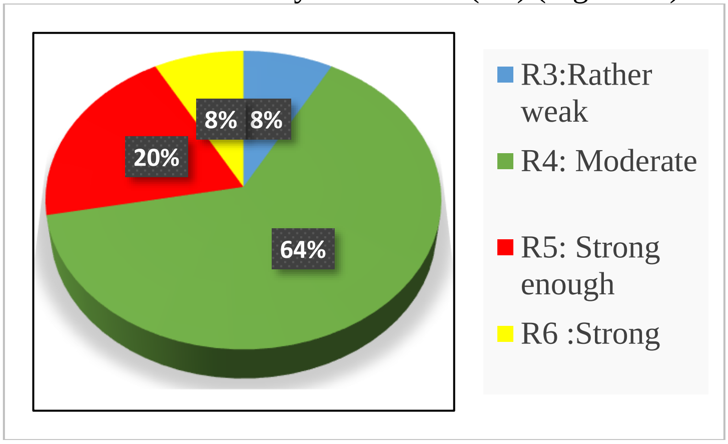

Figure 12: Relief classes of Copargo watershed heads

Specific elevation and size of watershed heads

Figure 13 shows us the variation in the specific height difference of the watershed heads as a function of their size. Thus, in the majority of cases the greatest differences in height are observed on large WSH.

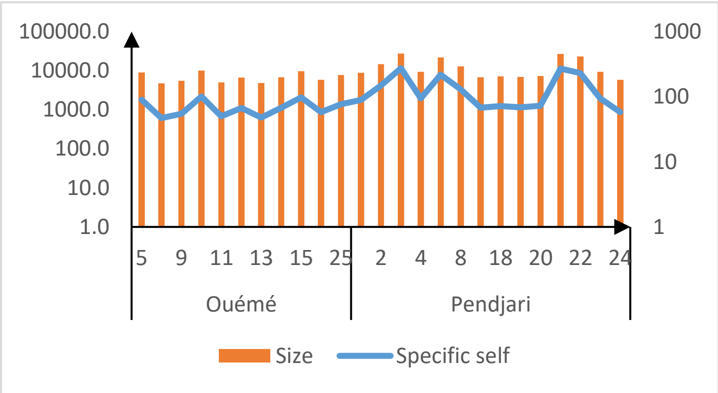

Figure 13: Size and specific elevation of watershed heads

Average morphometric characteristics of watershed heads by watershed

More numerous, the Pendjari WSH are also smaller with an average area of 21 km² +/- 9 km² compared to 23.6 km² +/- 13.4 km² on Ouémé. The numbers and variability of the two groups being comparable, the comparison of the WSH according to their basin of belonging is summarized in table 4 below.

Table 4: Geometric and morphometric characteristics of WSH by watershed in Copargo

	Ouémé watershed	**Pendjari watershed**
Number of watershed heads	11	14
Min-Max area	9.3 – 44.4 km^2	7.1 - 42 km^2
Average area	23.6 km^2	21 km^2
Total area	259.4 km^2 (69.4%)	293.7 km^2 (59.4%)
Compactness index (KG)	1.2 – 1.5	1.1 – 1.6
Average perimeter	22.3 km	21 km
Length of hydrographic network	132 km (83.5%)	198 (85.7%)

Relationship between the morphology of the watershed heads and their delimitation

The results of the PCA carried out using the morphology criteria of the WSH (figure 14 and 15) reveal low hair density for high compactness and large surface area of the WSH (first axis and first plane of the PCA). The second axis separating the WSH according to the slope and their difference in altitude shows a significant difference in altitude for high slopes. WSH with a high density of watercourses are marked by a steep slope. A correlation can be made between low point density and compactness. This correlation therefore indicates a strong presence of marked thalwegs on the elongated WSH slopes. Due to the low variability between individuals, WSH can be grouped into classes of homogeneous morphology.

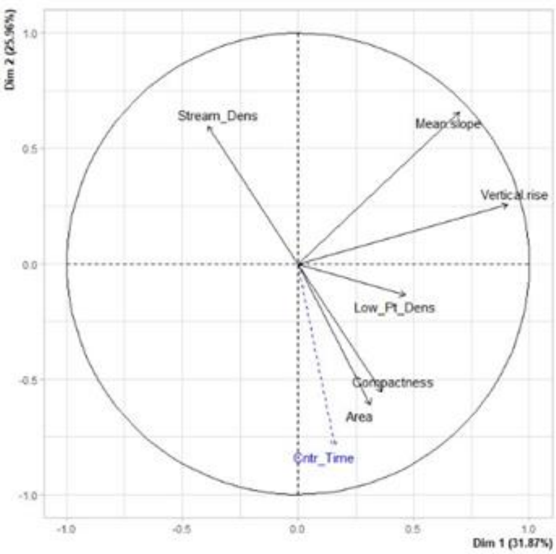

Figure 14: Graph of variables representing dimensions 1 and 2 of the PCA on the morphology of the WSH

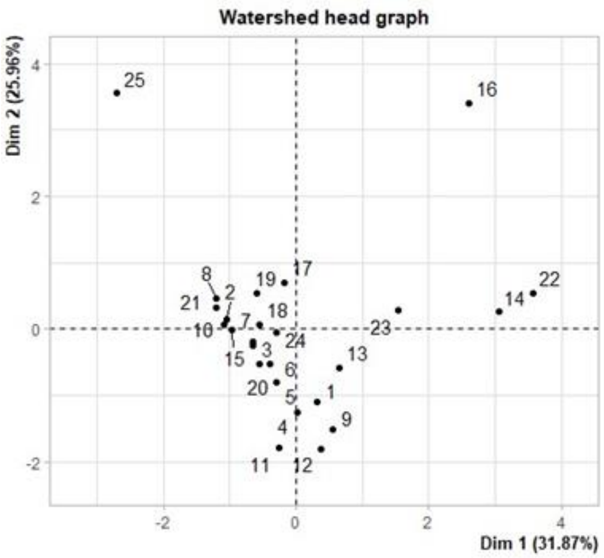

Figure 15: Graph of individuals representing dimensions 1 and 2 of the PCA on the morphology of the WSH

Grouping of watershed heads into homogeneous morphology classes

The classification carried out using the first five (5) dimensions of the PCA made it possible to divide 3 classes of homogeneous morphology each. Morphological class 1 (MC1) is made up only of TBVs from Ouémé (4%) while morphological classes 2 (MC2) and 3 (MC3) are each respectively made up of 32% of WSH from Ouémé followed by 48 % of WSH in Pendjari and 8% of WSH in Ouémé and those in Pendjari (table 5).

Table 5: Morphology classes of WSH according to their watershed of belonging

Morphological class	Watershed	
	Ouémé	Pendjari
MC1	4%	0%
MC2	32%	48%
MC3	8%	8%

The statistical trends characterizing each of the classes obtained from the point of view of morphological criteria are summarized in table 6. For each morphological class, the average values obtained are indicated and when the latter are not significantly different from the average of all WSH, NS (Not Significant) is indicated.

Table 6: Description of morphology classes by morphology criteria.

		Area	Compactness	Stream_Dens	Low_Pt_Dens	Cntr_Time	Mean slope	Vertical rise
MC1	Mean	2969,68	1,53	2,85	1,18	0,50	0,015	77,00
	σ	0,00	0,00	0,00	0,00	0,00	0,000	0,00
MC2	Mean	2304,06	1,30	6,24	2,25	0,42	0,019	NS
	σ	868,13	0,10	2,42	0,50	0,11	0,004	51,03
MC3	Mean	1564,86	1,34	4,56	1,38	0,33	0,019	112,50
	σ	612,01	0,01	0,28	0,34	0,07	0,002	58,75
Total	**Mean**	**2212,42**	**1,32**	**5,84**	**2,07**	**0,42**	**0,019**	**105,84**
	σ	859,59	0,09	2,00	0,55	0,10	**0,004**	50,80

The information contained in the different morphology classes provided by tables 5 and 6 is summarized in table 7 below.

Table 7: Summary description of WSH morphology.

Class	Description
MC1	Elongated watershed head profile with low mean slope and gradient and high time of concentration
MC2	Watershed head profile with high gradient, high stream density and presence of talweg
MC3	Small watershed head profile, not very elongated, low time of concentration, high gradient and gradient difference

Environmental characteristics of the watershed heads

Direct observation and on-site analysis in the Copargo watershed heads show several aspects including the existence in the watershed heads of various crops ranging from corn fields to cotton fields through yam fields, beans, soybeans, etc. Fallowed agricultural areas are also found in TBV. Water works (wells and water boreholes) are found in certain places in the TBV. The non-cultivated areas in the TBV are sufficiently forested. There are crops grown near watercourses, including corn, soya, millet and sorghum. And in the lowlands and in certain humid areas, we note rice crops. Several types of plant formations are found in the area. There are trees, shrubs, the tree-shrub-herbaceous association, and herbaceous plants.

Classification of watershed heads according to their issues

a. Issues specific to morphological classes

The different morphological classes are characterized by greater burial risks. Class M1 is characterized by more or less significant risks of vertical transfer from the point of view of concentration time and by an agricultural crop rotation. Class M2 is distinguished, conversely, by a greater density of wetlands in terms of the presence of thalwegs, a lower risk of burial and a lower urbanization dynamic. Finally, the M3 class stands out from the others by forest context and horizontal transfer risks from the point of view of their short concentration time.

b. Land use profile and associated issues

The distribution of the percentages of coverage of the main land uses is illustrated in three classes in Figure 15. According to these histograms, we find a high proportion of agricultural areas in the majority of WSH (12) and some WSH having a low proportion. The trend is opposite for forest areas (class 3). Case 2 brings together few watershed heads with a fairly high proportion of urbanized surface area and this rarely exceeds 20% of the total surface area of the WSH (figure 16).

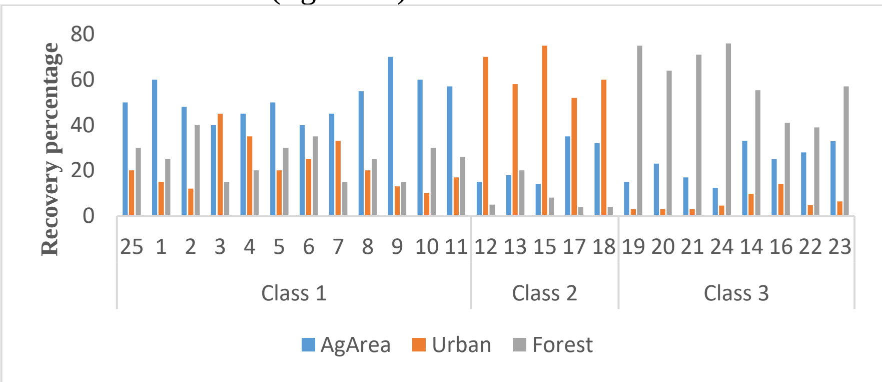

Figure 16 : Distribution of the percentages of coverage of the main land uses of the watershed heads

The PCA was carried out on all WSH according to these three types of land use.

According to the dendrogram, it was chosen to carry out 3 classes. The variance explained by the classification is approximately 80%. We were thus able to separate WSH according to their majority profile (agricultural, urban and forestry) (table 8).

Table 8: Land use profiles obtained and associated land use percentages.

	Class 1 :Ag		Class 2 :Ur		Class 3: Fr		Total	
Profile	**Agricultural**		**Urban**		**Forestry**			
NB	12		5		8		25	
	Mean	**σ**	**Mean**	**σ**	**Mean**	**σ**	**Mean**	**σ**
Agri	51,66	7,27	22,8	8,56	23,27	6,45	32,58	0,75
Urb	22,08	8,27	63	7,6	6,05	3,01	30,37	2,19
Forest	23,28	6,45	6,05	3,01	59,79	11,71	31,16	2,75

Discussion

Delimitation obtained and morphometric characteristics

The commune of Copargo is shared between two watersheds: the Ouémé watershed and the Pendjari watershed. In Copargo, the headwaters occupy 69.4% of the surface area of the Ouémé basin and 59.4% of that of the Pendjari. Their watercourses represent respectively 83.5% and 85.7% of the length of their hydrographic network from Ouémé and Pendjari to

Copargo. These results are in agreement with data from the literature where several studies have shown that the drainage network of the watershed heads represented more than two thirds of the total watershed network (Choucard, 2011; Marchand, 2018). According to certain authors who have also worked on the heads of watersheds, they represent 60 to 85% of watersheds (Alban, 2014); for others, they represent 50% of the surface area of their basin and their watercourses make up 48% of the length of the hydrographic network (Choucard, 2011). The more or less observed differences in these data can be explained by the fact that the definition of a WSH diverges depending on the regions of the world and depending on approaches. Indeed, the slope criterion strongly impacts the extent and number of watercourses of a WSH. Taking the latter into account can significantly reduce the extent or surface area of a WSH. Likewise, whether or not watercourses of rank greater than 2 are taken into account has a strong impact on the characteristics of a WSH.

In the United States, it is assumed that the surface area of a watershed head does not exceed 2 km² and that the minor bed is less than 1 m wide. In Japan they correspond to the sectors upstream of the dominant sedimentation zone and in most of certain countries, it is defined on the basis of Strahler's ordination theory as in Benin and whose slope criterion can be taken into account or not depending on the local context and the objectives of the delimitation. From these findings, it appears that the area occupied by WSH in a watershed depends on the definition given to the WSH and the identification approach. The results obtained in one country cannot constitute a standard to be respected elsewhere because it is difficult to generalize the results and transpose them to any watershed.

The Gravelius compactness index of each of Copargo's WSH greater than one (1) shows that they have more or less elongated to elongated shapes. The elongated shape of these WSH will thus influence their hydrological response. Indeed following a downpour, the water will take longer on a WSH having an elongated shape before reaching the outlet. Therefore on these WSH, the hydrological response will be weak. This weak hydrological response favors water infiltration.

The variation of most of the average slopes of WSH is not a function of their specific height difference. This observation is explained by the elongated shape of the WSH.

According to the specific elevation differences obtained, Copargo's WSH are divided into four relief classes ranging from fairly low relief classes to strong relief classes.

From the point of view of physical and geographical characteristics, the results obtained from the delimitation are similar to the orders of magnitude found in the literature review, whether for the lengths of watercourses or for the surfaces concerned (Alban, 2014; Clarke et al., 2008). The differences in terms of surface area and number of WSH between Ouémé and Pendjari can be explained by the differences in facies that exist between the 2 watersheds. Indeed, thanks to the results observed on the morphology classes, we can notice that the TBVs of classes M1 and M2 (classes with the largest WSH) are more composed of WSH from Ouémé while those of classes M3 and M5 (classes with the smallest TBV and the steepest slopes) are mainly represented in the Pendjari BV.

Land use and associated issues

The issue at the head of the watershed is reflected in changes in land occupation and use. Land use is an important component in understanding the functioning and spatial organization of a watershed, and the types of pressures that are or will be exerted there. It has a significant impact on variations in water quality and can also play a more important role than the climate or the morphology of the watershed on this point (Dodds & Oakes, 2008). The high proportions of agricultural area on the Copargo WSH demonstrate the extent of anthropogenic pressure which has strong repercussions on the water and soil resources of the said municipality. Indeed, agriculture is a source of diffuse pollution which a priori affects the first concentric flows (Kagan, 2017). From the source, the nitrate concentration is noted. In France for example, 60% of the nitrate load found in order 3 rivers comes from order 1 rivers (LE Bihan, 2009). The alteration of the basin heads has strong repercussions on the overall functioning of the watershed because the negative effects are reflected and amplified downstream.

Changing land use can indeed cause significant damage to the morphology of small watercourses (Roy & Sahu, 2016). The watersheds heads constitute environments that are often very vulnerable to pressure and not very resilient. It is their small size which accentuates the effect of pressure and gives them poor recovery capacities.

The redistribution of all WSH according to their land use profile made it possible to see that the majority of them will be subject to agricultural problems, especially since they occupy 60 to 70% of Copargo's watersheds. And from these properties, it is possible to associate with some of these classes a vulnerability linked to specific issues: a) in terms of ecological continuity, and more generally in the face of issues linked to the impact of bodies of water, b) in terms of diffuse pollution issues, class M2 which brings together the highest number of WSH (8) could be the subject of more particular attention. Indeed, according to the description established based on the characterization criteria, these would be agricultural landscapes at risk of being more degraded, of being affected by more intensive practices (very high proportion of crops).

Taking into account watershed heads in the future

The functional interest and strong pressures of WSH watercourses and wetlands make the need to take greater account of the watershed heads in future decisions legitimate. If the concept of WSH slope has become widespread, it is because there is a desire to adopt a holistic vision extended to their entire catchment area, to the anthropogenic practices and developments found there. . It is also the need to adopt an integrating vision, combining multiple issues (biodiversity, diffuse pollution, ecological continuity, morphology, etc.) in order to make coherent management choices.

In terms of surface area, WSH cover the majority of a territory. Therefore, before adopting decisions on a global scale, it is necessary to increase awareness-raising efforts among managers, users, elected officials and the general public. The first step will be to make known the specificities of these areas, their role, their state of degradation, and the scale of the surfaces concerned. This, with the aim of changing views on the interest that must be taken in safeguarding their waterways and wetlands and showing that despite their reduced size, they should not be considered insignificant. By improving knowledge of the state of these WSH, the scale of certain issues could be reconsidered and their problems could evolve. Beyond planning, work on WSH must also be considered operationally. The cartographic representation of characterization data can be a support that will help managers adopt an integrated approach in diagnosing WSH.

Conclusion

This study made it possible to identify and delimit the watershed heads of the municipality of Copargo then to characterize them according to the criteria of morphology and land use. To provide knowledge on the issues and functioning of these little-known areas, cartographic tools are used and have made it possible to delimit them and provide information on some of their characteristics. The watershed heads thus demarcated are the watersheds of Strahler’s order 1 and 2 watercourses. Thus, for rivers such as the Ouémé and the Pendjari, a watershed head extends over a surface or area delimited by the watersheds of Strahler's order 1 and 2 watercourses. In Copargo, twenty-five (25) watershed heads have been demarcated, including 14 in the Pendjari watershed and 11 in the Ouémé watershed. They cover more than 70% of the territory and are all more or less elongated in shape and characterized by steep slopes. The watercourses at the head of the watershed make up between 83.5% and 85.7% of the length of the Ouémé Pendjari hydrographic network respectively. The majority of Copargo watershed heads are characterized by a high proportion of agricultural area with average forest cover and a low proportion of urbanized area. The high proportion of agricultural land is not without consequences on water and soil resources in these areas where the slopes are more or less high and exposes water resources to diffuse pollution. The specificities of the watershed heads, and in particular their link with the rest of the hydrographic network, must lead managers to take an interest in them in order to better manage these aquatic environments. Thus, the database provided by this study constitutes a reference for decision-makers and in the future, it is necessary to continue to acquire knowledge on these areas where the state of aquatic environments is less known that this either thanks to available databases or thanks to field diagnostics. This will make it possible to support a transition in morals towards a vision which more considers the role of the heads of the watershed and their current state. In view of the results obtained, it would be desirable for research to continue to better present the situation of these Watershed Heads with a view to guiding future actions to be undertaken for their appreciable protection, but above all to fairly easily identify the priority areas of 'intervention. It is in this perspective that after this characterization study based on the criteria of morphology and land use, a study will be carried out on the physico-chemical and bacteriological characterization of water resources in these watershed heads in the commune of Copargo.

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Data Availability: All data are included in the content of the paper.

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