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RESEARCH ARTICLE

ANTHROPOGENIC PRESSURE IN RURAL AREAS: DIAGNOSIS AND MAPPING OF POTENTIAL POLLUTION SOURCES AFFECTING WATER RESOURCESIN THE WATERSHED HEADS OF THE OUÉMÉ AND PENDJARI RIVERS IN THE COMMUNE OF COPARGO (NORTH-WEST BENIN)

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Abstract

Critical in assessing the quality and quantity of watercourses, headwaters of watersheds have been under anthropogenic pressure for several years, which has had negative impacts on water resources and soils. This study aims to assess the state of anthropogenic activities within the headwaters of the Copargo watersheds, followed by identifying and mapping potential sources of pollution to the water resources of the Ouémé and Pendjari river headwaters in the Copargo municipality. To achieve this, data were collected through surveys, interviews, direct field observations, and remote sensing using Google Earth Engine. The results indicate that agriculture is the main activity, practiced by 90.84% of the population. Livestock farming (8.9%) and wood exploitation (7.2%) follow. The surveys reveal that the land is rarely left fallow, indicating overexploitation. The average duration of land cultivation during an agricultural season is 7.77 months. The agricultural inputs used include chemical fertilizers (NPK fertilizers and urea) and pesticides (herbicides and insecticides). On average, 120.5 kg of NPK fertilizer, 63 kg of urea, and 6.99 liters of pesticides are used per season per farmer. 2% of the producers attribute soil depletion to the use of agricultural inputs. The results of this study show that the potential sources of pollution in the study area remain anthropogenic activities, particularly agriculture, through the increased use of chemical fertilizers and pesticides (herbicides, insecticides). The absence of industrial units in the study area eliminates any risk of pollution from factories. Given the activities carried out in the area, this study will be followed by a physicochemical characterization of water resources and soils to evaluate their physicochemical and chemical quality.

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Introduction:-

The pollution of the environment in general, and that of aquatic ecosystems in particular, has increasingly become a growing concern in today's world. The condition of terrestrial aquatic environments has progressively deteriorated in terms of physical, chemical, biological, or hydromorphological quality (Reyjol et al., 2013). The primary cause of this degradation is the profound changes brought about by human activity. Source areas, which should be teeming with watercourses in good ecological condition, are now victims of anthropogenic activities, raising significant concerns about their integrity. The headwaters of watersheds, which are the upstream and source zones of watercourses, serve as the interface between terrestrial and aquatic environments. These areas have high potential for ecosystem services and are of interest to the local population for various purposes. These zones, delineated by Strahler's 1st and 2nd order streams and having a slope greater than 1% depending on the context, are essential territories for the functioning of the water cycle (Cirou, 2017; Kagan, 2017). They represent a major challenge for water management because the integrity of these areas is crucial for the entire functioning of downstream rivers, both in quantitative and qualitative aspects. These zones are responsible for 60% of the water quality in higher-order streams(Kagan, 2017; Maman, 2007)**.** But in recent years, headwaters of watersheds and their associated wetlands have been under anthropogenic pressures, primarily characterized by the expansion of agricultural areas, followed by the development of the local wood industry, urbanization dynamics, and other subsistence activities in rural areas. The activities undertaken in these zones can have significant repercussions on water and soil resources, highlighting the need for a special focus on these headwater hydrosystems. Like most developing countries, Benin is a nation where the agricultural sector is rapidly growing, engaging the majority of the active population (approximately 70%) and contributing about 33.2% to the Gross Domestic Product (GDP) (INSAE, 2008). This prominent position that agriculture holds in the economic sector has consequences for the environment, particularly on arable land and water resources, with many of these ecosystems undergoing degradation due to increased anthropogenic activities (Agbanou, 2018).

Copargo, a rural area in Northwestern Benin, is located at the headwaters of the Ouémé and Pendjari rivers, serving as the source zones for these rivers within its jurisdiction. The wetlands provided by these rivers make Copargo an attractive rural area, where anthropogenic pressure increases each year in zones that should remain free from any activity. The depletion of lands in the valleys due to overexploitation, combined with the effects of climate change, forces the population to seek new arable lands. Consequently, due to a lack of awareness of their existence and/or importance, the headwaters of watersheds, which are drained by the first watercourses of the hydrographic networks, are increasingly being exploited to address these challenges. However, these areas are the foundations of the watershed (Saunders et al., 2002), and therefore are essential environments to consider in the management of water and soil resources. Sustainable and integrated water resource management inherently requires upstream work, which involves diagnosing the various threats that water and soil resources face or may face. This diagnosis forms the indispensable foundation upon which various actions, management plans, and development schemes must be based. What activities and associated threats might compromise the integrity of the headwaters of Copargo's watersheds, given the observed changes in land use and occupation in recent years?

In light of all the above, this study aims to diagnose the different anthropogenic pressures that may be potential sources of pollution in the headwaters of the Ouémé and Pendjari rivers within the Copargo municipality.

Materials and Methods:-

Study area

The present study took place in the municipality of Copargo. Bordered to the northeast by Kouandé, to the northwest by Boukombé, to the southwest by Ouaké, to the southeast by Djougou and to the west by the Republic of Togo (figure 1). The municipality of Copargo lies between 9°40'50" and 10°4'31" north latitude and between 1°20' and 1°45' east longitude. It covers an area of 876 km^2. The climate is Sudanese-Guinean, tempered by the Atacorian relief. The dry season is marked by the harmattan, a cool, dry wind. There are two seasons in the study area: a dry season running from mid-October to mid-April, and a rainy season covering the period from mid-April to mid-October. Rainfall is unevenly distributed throughout the year, ranging from 800 mm to 1300 mm (Gnonhoue, 2020; Mathieu & Bernard, 2020). August and September are the wettest months of the year (Mathieu & Bernard, 2020). The highest average monthly maximum temperature is observed in March, at around 36°C, while the lowest average monthly minimum is 32°C in August. The area is characterized by vegetation consisting of wooded and grassy savannahs. Shea, néré, mango and caïlcédrat trees are also found throughout. As for forests, there are gallery forests and a classified forest with a surface area of 1,091 ha (République du Bénin, 2019). The relief is dominated by a mountainous area: the Atacora chain, with its highest point reaching 654 m at Tanéka-Koko located to the west of the municipality. The rest of the territory is made up of vast wooded plains alternating with valleys and basins that are often humid and favorable to crops. Wetlands are concentrated in the north-western part of the municipality, at altitudes between 329 and 396 m (Mathieu & Bernard, 2020). In terms of hydrography, Copargo is crossed and watered by several rivers, the main ones being the Ouémé and Pendjari, which provide two sub-watersheds. The Pendjari has a seasonal regime, while the Ouémé flows permanently southwards into the Atlantic Ocean (République du Bénin, 2019). The soil types encountered are unconcretioned and indurated leached tropical ferruginous soils covering mainly the summits and slopes, light soils with low water retention capacity which are encountered mainly in the arrondissements of Anandana and Singré (Gnonhoue, 2020; Mathieu & Bernard, 2020). Geologically, the formations encountered are the Atacorian (extending into Togo and Ghana), the first outcrops of the Dahomean or Benino-Togolese basement formed of very ancient eruptive rocks, the series formed of quartzites, schists, micaschists and the deposits of the Buem series (UNEP/GEF/Volta/NR Benin, 2010). The water resources exploited in Copargo consist of both groundwater and surface water. The economy of the municipality is mainly based on agriculture, fishing, hunting, trade and manufacturing. Agriculture is the main activity in the commune, employing over 90% of the working population (INSAE, 2008).

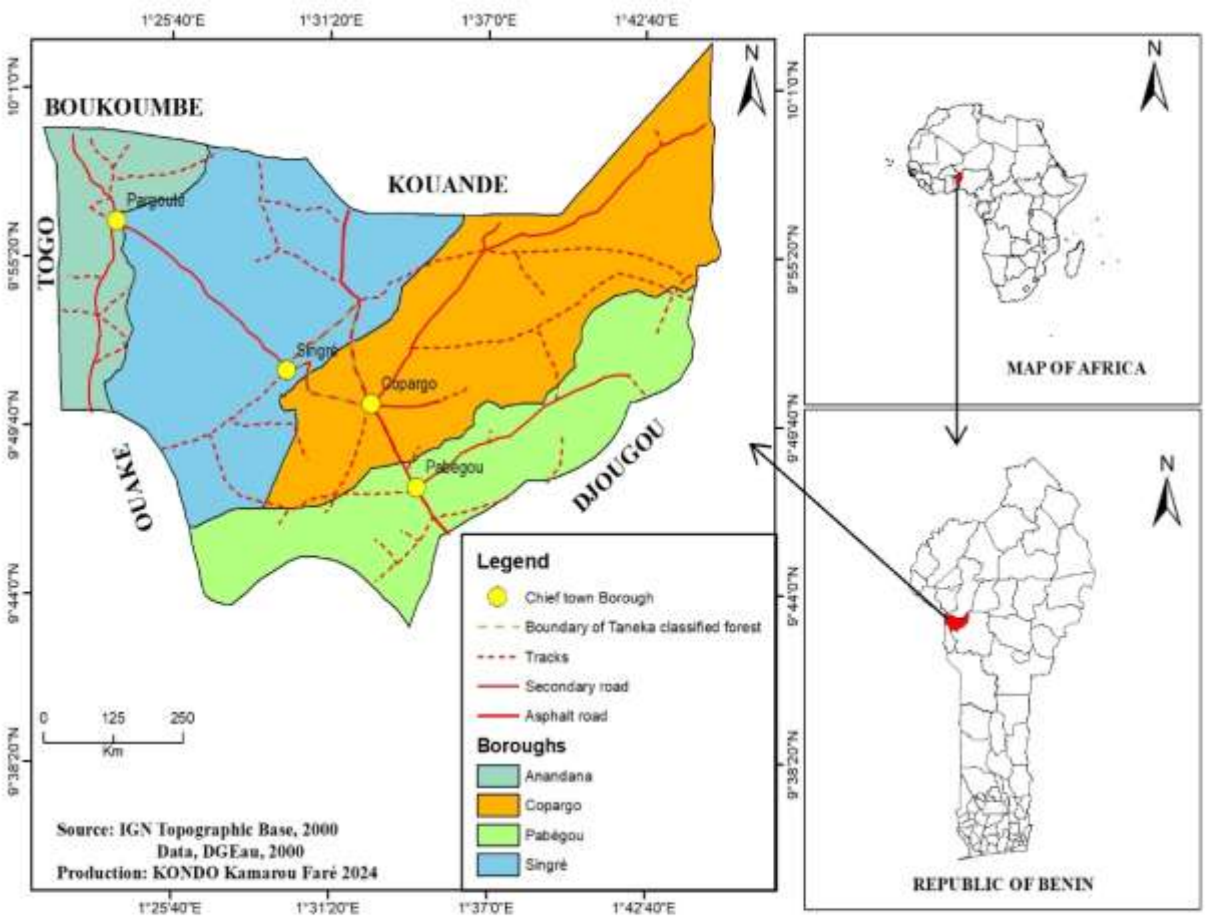

Figure 1:- Geographical location of the study area: municipality of Copargo.

Anthropogenic pressures and diagnosis of potential sources of pollution

Field survey studies related to anthropogenic activities and agricultural practices, followed by direct observations on the ground combined with studies of land use dynamics through satellite imagery of the study area, have provided an overview of the current situation in the municipality of Copargo regarding pollution or potential pollution risks in the headwaters of the Ouémé and Pendjari rivers.

Field surveys

Study population and sampling

The study covered the population of the commune of Copargo and was based on a probabilistic and representative sample of this population spread over the four (4) arrondissements of the commune of Copargo.

Sampling Method:-

Sample size

The size of the sample surveyed was calculated using the statistical software Epiinfo version 7.2.1.0 with its STATCALC population survey option. Given that no previous study had addressed this specific issue in the study area, the estimated standard prevalence was set at 50%, on a 95% confidence interval, with an acceptable margin of error of 5%. Based on the total population of the Copargo commune, estimated at 71,000 (RGPH 4, 2013), the sample size obtained after calculation was 382. 382 people representative of the Copargo commune werethereforesurveyed.

Sampling techniques

Reasoned choice and probability sampling techniques were used to identify the people surveyed. For the number of people surveyed per district and per village, the density criterion per district and per village was used, based on data from the RGPH4 2013.

Collection technique and data collection

The survey of the population was carried out in each village of the commune of Copargo through field visits during which any person, whether or not they were in the process of carrying out their activity and who agreed to give us some of their time, was surveyed. The type of person to be interviewed was left up to the interviewer. However, the interviewer was guided by the need to ensure that the survey area was representative. Data was therefore collected using survey questionnaires (survey sheets), the observation grid and the interview guide. The survey questionnaires were administered to all respondents in the study area. The data collection method used was the interview, and more specifically the interview by interviewer, i.e. face-to-face (Figure 2), as it allowed the highest response rate to the greatest number of questions. Direct observation of the environment in the study area was carried out using the observation grid, with each interviewer rigorously completing the grid in his or her area. Data on agricultural inputs were obtained from the structures in charge of agriculture using an interview guide.

Figure 2:- View of the face-to-face interview between the interviewers and the farmers in their fields

Structure of the survey questionnaire

The different areas of interest in the questionnaires drawn up are: (1) the activities carried out by the populations in the headwaters of the watersheds of the Copargo commune, (2) the types of crops grown, the use of agricultural inputs and their consequences, (3) knowledge of the concept of pollution, (4) the dynamics of land use, (5) the population's perception of the activities that degrade the plant cover, (6) the methods of land acquisition and development.

Observation grid (direct observation in the field)

The different areas of interest in the observation grid are: the environment of the study area, the infrastructures, the activities carried out (housing, crops, pastures, etc.), the uses of water, the distances of housing and fields from watercourses, and so on.

Interview guide

The purpose of the interview guide was to obtain information and data from the structures in charge of agriculture on the types and quantities of agricultural inputs legally distributed during each crop year, and the quantities of agricultural inputs required for a one-hectare crop.

Data collection criteria

Inclusion criteria

Any person, working or not, living in the commune of Copargo during our study period and having voluntarily agreed to answer our survey questionnaire was included in the study.

Non-inclusion criteria

Anyone living in the commune of Copargo and not practising or having any activity in our study area was not included.

Exclusion criteria

Questionnaires that were incorrectly completed and/or did not contain sufficient information to allow the data to be processed were excluded.

Conduct of the survey

The first stage was to recruit data collectors on the basis of a number of criteria (knowing how to speak the dialect of the study area, knowing how to read and speak French, mastery of geolocation software on android mobiles (UTM Géomap available on Google Playstor)). Five (5) candidates were trained on 21 September 2022. Next, a timetable detailing the data collection schedule in each of the villages in the four (4) arrondissements of the Copargo commune was drawn up. The commune was subdivided into four zones, representing the four arrondissements, with a timetable for the interviewers' visits. First of all, a visit was made to the mayor of the Copargo commune. The aim was to present the authorisation note for the research, the objectives of the study, the schedule for visits to the neighbourhoods and to obtain his approval to carry out activities on his territory. The survey itself took place from 22 to 29 September 2022.

The five (5) interviewers collected data simultaneously in the same district each day, sharing out the villages in the district concerned. At the end of each day, the interviewers met under the supervision of the supervisor to validate the data collected.

Analysis and processing of field survey data

Once the survey questionnaires had been opened manually, the data collected was compiled and processed using Epiinfo 7.2.1.0 software. Excel 2013 was used to produce the tables and graphs.

Supervised classification: land use map

The land cover map was produced following supervised classification by remote sensing using the Google Earth Engine on Landsat TM and Landsat 8 OLI/TIR images.

Identification and mapping of potential sources of pollution

In order to map potential sources of pollution, these sources had to be identified in the study area. These sources were meticulously identified during the survey and field observation studies, during which the coordinates of the sources of pollution at the head of the watersheds were recorded using a GPS and a digital camera. The various coordinates identified were then projected onto a map of the municipality of Copargo using ArcGis software to obtain a map showing the distribution of the various potential sources of pollution in the study area.

Results:-

Field surveys

Socio-professionalcategories by arrondissement

During the survey period, 392 people in the four (4) districts of Copargo agreed to answer the questionnaire, and 382 answered correctly (Table 1). We have therefore retained the latter, which corresponds to the sample size calculated on the basis of the 95% confidence interval. A total of 51 people were surveyed in the Anandana district, 165 people in the Copargo district, 63 people in the Pabégou district and 103 people in the Singré district.

Table 1:- Breakdown of socio-professional categories surveyed by arrondissement.

	Arrondissement	Farmers	Breeders	Wood operator	Total surveyed population
Copargo	Anandana	50	1	0	51
	Copargo	132	32	1	165
	Pabégou	63	0	0	63
	Singré	102	1	0	103
Total		347	34	1	382

Socio-demographic characteristics (age, gender, level of education and occupation)

The average age of respondents was 49.77 ± 7.50 years, with extremes of 25 and 70 years. The most common age group was [45-55], accounting for 52.89% of respondents (Figure 3). In terms of gender, the majority of respondents (376), or 98%, were male, compared with 2% who were female.

The majority of the population (210), or 54.97%, had not attended school, compared with 1.57% (6) who had a higher level of education. 34.8% (133) hadprimaryeducation, 8.38% (32) secondaryeducation and 0.26% (1) secondaryeducation (Figure 4).

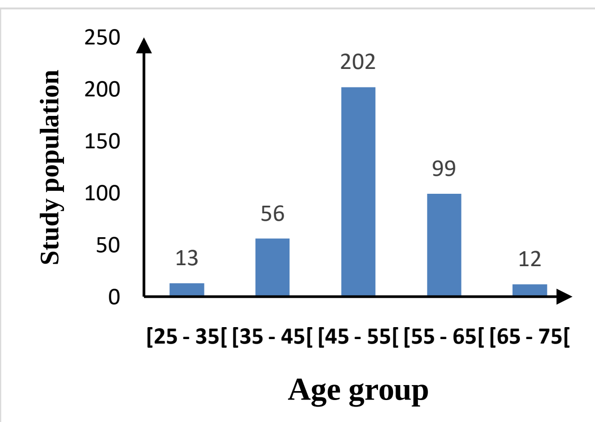

Figure 3:- Breakdown of study population by age group.

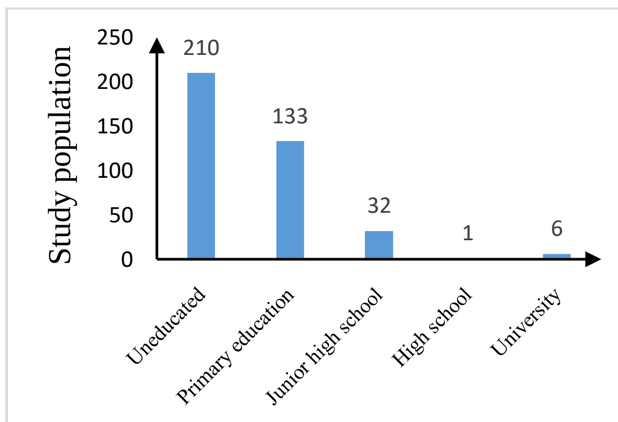

Figure 4:- Breakdown of study population by profession.

In terms of occupation, the majority of the population surveyed (90.8%) were farmers, followed by livestock farmers (8.9%) and loggers (0.3%) (Figure 5).

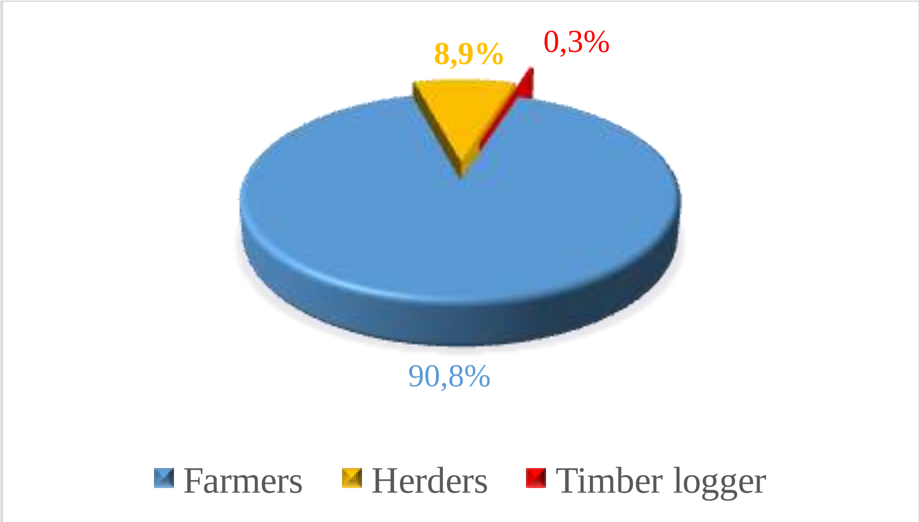

Figure 5:- Breakdown of study population by profession.

Cropping systems and use of agricultural inputs

The cropping systems practised at Copargo range from monoculture to mixed cropping. In the majority of cases (20%), cotton is grown as a monoculture (Figure 6). Alternate cropping in the area involves a change in land use, with cowpeas followed by maize, millet or sorghum, or groundnuts followed by maize, millet or sorghum, or groundnuts or cowpeas followed by soya. In most cases, the mixed system involves yamsgrown (Figure 7) in association with millet or sorghum on the one hand, and groundnuts or soya in association with maize (Figure 8) or millet and sorghum on the other. Land is rarely left fallow. For the agricultural activities practised, the average length of time the land is cultivated during a crop year is 7.77 ± 3.1975 months.


Figure 6:- Cotton fields at Singré.


Figure 7:- Yam fields at Afio.


Figure 8:- Maize fields in Copargo.

Use and types of agricultural inputs

In Copargo, all farmers use agricultural inputs. Figure 9 below shows that the types of agricultural inputs used are chemical fertilisers and pesticides. According to the crops grown, 57.64% of farmers use chemical fertilisers and pesticides, compared with 27.95% who use only chemical fertilisers and 14.41% who use only pesticides. According to farmers, chemical fertilisers are used to enrich the soil and increase yields of the following crops: maize, cotton, yams and rice.

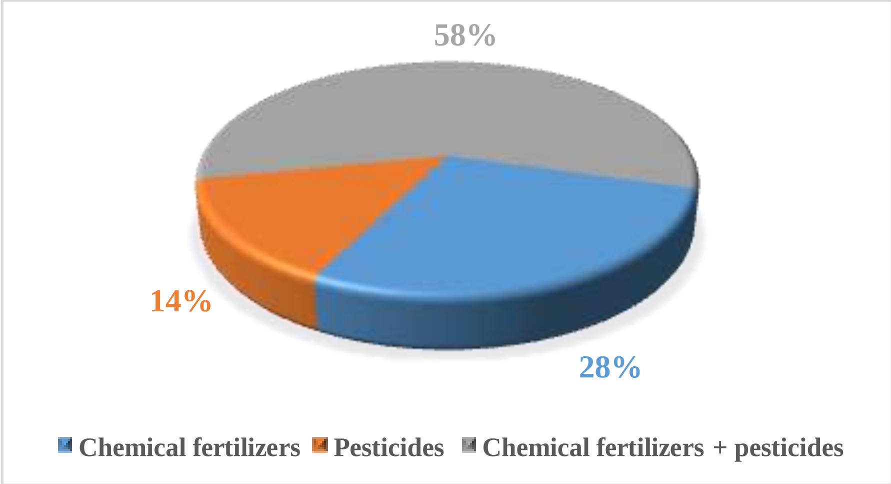

Figure 9:- Distribution of types of agricultural inputs used in the commune, according to producers.

Types of fertiliser used

Figure 10 below illustrates the types of chemical fertiliser used by growers in the study area. According to this figure, 43% of farmers use NPK (15;15;15) + urea (46%N), followed by 39% who use NPK (15;15;15) + urea (46%N) + NPK cotton and 18% who use only NPK cotton.

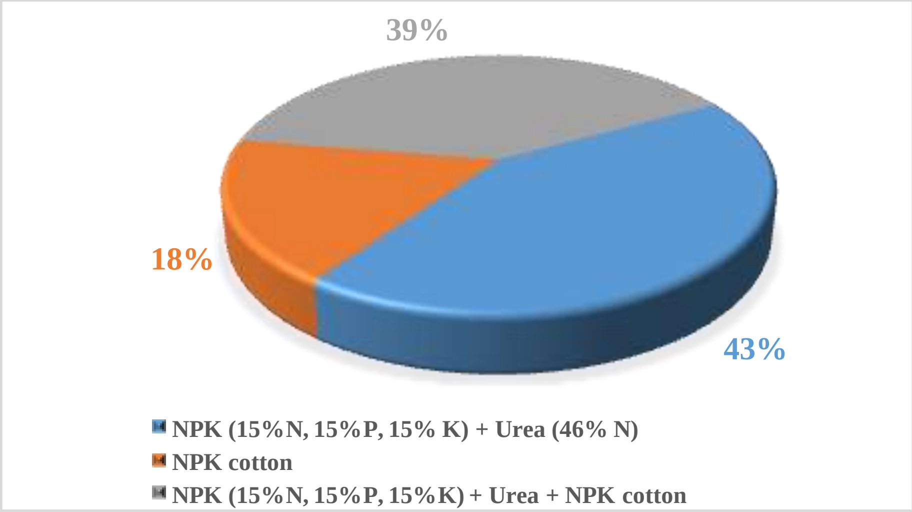

Figure 10:-Distribution of types of chemical fertiliser used in the study area according to producers.

The types of pesticide used in the study area are insecticides and herbicides. According to the producers, insecticides are used to control harmful insects. They are used to treat crops and preserve cereals. Herbicides are used to weed uncultivated areas (land clearing) and to destroy weeds in fields of various crops. For example, 100% of farmers use insecticides to treat cotton crops. 9% use them to treat cowpea and market garden crops, while 10% use them to preserve cereals (Figure 12). As for herbicides, 97% of growers use them for clearing and destroying weeds in the fields. According to farmers, herbicides are used to compensate for the lack of manoeuvrability and to increase the surface area of agricultural plots in record time (Figure 11).

Figure 11:- Agricultural plot stripped bare with herbicide.

Figure 12:- Treatment of the crop by spraying with insecticide.

The insecticides used range from DDT and heptachlor to lindane, dieldrin and endosulfan, depending on the respondent. The herbicides used are also made up of a range and variety of names found on the market, the common active ingredient being glyphosate. These herbicides include cotochem, ganorsate, siakosate, force up, une minute, fosefe, mécaplus, wedd magic, sunphosate and tackle, most of which are available on the market (figures 13 and 14).

Figure 13:- Types of herbicides found in the homes of certain growers.

Figure 14:- Different types of herbicide found on the Copargo market.

Quantities of agricultural inputs used

Figure 15 shows the average quantities of chemical fertilisers and pesticides used per hectare and per crop year by growers. According to this figure, an average of 120.59 kg of NPK fertiliser and 62.91 kg of urea are used per grower per hectare. As for pesticides (insecticides and herbicides), 2.39 litres are used per hectare. In one crop year, 350 kg of NPK fertiliser and 177 kg of urea are used, compared with 6.99 litres of pesticides (insecticides + herbicides).

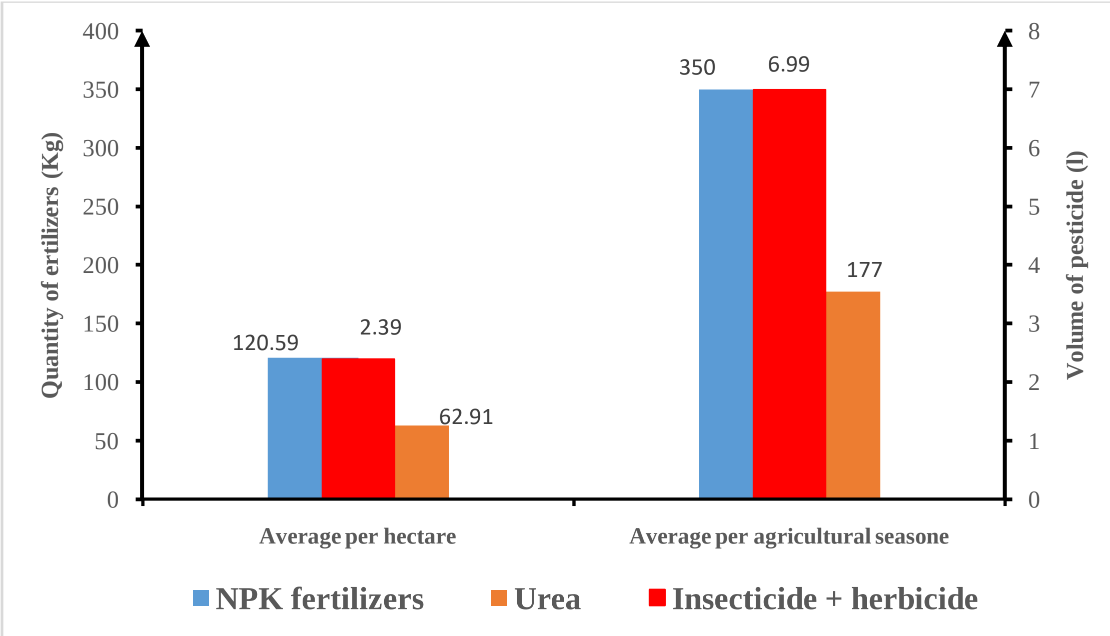

Figure 15:- Average quantities of agricultural inputs used per hectare per crop year by producers in the study area.

Sources of agricultural inputs

The main source of agricultural inputs in the commune of Copargo is SODECO (Figure 13). The majority of producers (81.3%) obtain their agricultural inputs from SOECO (an official state structure), compared with 12.08% who obtain them on the market. 6.62% of producers have a mixed source of supply (Figure 16).

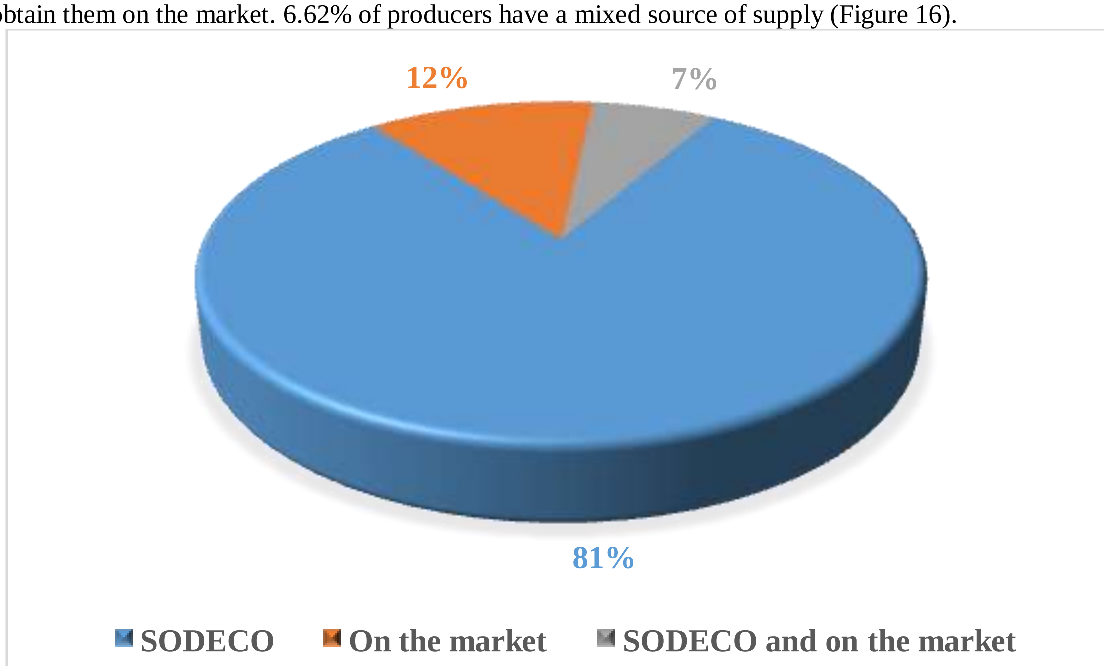

Figure 16:- Distribution of sources of supply for agricultural inputs (fertilizers and pesticides) according to the population.

Producers' knowledge of the risks associated with the use of agricultural inputs

Of the total population surveyed, 198 (66%) said they recognised the risks associated with the use of agricultural inputs, compared with 102 (34%) who were unaware of the risks associated with the use of agricultural inputs.

For 42% of farmers, the use of chemical fertilisers and pesticides poses a risk of environmental pollution. Poisoning is cited by 56% of farmers as a risk associated with the use of chemical fertilisers and pesticides. Finally, 2% attributed soil impoverishment to the use of agricultural inputs (Figure 17).

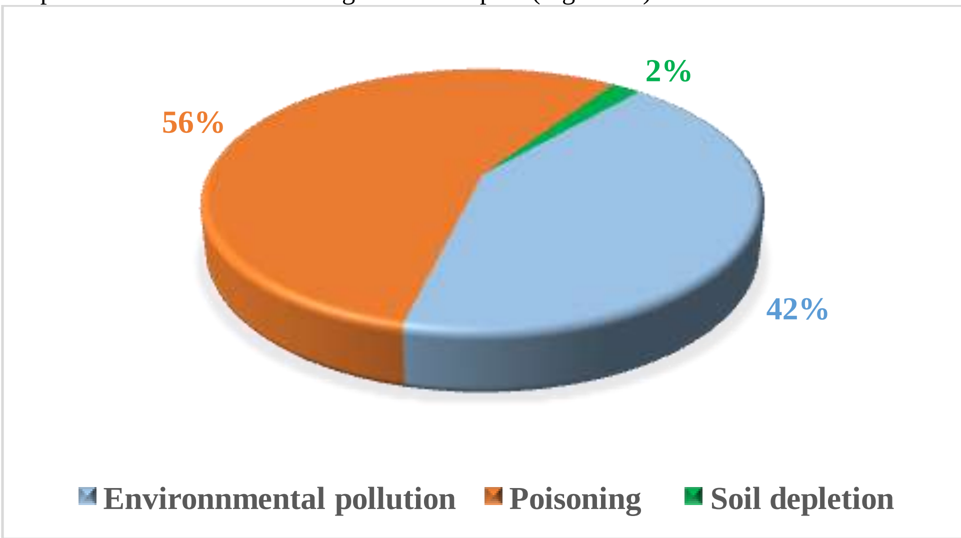

Figure 17:- Distribution of the risks of using agricultural inputs according to the producers surveyed.

On the question of knowledge of the headwaters of watersheds, 97.63% of producers said they had no idea of the existence of the headwaters of watersheds. And 80% of them have their fields in the immediate vicinity or not far from streams and/or watercourses, despite their recognition of certain risks associated with the use of chemical fertilisers and pesticides.

(a) (b)

Figure 18:- Maize crops on the banks of the Pabégou (a) and Tanéka Koko (b) rivers.

Change in area under cultivation

Figure 19 shows changes in the average area under cultivation from 1990 to 2022 in the study area, according to farmers. According to this figure, the average area under cultivation increased each year from 1990 to 2022. On average, they increased from 2.6 hectares per person in 1990 to 7.07 hectares per person in 2022. This represents an increase of 4.47 hectares in 32 years.

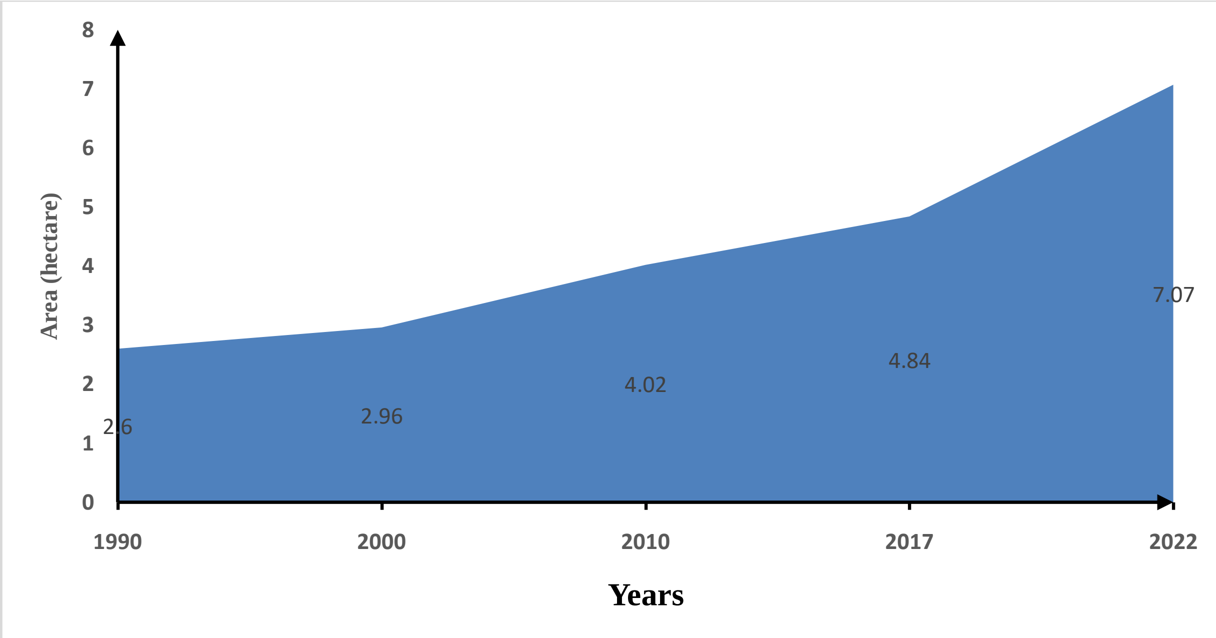

Figure 19:-Average cultivated areas from 1990 to 2022 according to farmers.

Direct field observation: environmental characteristics of the study area

The analysis and direct observation of the study area reveal significant anthropogenic influence on most of the headwaters of the watersheds, manifesting in agricultural activities, livestock farming, grazing, and vegetable farming. Additionally, ornamental stones resulting from rock crushing have been observed in the study area. These products and their derivatives are sold locally, providing a source of income for the population. Hydrographically, the study area is characterized by a dense network of streams and rivers, as it is the source region for the Ouémé and Pendjari rivers. There is also a classified forest in the study area: the Tanéka Béri forest. Observations also revealed the presence of gallery forests, trees, shrubs, herbs, and tree-shrub-herb associations in the headwaters that are either not yet or only partially anthropized. The relief observed in the area is characterized by a mountainous zone extending from Tanéka Béri, where the Ouémé river originates, to Tanéka Koko, as well as vast plains. The headwaters of the Copargo watersheds are also marked by the presence of wetlands. The water resources consumed by the population consist of both groundwater (spring water, wells, and boreholes) and surface water (streams, rivers, and reservoirs). Most of the observed crops are cultivated near and along the watercourses, and sometimes within the riverbeds themselves. Vegetable farming activities are particularly noted around the Tchandégou reservoir, which is surrounded by an agricultural farm, as well as along rivers with a permanent flow regime.

Land Use from 1985 to 2022

The main land use units in 1985 and 2022 are represented in Figure 20. This figure highlights the following units: forests, settlements, and mosaics of fields and fallow land. The analysis of these different units shows that in 1985, forests covered 81% of the area of the commune of Copargo, but by 2022, they only represented 48.43%, indicating a loss of 32.57% in forest cover. The mosaics of fields and fallow land increased from 18.5% of the area of Copargo in 1985 to 50.2% in 2022, reflecting an expansion of 31.7% in cultivated land. As for settlements, which only represented 0.5% of the area of Copargo in 1985, they grew to 1.37% in 2022, indicating an increase of 0.87% in built-up areas.

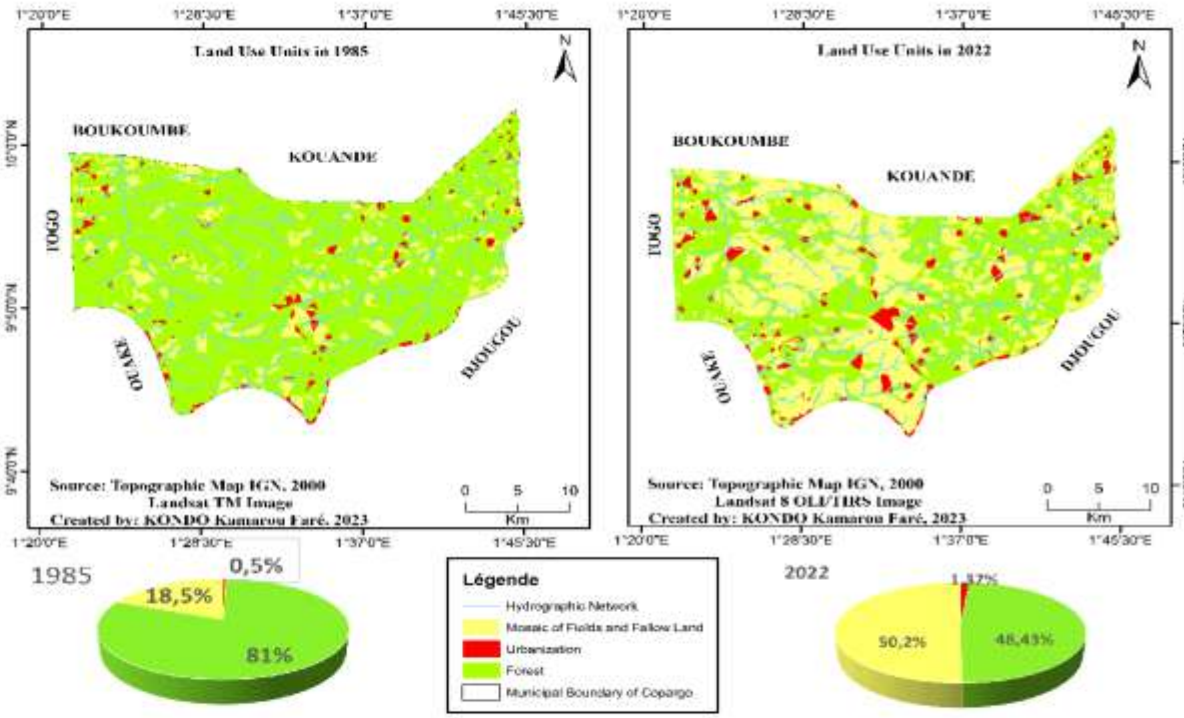

Figure 20:- Map of Land Use Units in the Commune of Copargo in 1985 and 2022.

Identified Potential Sources of Pollution

Field surveys and observations conducted in the four districts (Copargo, Singré, Anandana, and Pabégou) identified the main activities that could potentially cause pollution in the headwaters of the watersheds in the commune of Copargo. Most of these activities are related to agriculture. Figure 21 illustrates the map of the distribution of the different potential sources of pollution affecting the water resources in the headwaters of the Ouémé and Pendjari rivers in Copargo. This figure shows that most of the potential sources of pollution are located close to watercourses and could pose risks of diffuse or even point source pollution to the water resources.

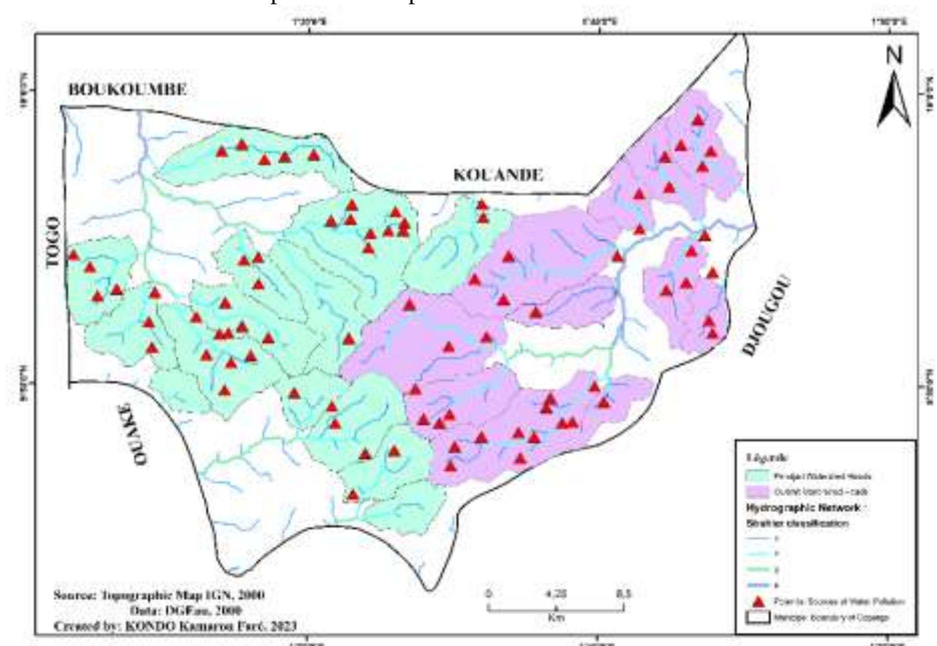

Figure 21:- Map of the distribution of potential pollution sources in the headwaters of the Copargo watersheds.

Discussion:-

Field surveys

In Copargo, over 90% of the population practices agriculture. This proportion indicates that agriculture is the main source of income in Copargo and occupies the majority of the active population. The higher proportion of men compared to women in agriculture during our study shows that agricultural activities are primarily reserved for men due to the physical strength required. The average age of 49.78 years, with the most represented age group being [45 – 55[years, found during our survey reassures the maturity and experience acquired by producers in agricultural production and consequently the reliability of the responses to the questionnaires. More than half of the producers (54.97%) are uneducated. The low educational level of producers in the study area is explained by the fact that in rural areas, most people prioritize farming work that feeds their families over education or sending their children to school. Indeed, in rural areas, for some fathers, sending their child to school constitutes an expense and a waste of time. They find it more beneficial to go or send their children to cultivate the land.

The farming systems practiced in Copargo depend on the type of crops and the resources available to the producer. Monoculture, which consists of having only one type of crop on a plot during a farming season, is also observed in Copargo. Thus, with the goal of reducing expenses, mixed cropping systems are also practiced. This system involves crops that can coexist in symbiosis, often with two different crops in the same field. This includes: peanut-maize, peanut-millet, yam-maize, yam-millet, etc. It mainly concerns the cultivation of maize, cotton, and soybeans. Along the same lines, the crop rotation system is practiced. This system involves changing the type of crop at the end of the ongoing crop cycle or at the end of the season. In Copargo, during the same agricultural season, the system is marked by the cultivation of peanuts or cowpeas followed by soybeans before planting maize or millet or any type of crop that the producer deems appropriate. The first crops (peanuts, cowpeas, etc.) contribute to soil fertilization through their biodegradation after harvesting. These systems are thus practiced to provide nutrients to soils that are degrading and becoming increasingly poor in fertilizers. This is also why chemical fertilizers and pesticides are used.

In Copargo, agriculture is generally characterized by the use of agricultural inputs by producers (farmers). Chemical fertilizers are used in response to soil poverty and non-productivity, aiming to fertilize the land and increase agricultural production yields. On average, 350 kg of NPK fertilizer and 177 kg of urea are used per year and per producer according to the surveyed population. According to Atchichoe et al.(2024)in their study, 53% of households surveyed in southern Benin use NPK fertilizers in their crops, which are likely to pollute the Sô and Djonou rivers, tributaries of Lake Nokoué. Similar observations were made by Mbianda Nfong-Ya et al. (2024) in Congo Brazzaville, where over 60% of respondents use chemical fertilizers (NPK and urea) to enhance soil productivity. Thus, 7 kg of fertilizer and 7 ml of urea are used in fields for soil amendment (Mbianda Nfong-Ya & al., 2024). However, these quantities used are significantly lower than those used by the population in our study area. The observed difference can be attributed to the fact that our study area is a rural zone, characterized by high agricultural pressure. It is therefore evident that today, agriculture can no longer do without agricultural inputs, especially chemical fertilizers.

Regarding pesticides, the types predominantly used by agricultural producers are insecticides and herbicides. In fact, these are the most widely used types of pesticides globally, though with certain regulations in some countries, Mbianda Nfong-Ya& al. (2024) studies have also revealed the use of herbicides (29% of cases) and insecticides (42% of cases) by the population in the Brazzaville agglomeration. Insecticides are not only used for pest control or prevention in crops (cotton, cowpea, pepper, beans, etc.) and against harmful insects and pests, but also for the preservation of agricultural products, particularly cereals (maize, millet, sorghum, beans, cowpea, etc.). Other herbicides are used for weeding (non-selective herbicides) and for destroying weeds in crops (selective herbicides). For producers, the use of herbicides is a great advantage because, on the one hand, it allows for clearing large agricultural areas in record time and at a lower cost with minimal effort, and on the other hand, it helps address labor shortages. This suggests that each passing year, agricultural producers prefer the path of simplicity and ease without fully understanding the consequences. Thus, in one agricultural campaign, an average of 6.99 liters of insecticides and herbicides are used per person, according to the surveyed population.

Eighty-one percent of the agricultural inputs used by producers come from the official state structure, SODECO, which regulates their use. Twelve percent of the inputs used come from dubious sources, particularly from markets and neighboring countries, notably Nigeria, raising concerns about their quality.

The overexploitation of land in Copargo is reflected in the fact that most of it is not left fallow. The area under cultivation is increasing every year. This growth is explained by population growth, which leads to an increase in demand for food products, especially those of agricultural origin. Despite their low level of education, 66% of agricultural producers claimed to recognize the risks associated with the use of agricultural inputs.

Land Use and Potential Pollution Sources

The dynamics of land use are progressive at the expense of forest cover and in favor of built-up areas and cultivated land. Over 37 years, the proportion of cultivated land increased from 18.5% in 1985 to 50.2% of the study area in 2022. These figures confirm the statements of producers, who report that the area cultivated per producer has increased each year, rising from 2.7 hectares in 1980 to 7.07 hectares in 2022. Similarly, the demographic growth of Copargo affects the integrity of the headwaters.

From this study, it appears that, from a human perspective, the potential sources of pollution in the headwaters of Copargo are diversified. They include agriculture, livestock farming, forestry exploitation, and urbanization. The diffuse sources of pollution in Copargo are primarily agricultural in origin, linked to the use of chemical fertilizers and pesticides in agriculture and to the increase in livestock. Our results corroborate with those of Bah et al.(2016)where they also found that diffuse pollution sources in Faranah were linked to agriculture. Indeed, agriculture involves the use of agricultural inputs (fertilizers and pesticides (insecticides + herbicides)) that are not without risk to the environment and even human health. Agriculture thus contributes to the pollution of groundwater through infiltration and surface water through runoff due to the use of fertilizers and pesticides that farmers add to increase the productivity of the land and crop yields(Bitar et al., 2013). The work conducted by Sambiénou et al.(2018)on the Pendjari watershed in North-West Benin revealed that the presence of nitrates at levels exceeding WHO standards in certain groundwater is linked to anthropogenic activities, particularly agriculture. Similarly, according to Sebei et al.(2004)the presence of high levels of nitrates in the groundwater of Grombalia in Tunisia is attributed to the leaching of cultivated lands and the degradation of organic matter. Most often, these agricultural inputs used are of questionable origin and quality, negatively impacting the quality of water and soil resources due to their chemical constituents. The amount of nitrogen leached into the aquifer or runoff into watercourses is estimated at around 10%(Bitar et al., 2013). Thus, significant quantities of nitrates can reach water resources. In Morocco, on the Oum Erbia watershed, approximately 3,500 tons of nitrates from fertilizers reach the Tadla aquifer through leaching, and the pollution caused by pesticides is estimated at 2.2 tons per year (Bitar et al., 2013).Regarding livestock, the waste generated by animals also affects the quality and quantity of surface water runoff(Bah et al., 2016). The increase in population has led to the urbanization of most of the watersheds and along certain waterways where the riverside population does their laundry. This laundry practice pollutes water resources, particularly through the enrichment from the addition of orthophosphates. As for deforestation, it exposes the soil, leaving it vulnerable to rain-induced erosion.

Conclusion:-

At the end of this study, it is clear that agriculture is the main activity practiced by the population in the watersheds of the Ouémé and Pendjari rivers in Copargo. For their crops, producers use chemical fertilizers and pesticides to increase yields. Thus, agriculture constitutes the primary potential source of pollution for water and soil resources in the study area through the application of fertilizers and the spraying of insecticides and herbicides in the fields, which, under the influence of rain, enter the groundwater and waterways through infiltration and runoff, respectively. As for land use, the dynamics are progressive and proportional to the demand and increase in population.

Given the importance and strategic role of watersheds, these areas should be free from all anthropogenic activities in order to preserve their natural integrity. In order to evaluate the impact of these anthropogenic activities on water resources, a physico-chemical characterization study of the waters in the watersheds of Copargo will be conducted.

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