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Impacts of Agrochemicals on Water Quality Parameters in Aboisso Region (South-East of Cote d'Ivoire)

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Authors' contributions

This work was carried out in collaboration among all authors. Author AA designed the study, performed the statistical analysis, wrote the protocol, and wrote the first draft of the manuscript. Authors KOJG and GFM managed the analyses of the study. Authors OYMS and BJ managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

Aboisso region is experiencing unprecedented agricultural activities. Cultural techniques such as the use of insecticides are harming the quality of water. This study aims to assess the impact of insecticides on the water quality in the Aboisso region. Thirty-one (31) water points (10 surface water and 21 groundwater) were sampled. The determination of physicochemical parameters as well as the multi-residue method used for insecticides analysis in the samples allowed us to achieve our objective. The result of the physicochemical analysis shows that the temperature of groundwater (27.91°C) is higher than surface water temperature (26.77°C). These waters are mostly acidic with a slightly lower pH for groundwater (6.46) compared to surface water (6.54). The conductivity is higher in groundwater (average of 130.46 µS/cm) as opposed to surface water (average of 43.50 µS/cm). After applying the multi-residue method, the results reveal the presence of nine (9) active ingredients. In surface waters, all these molecules, except Lambda-cyhalothrin and Deltamethrin,

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exceed the WHO guide values (0.1 µg/L). The highest concentrations recorded concern ethyl parathion and profenofos (8.24 µg/L and 8.04 µg/L respectively). In groundwater, it is rather Parathion-methyl, Profenofos, Dimethoate, Chlorpyriphos-ethyl, Lambda-cyhalothrin and Deltamethrin that are often at below WHO standards. However, the present study reveals that all of the water samples analysed were polluted, owing to anthropogenic used of insecticides in the region, and other chemicals with high concentrations of parathion-ethyl: 8.24 µg/L and profenofos: 8.04 µg/L. These waters are therefore unfit for human consumption.

Keywords: Agricultural activities; insecticides; water quality; pollution; Aboisso; Cote d'Ivoire.

1. INTRODUCTION

Achieving sustainable social and economic development in Africa is strongly linked to the development of its agricultural sector on which more than 60% of its population and more than 80% of the people living in poverty depend [1]. This observation justifies the slogan promoted by the Ivorian authorities in the early hours of Côte d'Ivoire's independence, which states that: "the success of this country depends on agriculture". Therefore, the agricultural sector has been the driving force behind Côte d'Ivoire's economic growth from independence to the present day. The agricultural products that are strongly focused on export crops were dominated by the coffee and cocoa combination. To reduce the country's over-dependence on these crops, the political authorities initiated a process of crop diversification across the country in the early 1960s, with new crops such as oil palm, coconut, rubber, banana, pineapple, cotton, sugar cane, etc. [2]. However, the growth of the agricultural sector is not without consequences for natural resources generally and water resources in particular. In recent decades, the rapid growth of agricultural production using agrochemicals and mechanization has led to soil and water degradation in many parts of the world [3]. Water pollution from agricultural sources is generally linked to nitrates and phosphates. The highlighting of pesticide pollution (herbicides, insecticides and fungicides) is recent [4]. Aboisso region, which has favorable natural conditions, is one of the regions of Côte d'Ivoire that is under very strong agricultural pressure [5]. This region, which sheltered the country's first cocoa and coffee trees, continues to be solicited by agro-industries for the exploitation of new crops (oil palm, rubber, banana, pineapple, etc.). Thus, all these agricultural pressure leads to questions about the quality of its water resources. The main objective of this study is to access the impact of agrochemicals on the quality of water resources in Aboisso region.

2. GENERALITY ON PESTICIDES

2.1 Definition

According to the FAO [6] pesticides are defined as: "any substance or combination of substances that is intended to control, destroy or eradicate pests, including vectors of human or animal disease, and undesirable species of plants or animals that cause damage or are harmful in any way". Depending on the objectives pursued through their use, pesticides have several names. For example, an insecticide is called plant protection or plant protection product when used on wheat, but it is called a biocide when used on timber [7].

2.2 Water Pollution Caused by Phytosanitary Product Applied to Plant

The dose of pesticide effectively applied to the plant being treated is between 0 and 23% of the total quantity applied [8]. The large part of the active substance applied that does not reach its target will then be likely, in the more or less long term, of transferred to surface water and groundwater. Rainfall through surface runoff processes and leaching into the depths of the soil are the main contributors to the transfer of plant protection products to groundwater and rivers (Fig. 1).

2.2.1 The leaching processes

The process of pesticide leaching involves the transport of molecules from the soil surface to groundwater. This transfer of agrochemicals to groundwater concerns molecules that are in solution in the aqueous phase of the soil or that are adsorbed on solid particles carried by a vertical water flow [9].

2.2.2 The runoff processes

Runoff is the main means of transferring pesticides to surface waters. These chemicals can be transported in several ways: in solution

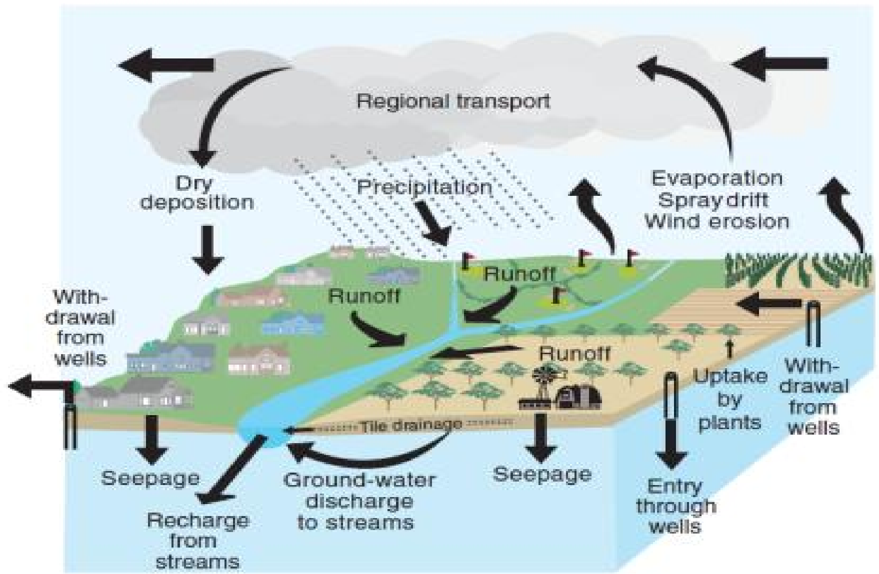


Fig. 1. Pesticide movement in the hydrological system [10]

in runoff water, in suspension or attached to soil particles that are torn off by the runoff water. There are two types of runoff: Hortonian runoff, which is caused by exceeding the infiltration capacity of the soil, and hypodermic runoff or sub-surface runoff, which occurs when the lateral conductivity is greater than the vertical conductivity [8].

2.3 Health Impact of Pesticides

Despite their selectivity and specific mode of action, pesticides cause harm to unintentionally exposed organisms by contaminating the environment and the food chain. Results from various studies indicate that pesticides, especially insecticides, are classified as cytotoxic, neurotoxic, embryotoxic, mutagenic, teratogenic or carcinogenic [8]. Several pesticides and their degradation products have been recognized as potential risk factors for reducing male fertility, particularly through testicular toxicity [11]. There is evidence that exposure to certain substances can lead to immune system dysfunction [12]. Some pesticides are also considered to be endocrine disruptors, i.e. they interact with hormones by simulating their action. Chronic exposure to pesticides has been associated with symptoms of children's chronic respiratory diseases, especially asthma [13]. Farmers who prepare the mixtures and carry out the treatments are more exposed to cancer risks than the rest of the population. These are generally infrequent or even rare cancers such as cancers of the lips, ovary, brain, skin melanoma and the majority of hematopoietic system cancers (leukaemia, myeloma, and lymphoma). Prostate and stomach cancer, which are much more common, are also reported to be affected [14].

3. MATERIALS AND METHODS

3.1 Study Area

3.1.1 Location and socio-economic activities

Located in the extreme south-east of Ivory Coast, the department of Aboisso covers 4563 Km². It belongs to the Sud-Comoé region and is limited by three national borders (the department of Abengourou in the north and the sub-prefectures of Bonoua and Alepé in the west), by an international border in the east (Ghana) and by a natural border in the south (the Atlantic Ocean). The study area is limited to the southern part of this department. It includes five (5) sub-prefectures (Aboisso, Maféré, Adaou, Ayamé, Adjouan) and lies between longitude 5°45N and 5°90N and latitude 2°50 W and 3°25 W (Fig. 2). Like the country's forest regions, the department of Aboisso is densely populated with an estimated population of 322,498 inhabitants [15].

Agriculture is the main economic activity in the region with more than 75% of the area [16].

There are industrial and small-scale plantations in the area. Agro-industry is dominated by PALM-CI, which manages industrial coconut and oil palm plantations in Ehania and Toumanguié. PALM-CI has five (5) on-site palm oil processing plants, two (2) in Toumanguié and three (3) in Ehania. Other private companies also operate industrial plantations in the region. These include ATOE (Soumié) and DEKEL OIL (Ayénouan) which also produce palm seeds and palm oil. SELECTIMA located in Assouba produces pineapple. There are the CANAVERSE groups (Domaine d'Elima in Aboisso, SAKJ in Ayamé, SBMK in Assouba) and the SEEBA in Maféré, all specialized in banana production.

The study area belongs to the transitional equatorial climate, also called Attiéen climate, with four seasons, including two rainy and two dries seasons. The rainfall is very high, with annual rainfall over 1700 mm. That facilitates infiltration and leaching of agricultural inputs.

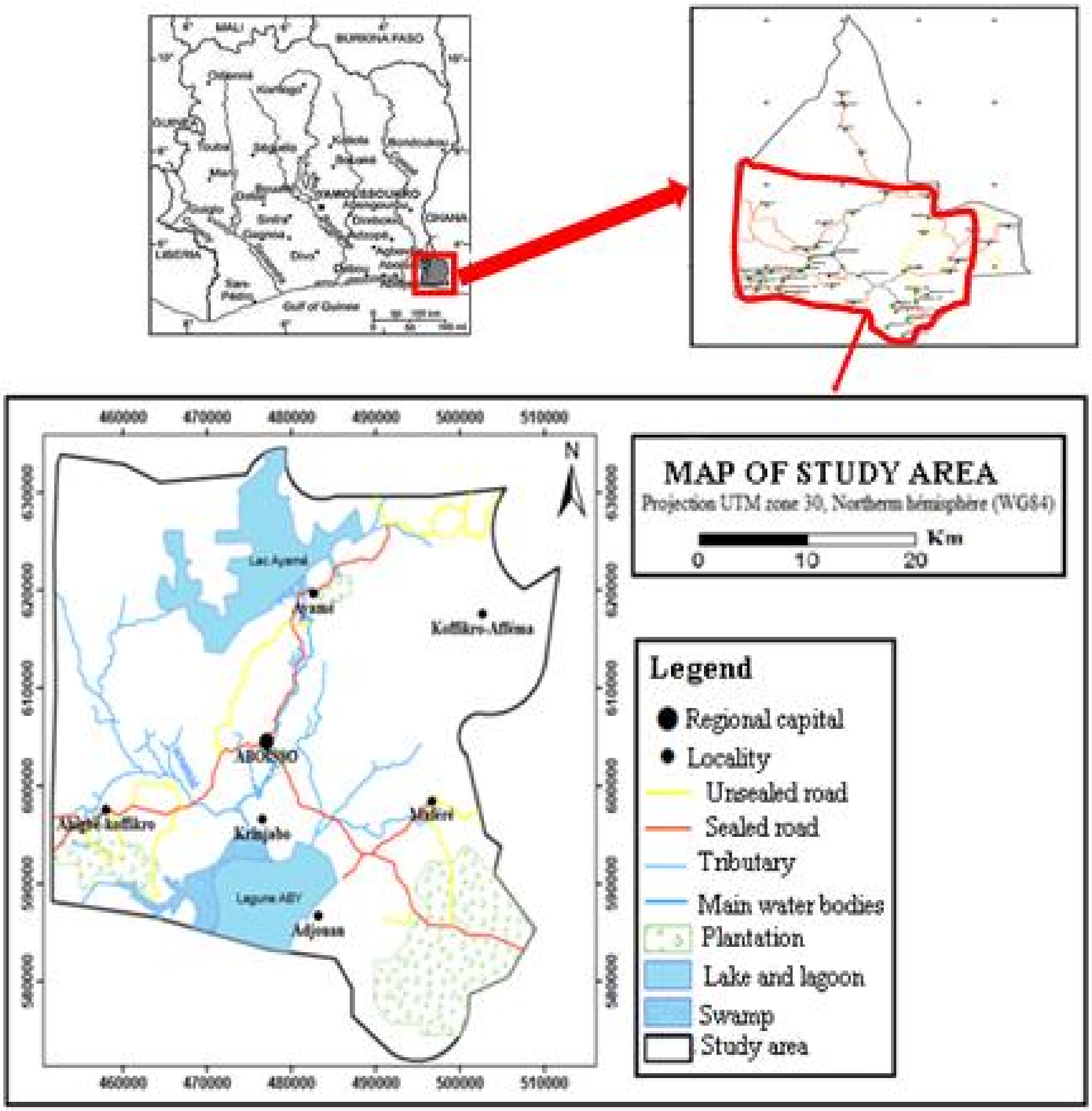


Fig. 2. Location of the study area

3.1.2 Geological and hydrogeological context

The study area straddles two geological domains (Fig. 3) consisting of the formations of the coastal sedimentary basin (in the South) and the crystalline and crystallophyllian bedrock (in the North). According to Geomine [17], Delor et al. [18] and Hirdes et al. [19], three main geological units are exposed in the Aboisso department:

- **Granitoids**: The granitoids observed are muscovite metagranites, biotite metamonzonites, biotite metagranodiorites and metadiorites [20].
- **Schists**: In Aboisso department, three types of schist formations can be found. There are tuffaceous schists with graphite and ampelite past, quartz schists as well as chlorite and amphibole schists [20].
- **Sedimentary formations**: These are Upper Cretaceous, Mio-Pliocene or Continental Terminal and Quaternary formations observed in the southern part of Aboisso. They reach a 20 m depth at the level of the bedrock-sedimentary basin contact up to 60 m in the southern part of the study area [21].

In terms of hydrogeology, there are therefore two main groups of aquifers:

- Classic aquifers of the sedimentary basin: Sedimentary units contain the most important aquifers. Indeed, at the level of these formations, the aquifers present are continuous and provide large volumes of water. This means that in these areas, drinking water is generally supplied to the localities by boreholes and surface water is not used to meet the demand [20]. Continuous aquifers are composed by Quaternary aquifers, Tertiary aquifers (Mio-Pliocene or Continental Terminal) and Upper Cretaceous aquifers (Maastrichtian).
- Discontinuous aquifers, also known as fracture or fissure aquifers, are found in the crystalline bedrock to the north of the study area. Depending on the hydrogeological characteristics and the lithological nature of the rocks, we identify alteration aquifers whose reservoirs are composed of lateritic cuirasses, clay sands and grained arenas, and fissure or fracture aquifers which are protected from various types of pollution and seasonal fluctuations. Such aquifers are developed in crushed and/or fractured areas and can provide fairly large water volumes when captured by boreholes. They are the most appreciated because of their properties mentioned above.

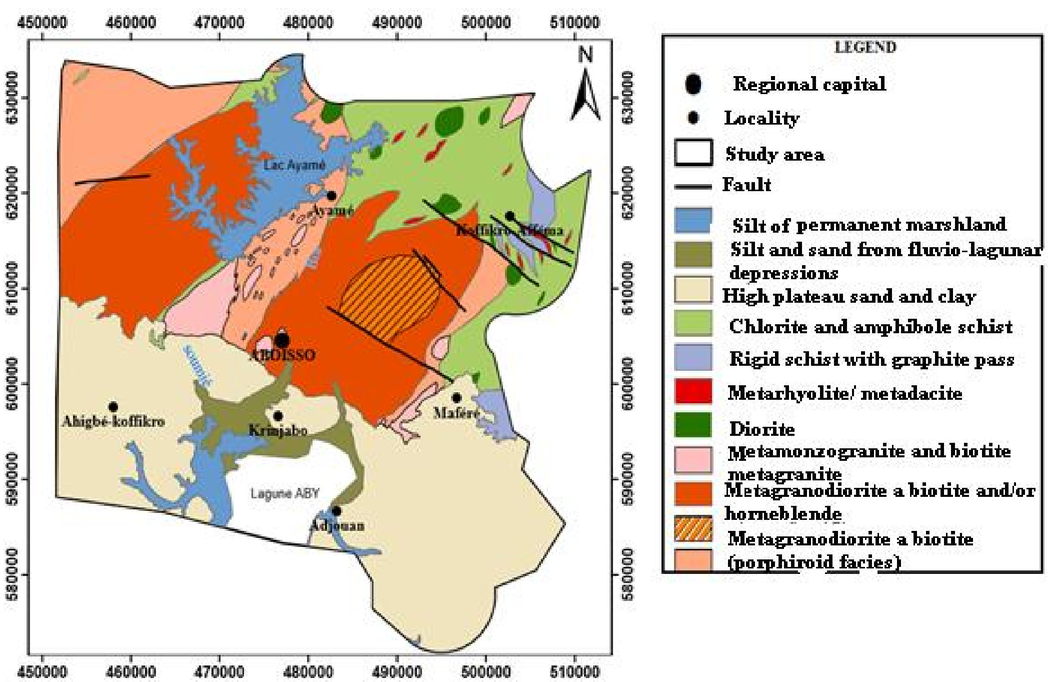


Fig. 3. Modified geological map of the study area [18]

The geological nature of formations and the aquifers encountered in the region influence the infiltration and runoff of precipitated water.

3.2 Sampling Method

3.2.1 Selection of sampling sites

The sampling sites were chosen based on their proximity to the large-scale plantations in the region. Samples were taken from twenty-one (21) groundwater points (9 well water, 7 borehole water, 1 spring water and 5 tap water) and ten (10) surface water points. Surface water is most often used for washing and dishwashing. The source identified at the locality of Carrefour barrage 2 and all the well water sampled is used as drinking water by local people.

3.2.2 Measurement of in situ parameters

According to Adiaffi [22] many chemicals, physical or biological reactions can occur in a sample for analysis, which can significantly alter the concentrations of some elements. It is therefore essential to take measurements of certain parameters such as temperature, pH and conductivity. It is therefore essential to take measurements of certain parameters such as temperature, pH and conductivity. This must be done immediately after the sample, ie in situ. Thus, the electrodes of the apparatus designed to measure these parameters for groundwater have been immersed in a bucket of water provided for this purpose. The material which was used in this study is presented by Plate 1. Thus, we used a Global Positioning System (GPS) of the Gamin type (map 62 S) to record the UTM coordinates of the various water sampling points. The conductivity measurement was carried out using a HACH-HQ 30d flexi brand conductivity meter. A multiparameter (of the YSI-Professional plus type) was used to measure the temperature and the pH of the water. A squeeze bottle containing distilled water was used to rinse the electrodes of the various measuring instruments. The water level in the wells was measured with a sound and light probe. A Toyota Pinic brand vehicle made it possible to connect the various sampling points.

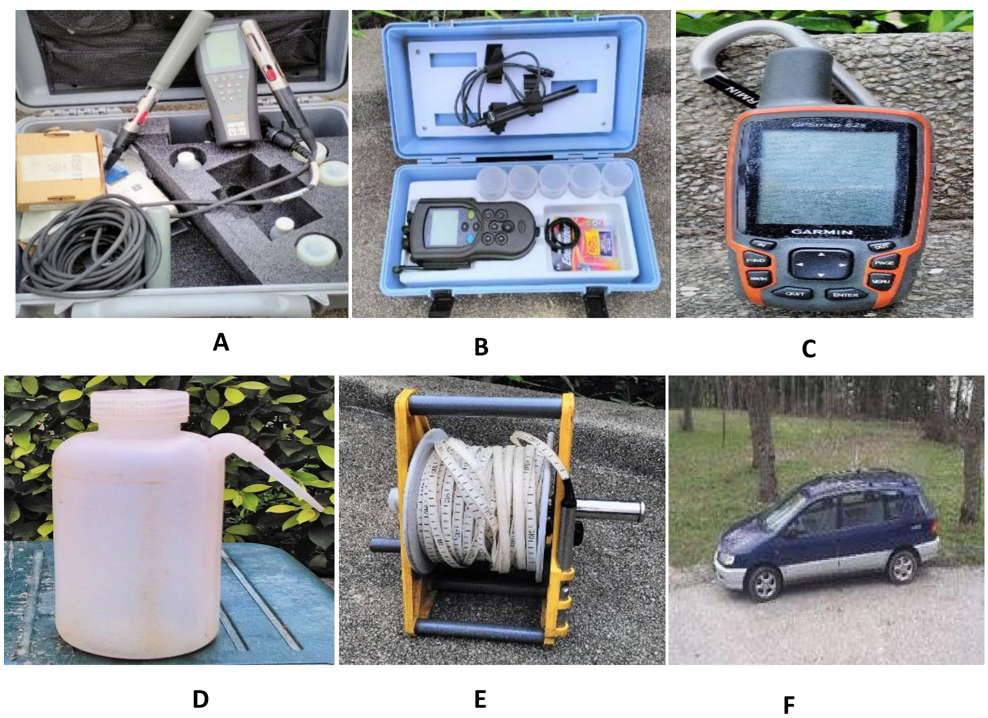


Plate 1. Equipment used in the field

A: Multi parameter; B: GPS; C: Conductivity meter; D: Wash bottle; E: Sound and light piezometer; F: Liaison vehicle

These electrodes were previously cleaned with distilled water and then with the water to be sampled. For surface water, the measurements were carried out directly by immersing the different electrodes.

3.3 Sampling

The sampling was done differently depending on the type of water taken. For surface waters, the 500 mL sterilized polyethene bottles were immersed directly into the water until they were filled. For well water, a sump was used to fill the bottles. All samples were then stabilized by adding a drop of sulfuric acid. The bottles were closed so that there were no air bubbles inside the samples. The bottles were labelled with codes corresponding to the sampling site. A cooler containing piece of ice was used to store the samples at a temperature of 4°C before sending them to the laboratory [22,16].

The water sample collection equipment (Plate 2) is therefore composed of:

- 31 polyethylene bottles of 500 mL to collect the water;
- 50 mL of sulfuric acid for stabilizing the pesticide molecules to be measured;
- A 10 mL glass graduated pipette placed a drop of sulfuric acid in each sample;
- A roll of tape and a marker were used to label the samples;
- A cooler for storing samples.

3.4 Laboratory Analysis

The analyzes were carried out at the Central Laboratory for Food Hygiene and Agro-industry (LCHAI). In the laboratory, the equipment used for the analysis of the parameters essentially consists of a high performance liquid chromatography (HPLC) line of the SHIMADZU type. This chain is made up of:

- a TRAY tank containing 10 mL of methanol;
- a DGU-20A5 degasser;
- a SIL-20A autosampler;
- an LC-20AT pump;
- a CTO-20A type oven;
- a UV / VIS SPD-20A detector for the quantification of pesticides.

Data acquisition was carried out using a computer equipped with LC solution software.

The technique used is the multi-residue determination based on solid-liquid extraction and analysis by liquid chromatography coupled with mass spectrometry. This method has detection limits between 0.002 and 0.0058 µg/L and has made it possible to detect a total of nine (9) active ingredients [23].

3.5 Principle

The analysis began with an extraction which consisted of taking 10 ml of water sample and activating the octadecyl (C-18) column by passing 10 ml of methanol and 10 ml of demineralized water. Then, the quantity (10 ml) of the sample taken from the C18 column is passed through before the absorbent is dried. The cartridge is then dried for 30 minutes, retaining the active molecules. The active molecules have been eluted with 5 mL methanol. Thirty (30) minutes later, the extract was recovered in a conical glass vial for chromatographic determination (HPCL). Standard solutions and samples were analyzed with a gas chromatograph equipped with a mass spectrometer in ion scanning mode. Insecticide concentrations in the sample are calculated by comparing the peak areas of the sample products with the areas obtained with standard solutions of known concentrations [23]. The results are expressed by the following equation:

$$\boldsymbol{C_P} = \frac{\boldsymbol{S_c \times C_e \times V_2 \times V_f \times F}}{\boldsymbol{S_e \times M_e \times V_1}}$$

$\boldsymbol{C_P}$: active ingredient concentration (mg/L); $\boldsymbol{S_c}$: sample peak area; $\boldsymbol{S_e}$: standard peak area; $\boldsymbol{C_e}$: standard concentration (mg/L); $\boldsymbol{V_1}$: volume to be purified (l); $\boldsymbol{V_2}$: volume after purification (l); $\boldsymbol{V_f}$: final volume (l); $\boldsymbol{M_e}$: sample volume (l); $\boldsymbol{F}$: dilution factor.

3.6 Data Analysis

To facilitate the exploitation of the data, a statistical analysis was conducted. This involved determining the extreme values (minimum and maximum), the means which are the central values and the standard delineation which are the dispersion parameters.

A B C D E

Plate 2. Sampling equipment

A: 500 mL polyethylene bottles, B: 10 mL graduated pipette, C: Sulfuric acid, D: Cooler, E: Roll of tape and marker

4. RESULTS

4.1 Physico-Chemical Characterization of Surface Water

The results of physico-chemical parameters are presented in Table 1. River Bia had the highest mean of surface waters temperature (29.8°C) and the lowest temperature (25.3°C) was recorded in River Bosso. These waters have an average temperature of 26.77°C±1.18°C. However, this average does not comply with the WHO guidelines which set the temperature of drinking water at a value lower than 25°C. The pH value had its range from 5.97 (Carrefour barrage) to 7.50 (Toumanguié village river) with an average of 6.54±0.48. Most of these values meet the WHO guidelines for pH (6.5<pH<9.5).

The conductivity values in surface waters range from 22.9 µS/cm (Mouyassué River) to 77.7 µS/cm (Bia River). The average is 43.50 µS/cm±16.53 µS/cm. None of these waters meets the WHO guidelines for electrical conductivity (180< EC< 1000). Fig. 4 shows the spatial variation of these parameters.

4.2 Physico-Chemical Characterization of Groundwater

In the groundwater, the temperatures recorded had its range from 26.3°C to 29.2°C. The average mean value was 27.91°C±0.85 (Table 2). It shows a slight increase compared to that of surface waters.

The pH values range from 5.51 (well water in Ayamé) to 7.54 (well water in Léhous) with an average of 6.46±0.62. Fig. 5 shows the pH variation in groundwater (well and borehole). Groundwater is more conductive than surface water with values that vary between 26.1 µS/cm (tap water in Toumanguié V1) and 568 µS/cm (water from the Biaka borehole). The average electrical conductivity is 130.46 µS/cm± 137.23

Table 1. Values of some physicochemical parameters of surface waters

Variables	WHO guideline	Unit	Min	Max	Standard delineation	Average
Temperature (T)	25	°C	25.30	29.8	1.18	26.77
pH	6.5<pH<9.5		5.97	7.50	0.48	6.54
Conductivity	>400	µS/cm	22.90	77.70	16.53	43.50

Table 2. Values of some physico-chemical parameters of groundwater system

Variables	WHO guideline	Unit	Min	Max	Standard delineation	Average
Temperature (T)	25	°C	26.3	29.2	0.85	27.91
pH	6.5<pH<9.5		5.51	7.54	0.62	6.46
Conductivity	>400	µS/cm	26.1	568	137.23	130.46

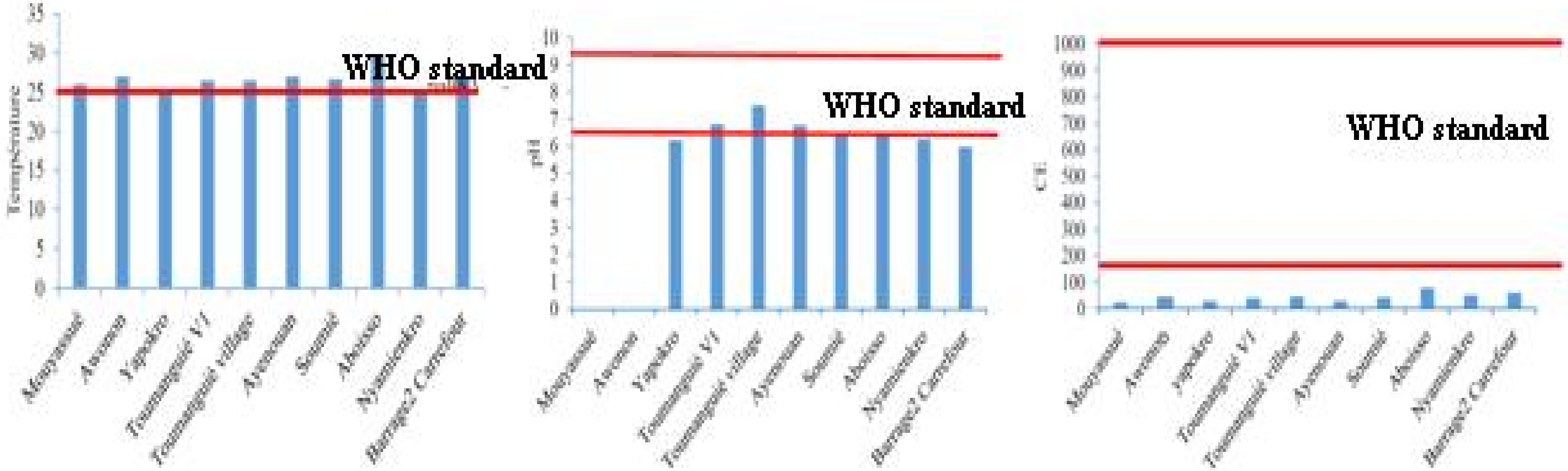
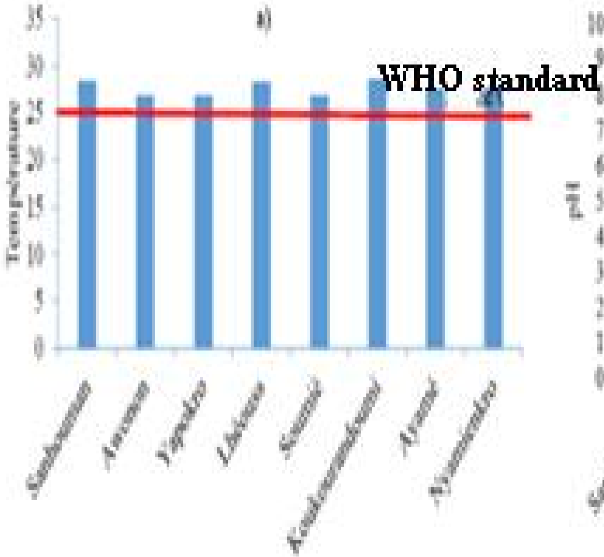


Fig. 4. Spatial variation of surface water physicochemical parameters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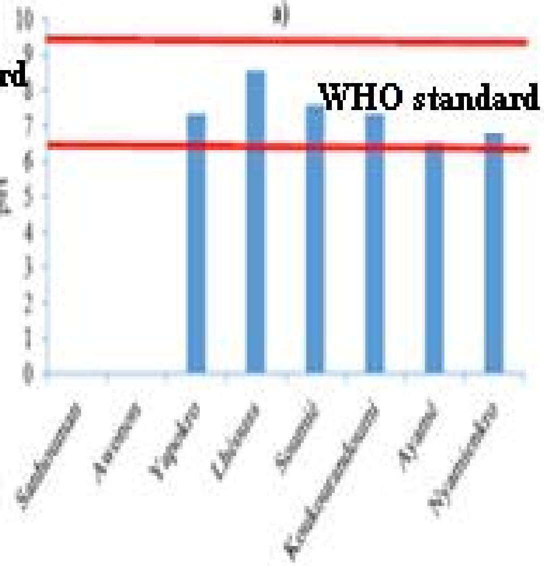
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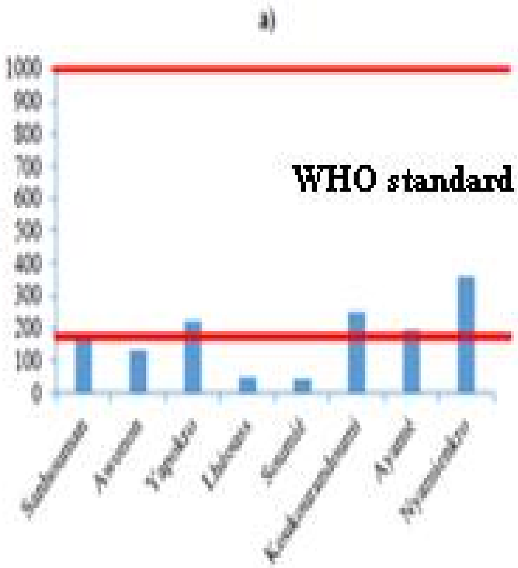
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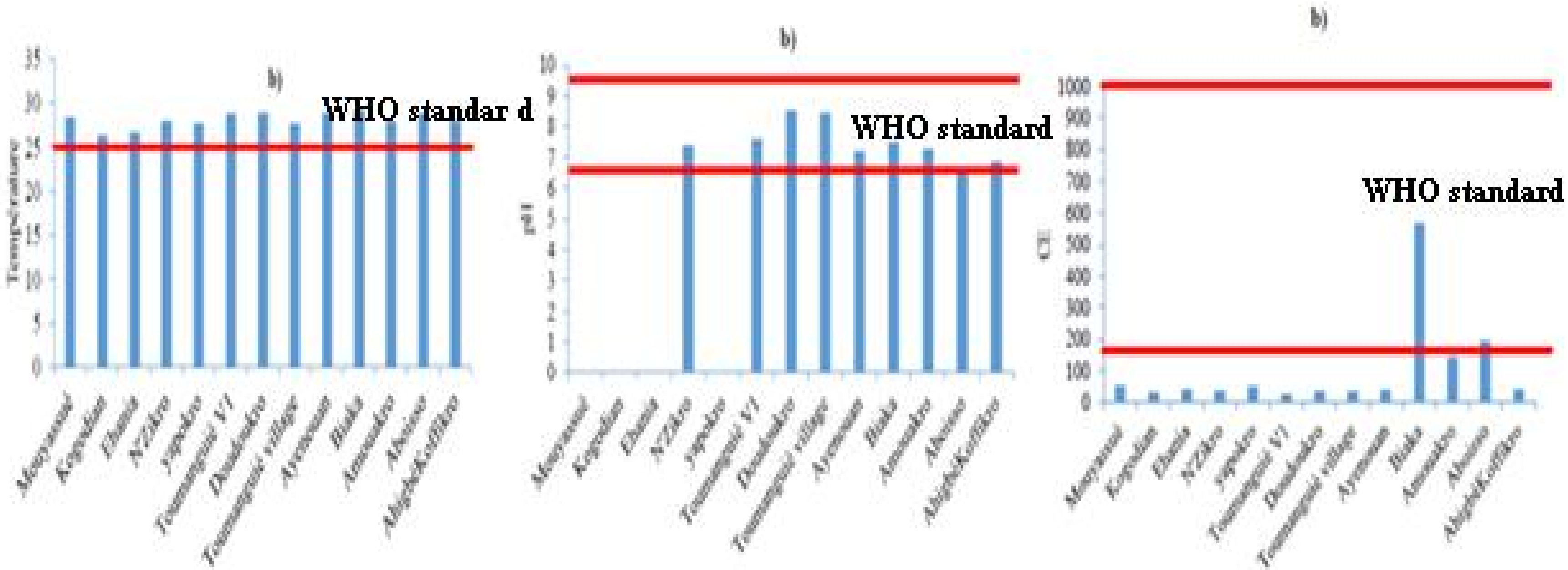

Fig. 5. Spatial evolution of groundwater physicochemical parameters (a-well water; b- borehole water)

4.3 Findings of the Study on Surface Water Contamination by the Active Ingredients

Table 3 shows the detection of nine (9) insecticide active ingredients in surface waters.

Thus, in these surface waters, methyl parathion values range from 0.27 µg/L (Soumié river) to 1.94 µg/L (Bosso river in Yapokro), with an average of 0.8 µg/L. The values for chlorfenvinphos vary from 0.134 µg/L (Factory V1 toumanguié) to 6µg/L (the Source du Carrefour Barrage2) with an average of 1.95 µg/L. Parathion-ethyl has concentrations between 0.17 µg/L (River Bia to Aboisso) and 7.03 µg/L (River Bia to Aboisso) and the average is 2.63 µg/L. As for Profenofos, concentrations range from 0.023 µg/L (Mouyassué River) to 8.05 µg/L (Source du Carrefour Barrage 2) with an average of 2.43 µg/L. Dimethoate values range from 0.027 (Bia River) µg/L to 1.18 µg/L (Awonon River) with an average of 0.75 µg/L. The average concentration of chlorpyriphos-ethyl is 1.34 µg/L with extreme values of 0 µg/L (Toumanguié River) and 6.34µg/L (Bosso River). The smallest concentration of carbosulfan in the surface water is 0.37 µg/L (Soumié River) and its highest is 6.39 µg/L (source of crossroads dam) for an average of 1.64 µg/L. The estimated average concentration of lambda-cyhalothrin and deltamethrin is 0.01 µg/L, with a minimum of 0 µg/L and a maximum of 0.032 µg/L and 0.073 µg/L respectively. The concentrations of the different active ingredients of insecticide in the surface waters of the localities investigated are shown in Fig. 6. This figure reveals that all these surface waters are polluted by at least four active ingredients of insecticides.

4.4 Findings of the Study on Groundwater Contamination by the Active Ingredients

Table 4 summarizes the concentration values of insecticides in groundwater. Thus, parathion-methyl ranges from 0 µg/L (Toumanguié V1 tap water) to 4.73 µg/L (Amouakro borehole water), with a mean of 1.32 µg/L. Those for chlorfenvinphos are considerably higher, with a minimum of 0.13 µg/L (Doudoukro borehole) and a maximum of 6.92 µg/L (Toumanguié village borehole), with an average of 1.85 µg/L. The average concentration of parathion-ethyl is 1.52 µg/L for a lower concentration value of 0.13 µg/L (Soumié well) and a higher value of 8.24 µg/L (Yapokro well).

Table 3. Insecticide concentrations in Surface water

Active ingredients	Min	Max	Standard delineation	Average
Parathion-methyl	0.27	1.94	0.65	0.80
Chlorfenvinphos	0.134	6	2.02	1.95
Parathion-ethyl	0.17	7.03	2.63	2.07
Profenofos	0.023	8.05	3.37	2.43
Dimethoate	0.027	1.18	0.49	0.75
Chlorpyriphos-ethyl	0	6.34	2.33	1.34
Carbosulfan	0.37	6.39	2.05	1.64
Lambda cyhalothrin	0	0.032	0.01	0.01
Deltamethrin	0	0.073	0.03	0.01

Table 4. Insecticide concentrations in groundwater

Active ingredients	Min	Max	Standard delineation	Average
Parathion-methyl	0	4.73	1.36	1.32
Chlorfenvinphos	0.13	6.92	1.92	1.85
Parathion-ethyl	0.13	8.24	2.21	1.52
Profenofos	0	8.24	2.21	1.52
Dimethoate	0.02	1.49	0.43	0.93
Chlorpyriphos-ethyl	0	6.10	2.10	1.39
Carbosulfan	0.20	6.43	1.96	1.77
Lambda cyhalothrin	0	0.92	0.27	0.11
Deltamethrin	0	0.32	0.07	0.03

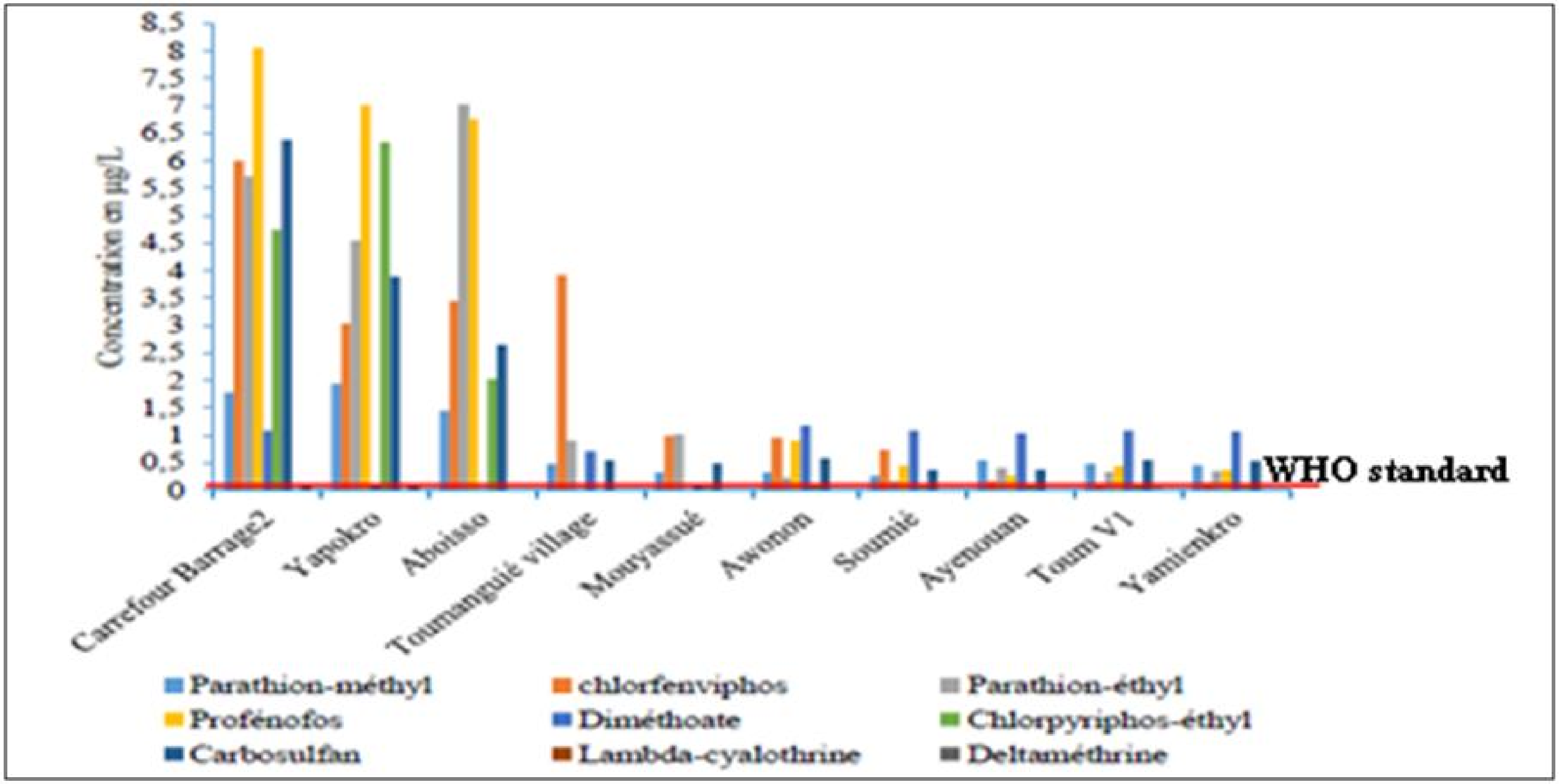

Fig. 6. Concentration of active ingredients in surface waters

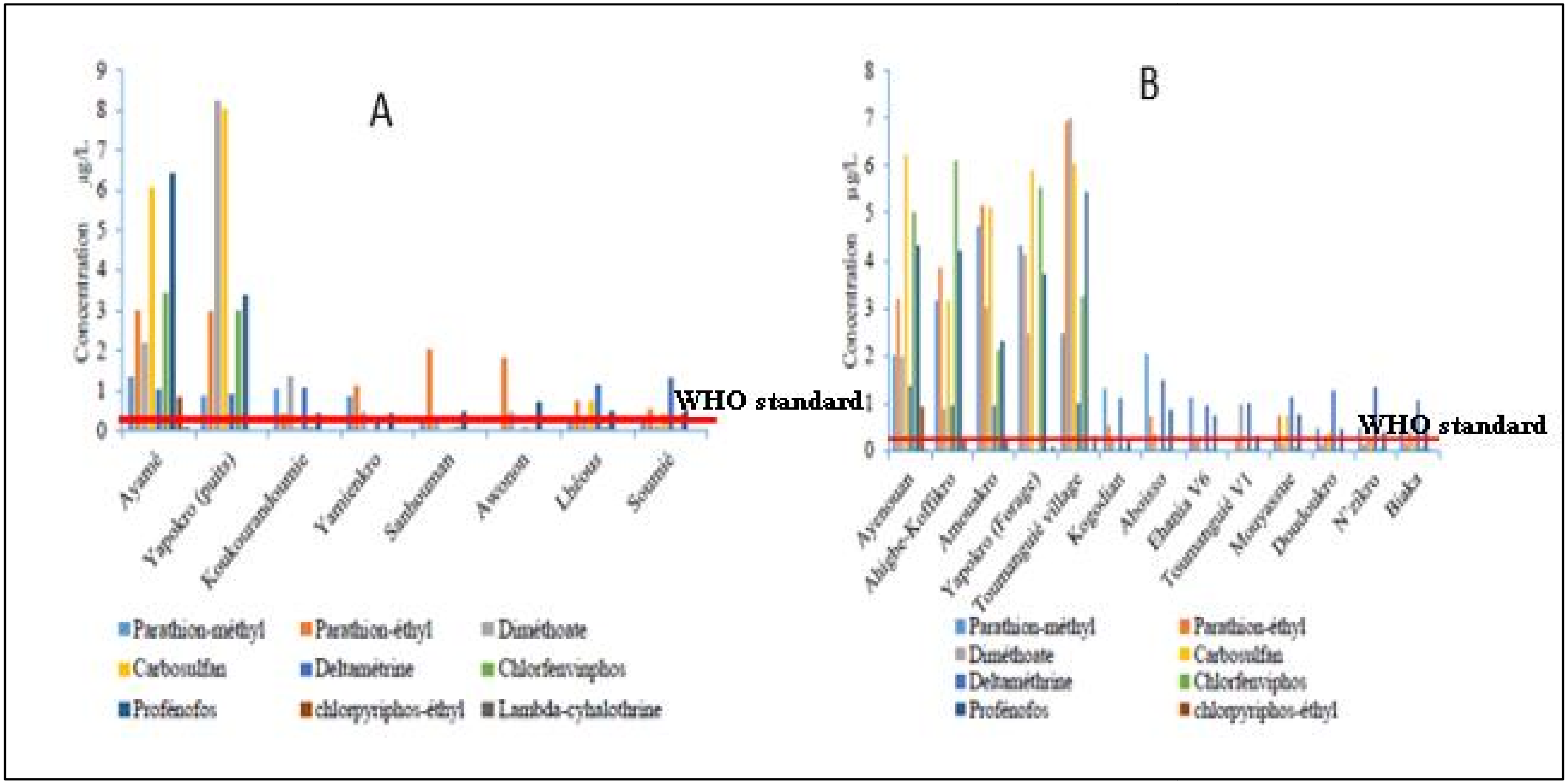

Fig. 7. Insecticides concentration in groundwater (A- Well water; B- Borehole water)

Profenofos and chlorpyrifos-ethyl have identical minimum concentrations of 0 µg/L in the Awonon and Yamienkro wells respectively. The maximum concentrations differ for these two molecules, with 8.04 µg/L (Yapokro well) for profenofos and 6.10 µg/L (Ahigbe-Koffikro tap water) for chlorpyriphos-ethyl. Dimethoate concentrations are a minimum of 0.02 µg/L (Yapokro well) and a maximum of 1.49 µg/L (Aboisso well) with an average of 0.93 µg/L. Carbosulfan is present in groundwater at concentrations ranging from 0.2 µg/L (SODECI borehole in Kogodian) to 6.43 µg/L (well in Ayamé) and an average of 1.77 µg/L. The lambda-cyhalothrin values in groundwater vary from 0 µg/L (in 61.92% of samples) to 0.92 µg/L (Ayenouan borehole) with an average of 0.11 µg/L. Deltamethrin, on the other hand, varies from 0 µg/L (in 66.66% of samples) to 0.32 µg/L (Toumanguié village borehole) for an average of 0.03 µg/L. Fig. 7 shows the concentrations of different insecticide molecules in groundwater. It can also be seen from this figure, as in the case of surface water, that all the groundwater studied is polluted by at least four active ingredients of insecticides.

Plate 3. Pesticide use sites in the south-east of Côte d'Ivoire

4.5 Probable Causes of Pesticides in the Waters of the Region

In the South-East region, several agro-industrial companies have been established for more than forty (40) years. The latter use pesticides for the treatment of herbs and plants. The photos on Plate 3 show the oil palm (A and B), banana (C), rubber (D), coffee and cocoa (E) plantations. In addition to these plantations, pesticides are also used by the populations of hydraulic works sites such as boreholes (G) and wells (H). These practices are believed to be the basis of the contamination of regional waters.

5. DISCUSSION

The physicochemical parameters analyzed in this study were temperature, conductivity and pH. According to the temperatures measured, groundwater is slightly warmer than surface water. These different temperatures, although higher than 25°C (standard accepted by the WHO), do not present a danger to the population. These temperatures are specific to tropical waters [16]. The conductivity of groundwater is higher than for surface water. However, the conductivities recorded show low values such as those obtained by Traoré [24], Kpan [16] and Orou [25]. These low conductivities are explained by the fact that the waters of the region are weakly mineralized. Indeed, according to the work of Eblin [26] and Kpan [16], the concentrations of salts (bicarbonate, chloride, sodium) are low in the waters of the region. Note also that in groundwater, these values are lower in the aquifers of the Continental Terminal (CT) and higher in the basement aquifers. This decrease would also be linked to a mixture of water. Once the water from the basement is found in the CT aquifer, it undergoes a strong dilution by less mineralized and more acidic water (recharge water from the surface) [16]. The mean pH values hardly vary either in groundwater (6.46) or in surface water (6.54). According to Adiaffi [22] and Eblin et al. [26], the acidity of groundwater is an essential characteristic of water in the Côte d'Ivoire and specifically in the south-eastern coast. This acidity is linked to the presence of free CO_2 in high quantities in the soil [27].

The results of this study show that water samples contain large amounts of active ingredients. These substances found in water at different concentrations belong to the insecticide group.
Some of these active molecules, such as parathion-methyl, parathion-ethyl and chlorfenvinphos, are neither registered nor authorized in Côte d'Ivoire [28]. The presence of unauthorized substances highlights the illegal use of pesticides. Indeed, as the study area borders Ghana, there is a proliferation of cheap chemicals from the neighbouring country like?. Traoré et al [29], Traoré [24] and Orou [25] also reported fraudulent use of pesticides in Buyo, Grand-Lahou, Yamoussoukro, around the Aghien and Poutou lagoons and in Agboville. For surface waters, only Lambda Cyhalothrin and Deltamethrin are present, in some cases, at concentrations below the guide value of 0.1 µg/L for each molecule, set by the WHO. The remaining molecules present in the surface waters sampled all exceed this standard. For some samples, these levels are extremely high (8.05 µg/L of profenofos in spring at Carrefour barrage Ayamé 2 dam). The order of abundance of these active ingredients is as follows: Profenofos (2.43 µg/L)> Parathion-ethyl (2.07

µg/L)> chlorfenvinphos (1.95 µg/L)> carbosulfan (1.64 µg/L)> chlorpyriphos-ethyl (1.34 µg/L)> Parathion-methyl (0.8 µg/L)> Dimethoate (0.75 µg/L)> Deltamethrin and Lambda-cyhalothrin (0.01 µg/L). In Côte d'Ivoire, pesticides are widely used in agriculture, especially for particularly important crops such as cotton, cocoa, coffee, bananas and rice. In 1976, 300 tonnes of DDT, 100 tonnes of Parathion-methyl and 30 tonnes of other organophosphates were used on cotton fields, and 600 tonnes of lindane on cocoa trees. Since 1979, DDT and other chlorinated hydrocarbons have been banned and have been replaced by natural and artificial organophosphates, carbamates and pyrethroids. On cocoa plantations, propoxide has replaced lindane and applications of 335 grams / hectare (75% active ingredient) are made twice a year between July and September. Before 1979, coffee trees were treated with DDT and lindane. These products have now been replaced by several pesticides belonging to different chemical families. Dieldrin is still used in combination with fenithrotion against the orthopteran Zonocerus variegatus. In banana plantations, phenamiphos (6 kg / ha at the foot of trees) (fao.org) is used as a nematicide. The long period of use of pesticides in Côte d'Ivoire could explain their presence in the waters of the region. Indeed, this region is one of the rainiest areas of the country. This causes infiltration of pollutants from the surface to depth, hence the contamination of groundwater. Most of the surface water points collected are either located close to the plantations (oil palm, rubber, coffee, cocoa, banana and small pineapple farms) or pass through them. These water points are often used by farmers to clean the spreading equipment. Pollution of these water sources by insecticides would be linked to direct pollution caused by this bad practice. Adingra and Kouassi [30] have also detected high concentrations of active ingredients, particularly dichlorodiphenyltrichloroethane (DDT) in the Ebrié lagoon. These authors found that most of the industrial plantations located in the coastal zone used large quantities of fertilizers and phytosanitary products such as insecticides, fungicides, nematicides, and herbicides. These high concentrations of active ingredients show the impact of pesticide use in agriculture on surface waters near plantations. According to Coulibaly et al. [31], surface waters near plantations are also exposed to diffuse pollution from these agricultural plots. The surface waters of the study area are therefore exposed to diffuse pollution from these plantations, which cause these high concentrations of insecticides. The high concentrations of insecticides found in surface waters could also be justified by the action of the wind which, during the application, carries part of the product towards these waters. Traoré et al. [32] show that the Aghien and Potou lagoons are polluted by pesticides due to the action of the wind. Indeed, during the spraying of the plantations bordering the waters, the polluted air loaded with pesticide particles reaches these water points. In groundwater (boreholes and wells), unlike surface water, dimethoate is the substance that is below WHO standards (<0.1 µg/L) (Leonard and al [33], FAO [34]). The other molecules found in these waters all show concentrations above this standard, in some cases showing values that are more extreme than those detected in surface water (ethyl parathion: 8.24 µg/L; profenofos: 8.04 µg/L). These high concentrations of insecticides are detected in a well located in the middle of a cocoa plantation in Yapokro, whose water is used for human consumption. As this well is not covered, it receives directly the residues of the chemicals used for treating the plantation. This explains the abnormal concentrations of active ingredients in this well. However, the average concentrations of active substances in the groundwater remain lower than those in the surface water.

6. CONCLUSION

The present study has shown that the waters of the south-eastern coastal region of Côte d'Ivoire are poor quality.

The measured temperatures reveal that groundwater is warmer than surface water. These different temperatures, although higher than the standards accepted by the WHO, do not present any pollution for these waters because they are characteristic of tropical waters. The conductivity of groundwater is higher than surface water conductivity. The average value of pH does not vary much either in groundwater (6.46) or in surface water (6.54). Analysis of the active ingredients reveals that surface and groundwater are polluted by the excessive and uncontrolled use of pesticides in the area. A total of nine (9) molecules of insecticides were found in water resources. They are Parathion-methyl, Chlorfenvinphos, Parathion-ethyl, Profenofos, Dimethoate, Chlorpyriphos-ethyl, Carbosulfan, Lambda Cyhalothrin, Deltamethrin. Extreme concentrations of parathion-ethyl (8.24 µg/L) and profenofos (8.04 µg/L) have been detected in groundwater located in the sedimentary part of the study area. In surface waters, these molecules also show high concentrations, in some cases with extremely high values not all the waters studied to comply with the WHO drinking water standards, which set the concentrations at 0.1 µg/L for an active ingredient and 0.51 µg/L for all the molecules contained in the sample.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. AQUASTAT. Irrigation en Afrique en chiffre. Rapport de la FAO Côte d'Ivoire sur l'eau; 2005.
2. SARA. L'agriculture ivoirienne à l'aube du XXIème siècle. Rapport du Salon de l'Agriculture et des Ressources Animales (SARA); 1999.
3. Francois L. Agriculture et pollution de l'eau : modélisation des processus et analyse des dynamiques territoriales. Thèse de Géographie univ. du Maine. 2012;185.
4. Keddal H. et N'dri Y. Impacts de l'intensification agricole sur la qualité des eaux de surface et des eaux souterraines. HTE. 2007;138:13.
5. Hauhouot C. Les pressions anthropiques sur les milieux naturels du sud-est ivoirien. Geo-Eco-Trop. 2004;289(1-2):69-82.
6. F.A.O. Elimination de grandes quantités de pesticides périmés dans les pays en voie de développement, Collection F.A.O. 1996;46.
7. IFEN. Les pesticides dans les eaux, bilan annuel. Jacques Le seigneur V. (Ed.). Etudes; 2002.
8. Kouzayha A. Développement des méthodes analytiques pour la détection et la quantification de traces des HAP et de pesticides dans l'eau. Application à l'évaluation de la qualité des eaux libanaises. Thèse de Doctorat, Université Bordeaux 1, France. 2011;233.
9. VAN DER WERF, HMG. Assessing the impact of pesticides on the environment. Agriculture, Ecosystems and Environment. 1996;60:81-96.
10. Barbash JE. The geochemistry of pesticides. In: Treatise on Geochemistry (Second Edition). H.D. Holland, K.K. Turekian, eds. Elsevier, Oxford. 2014;535-572.
11. Sanchez-Pena LC, Reyes BE, Lopez-Carillo L, Recio R, Moran-Martinez J, Cebrian ME, Quintanilla-Vega B. Organophosphorous pesticide exposure alters sperm chromatin structure in Mexican agricultural workers. Toxicology and Applied Pharmacology. 2004;196:108-113.
12. Rekha K, Jayasree R, Jayasree PK, Venkatachalam P, Jinu P, Thulaseedharan A. An efficient protocol for A. tumefaciens mediated genetic transformation in rubber tree (*Hevea brasiliensis*). Plant Cell Biotechnology and Molecular Biology. 2006;7(3&4):155-158.
13. Salameh PR, Baldi I, Brochard P, Raherison C, Abi Saleh B, Salamon R. Respiratory symptoms in children and exposure to pesticides. European Respiratory Journal. 2003;22:507-512.
14. Meyer A, Chrisman J, Moreira JC, Koifman S. Cancer mortality among agricultural workers from Serrana Region, state of Rio de Janeiro, Brazil. Environmental Research. 2003;93:264-271.
15. INS (Institut National de la Statistique). Recensement générale de la population et de; 2014.
16. Kpan OJG. Incidence de la variabilité climatique sur les ressources en eau, le développement agricole et la santé des populations dans le Sud-Est de la Côte d'Ivoire et prospectives : Cas de la zone littorale d'Abidjan à Aboisso. Thèse de Doctorat, Université Félix Houphouët Boigny, Côte d'Ivoire. 2017;225.
17. Geomine. Inventaire hydrogéologique appliqué à l'hydraulique villageoise. Ministère des travaux publics et des transports, Direction Centrale de l'Hydraulique, République de Côte d'Ivoire, Carte d'Abidjan, Cahier N°24. 1982;33.
18. Delor C, Diaby I, Simeon Y, Yao B, Tastet J-P, Vidal M, Chiron J-C. ET Dommanget A. Notice explicative de la Carte Géologique de la Côte d'Ivoire au 1/200 000. Feuille de Grand-Bassam, Mémoire de la Géologie de Côte d'Ivoire, n°4, Abidjan, Côte d'Ivoire. 1992;30.
19. Hirdes W, Konan KG, N'DA D, Okou A, Sea P. et, Zamble ZB. Carte géologique de la Côte d'Ivoire au 1/100 000. Partie Nord de la zone d'Aboisso. Feuille Grand Bassam, Coupures 4a, b, b bis; 2004.

20. DIBI B. Cartographie des sites potentiels d'implantation des points d'eau dans le département d'Aboisso (Sud-Est de la Côte d'Ivoire) : Apport du SIG et de l'analyse multicritère. Thèse de Doctorat de l'Université de Cocody. 2008;164.
21. Ake GE. Impact de la variabilité climatique et des pressions anthropiques sur ressources hydriques de la région de Bonoua (Sud-Est de la Côte d'Ivoire). Thèse de Doctorat de l'Université de Cocody. 2010;200.
22. Adiaffi B. Apport de la géochimie isotopique, de l'hydrochimie et de la télédétection à la connaissance des aquifères de la zone de contact "socle-bassin sédimentaire" du Sud-Est de la Côte d'Ivoire. Thèse de l'Université Paris-Sud, Orsay, France. 2008;217.
23. Carvalho JJ, Jeronimo PCA, Alpendurada MF. Evaluation of a multiresidue method for measuring fourteen chemical groups of pesticides in water by use of LC-MS-MS. Analytical and Bioanalytical Chemistry. 2008;392(5):955-968.
24. Traore A. Impacts des changements climatiques et du changement de l'occupation et de l'utilisation du sol sur les ressources en eau de l'environnement lagunaire d'Aghien et de Potou (sud-est de la côte d'ivoire). Thèse de Doctorat d'Etat en Sciences, Université Félix Houphouët Boigny, Côte d'Ivoire. 2016;260.
25. Orou KR. Influence de l'utilisation des intrants agricoles sur la qualité des ressources en eau et impacts sanitaires associés : Cas du département d'Agboville (Sud-Est de la Côte d'Ivoire). Thèse de Doctorat de l'Université Félix Houphouët Boigny. 2017;207.
26. Eblin SG, Soro GM, Sombo AP, Aka N, Kambiré O, Soro N. Hydrochimie des eaux souterraines de la région d'adiaké (sud-est côtier de la côte d'ivoire). Larhyss Journal, ISSN 1112-3680, n°17, Mars. 2014 ;193-214.
27. Ahoussi KE, Soro N, Kouassi AM, Soro G, Koffi YB, Zade GPS. Application des méthodes d'analyses statistiques multivariées à l'étude de l'origine des métaux lourds (Cu^{2+}, Mn^{2+}, Zn^{2+}, Pb^{2+}) dans les eaux des nappes phréatiques de la ville d'Abidjan. Int. J. Biol. Chem. Sci. 2010;4(5):1753-1765.
28. MINISTERE DE L'AGRICULTURE (M.A.). Liste des pesticides homologués et autorisés en Côte d'Ivoire. 2014;78.
29. Traore SK, Mamadou K, Dembele A, Lafrance P, Mazellier P, Houenou P. Contamination de l'eau souterraine par les pesticides en régions agricoles en Côte d'Ivoire (Centre, Sud et sud-ouest). Journal Africain des Sciences de l'Environnement. 2006;1:1-9.
30. Adingra AA. et Kouassi AM. Pollution en lagune Ebrié et ses impacts sur l'environnement et les populations riveraines. F. Tech. & Doc. Vulg. 2011;48-53.
31. Coulibaly L, Coulibaly S, Kamagate B, Sekongo N, Savane I, Gourene G. Distribution des pesticides d'origine agricole et évaluation de la vulnérabilité des ressources en eaux dans un bassin versant transfrontalier: Cas du Comoé, Côte d'Ivoire. European Journal of Scientific Research. 2012;76(4):601-613.
32. Traore A, Ahoussi KE, Aka N, Traore A, Soro N. Niveau de contamination par les pesticides des eaux des lagunes aghien et potou (sud-est de la côte d'ivoire) Int. J. Pure App. Biosci. 2015; 3(4):312-322.
33. Leonard RA, Knisel WG, Truman CC, Davis FM. The gleams model-a computer tool for evaluating agrochemical fate. Abstracts of Papers of the American Chemical Society. 1991;201:93.
34. FAO: La situation mondiale de l'alimentation et de l'agriculture en; 2017. Available:http://www.fao.org/3/i7658fr/I7658FR.pdf

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