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Agricultural Contamination of the Surface Waters of the Upper Ouémé in Benin: The Case of Heavy Metals and Pesticides

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Abstract

Objective: The main objective of this study was to assess the degree of contamination of surface waters by heavy metals and pesticides. **Method:** To this end, data were collected in December 2022 from four specific sampling stations: Okpara, Térou, Affon and Adjiro. Levels of heavy metals, including cadmium, chromium, copper, iron, mercury, nickel and lead, were measured and subjected to in-depth statistical analysis using graphical summation models. In addition, the concentrations of pesticide active ingredients present in the samples were interpreted and evaluated. The statistical data collected during this study were processed using R software, version 3.5.0. **Results:** The values obtained at the different stations Okpara, Térou, Affon and Adjiro are respectively Arsenic (2×10^{-4} mg/L; 2.2×10^{-1} mg/L; 1.2×10^{-4} mg/L; 2×10^{-4} mg/L), Cadmium (4.4×10^{-5} mg/L; 1.1×10^{-2} mg/L; 10^{-4} mg/L; 4×10^{-4} mg/L). Then Copper (7×10^{-4} mg/L; 3×10^{-3} mg/L; 7×10^{-4} mg/L; 1×10^{-4} mg/L), Iron (1.51 mg/L; 6.4×10^{-1} mg/L; 2.0012 mg/L; 2.9×10^{-1} mg/L), Lead (0 mg/L; 0 mg/L; 1.5×10^{-3} mg/L; 1.5×10^{-3} mg/L). Mercury, nickel and chromium were not detected in surface waters. It is important to note that the values obtained for trace metals (Cadmium, Chromium, Copper, Iron, Mercury, nickel and chromium were not detected in surface waters. It is important to note that the values obtained for trace metals (cadmium, chromium, copper, iron, mercury, nickel and lead) were all below the guideline standards set by the WHO in 2006 for uncontaminated surface waters. This indicates

that the surface waters of the Upper Ouémé were below acceptable contamination thresholds in terms of heavy metals. However, the presence of pesticide active ingredients such as cyfluthrin, endosulfan-alpha, endosulfan-beta, profenosfos, tihan, atrazine, gala super and glycel clearly indicates that these surface waters are subject to agricultural contamination.

Keywords

Agricultural Contamination, Heavy Metals, Pesticides, Surface Water, North Benin

1. Introduction

Surface waters are increasingly facing contamination due to the improper discharge of industrial effluents, untreated domestic waste, and agricultural residues [1] [2]. The presence of trace metals in soils has become one of the most worrying environmental issues [3]. Agricultural practices, including the use of excess organic or mineral fertilizers, as well as crop irrigation with potentially contaminated water, may contribute to surface water pollution [4]. In addition, agricultural areas are real sources of pesticides that can spread through ecosystems, affecting ecological services and the chemical quality of water bodies [5]. Inappropriate agricultural practices, such as the overuse of fertilizers to increase yields and the use of pesticides and herbicides, are among the major sources of surface water pollution [6]. The use of pesticides in agriculture is a growing public health and environmental concern [7]. Although Africa is the continent with the lowest pesticide use, the amount of products used in agriculture is significant. Unfortunately, information on the impact of these pesticides on human health and ecosystems is often unknown to suppliers, agricultural development actors, and farmers themselves [8]. The use of pesticides on crops poses real risks to public health and the environment [9]. In the aquatic environment, micropollutants are present in dissolved or particulate form [10]. Rapid population growth and economic development in Africa are affecting the environment and water resources [11]. As a result, agricultural areas have become important sources of pesticides that can spread to different ecosystems, affecting ecological services, chemical quality of water bodies, and the health of living organisms [5]. Environmental degradation is one of the consequences of economic development, which has too often prioritized economic imperatives to the detriment of ecological balance [12]. In addition, terrestrial ecosystems are increasingly contaminated by the widespread presence of pesticide residues, especially in the cotton sector [13]. Although industrial activity is less developed in most African countries, a growing awareness of the need for responsible management of aquatic resources and environmental wastes has been demonstrated by numerous studies [14]. In addition, pesticides, which are widely used in agriculture, are chemicals used to control organisms that are harmful to human activities [15].

The presence of toxic heavy metals in water, whether naturally occurring or due to human activity, poses a public health issue when concentrations surpass established safety thresholds [16] [17]. Nonetheless, the effects of heavy metal and pesticide pollution resulting from accidental or chronic buildup of these substances in the environment are not yet adequately researched [18]. The aim of our study is to assess the impact of agricultural practices on the environment, particularly with regard to heavy metal and pesticide contamination of surface waters in the Upper Ouémé.

2. Materials and Methods

2.1. Study Area

The studies focused on the surface waters of 4 watersheds (Affon, Okpara, Térou and Adjiro) in the communes of Copargo, Parakou, Bassila and Tchaourou in Benin, a West African country located between the parallels 6˚30' and 12˚30' north latitude and the meridians 1˚ and 30˚40' east longitude [19] [20] (**Figure 1**).

Geographical Coordinates of the Sampling Sites

The geographical coordinates of the four sampling sites mentioned below are indicated in **Table 1**.

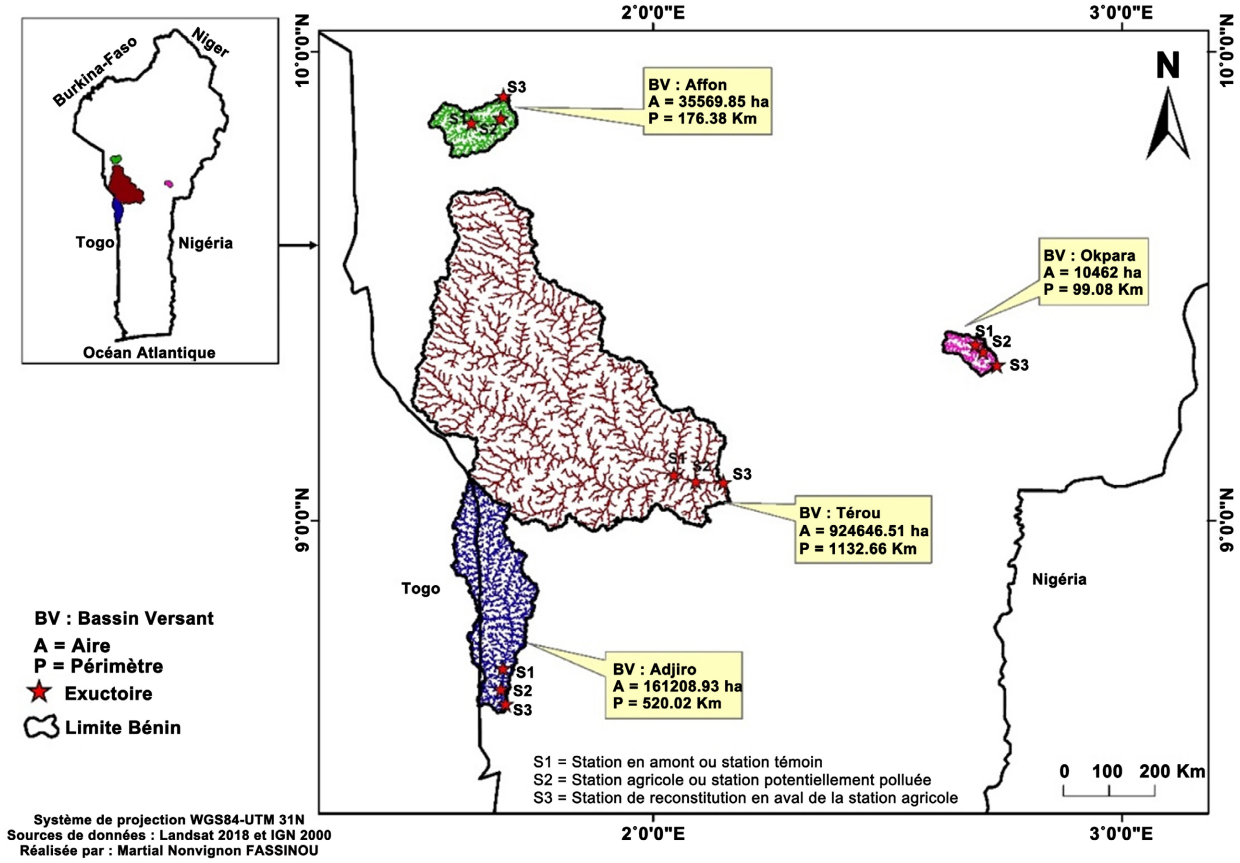

Figure 1. Geographical location of watersheds studied.

Table 1. Geographical coordinates of sampling sites.

	Geographical coordinates in UTM				Municipalities
Okpara (10,000 Km²)	Stations	X	Y	Précision (m)	Parakou
	S1	465,663	1,036,427	3 m	
	S2	467,449	1,034,714	2 m	
	S3	470,682	1,031,564	2 m	
Adjiro (8440 Km²)	Stations	X	Y	Précision (m)	Bassila
	S1	354,800	960,298	3 m	
	S2	354,333	955,375	3 m	
	S3	355,385	951,903	2 m	
Affon (4320 Km²)	Stations	X	Y	Précision (m)	Copargo
	S1	347,938	1,088,922	3 m	
	S2	354,769	1,089,968	2 m	
	S3	355,446	1,095,190	3 m	
Térou (3320 Km²)	Stations	X	Y	Précision (m)	Tchaourou
	S1	395,021	1,005,829	3 m	
	S2	400,155	1,004,274	3 m	
	S3	406,617	1,003,997	3 m	

S1 = Station upstream of polluted station; S2 = Polluted station; S3 = Restoration station downstream of polluted station.

- Okpara station: 9˚21'08"N, 2˚44'20"E, located in Borgou department, Parakou commune.
- Térou station: 9˚05'16"N, 2˚05'32"E, located in the south of Borgou and crossed by the Térou River.
- Affon station: 8˚52'29"N, 1˚30'51"E, located in Atacora department, Copargo commune, Tanéka Koko district.
- Adjiro station: 8˚36'50"N, 1˚40'51"E, located in Donga department, Bassila commune.

2.2. Data Collection

2.2.1. Choice of Sampling Stations

The largest tributaries of the upper Ouémé River were surveyed. The choice was based on proximity to agricultural areas, water availability, accessibility, water quality due to run-off of agricultural chemicals and sediments into the water-courses.

2.2.2. Sample Collection and Storage

Sample collection and storage procedures were rigorously followed in accordance with the recommendations of [21]. Plastic bottles with a capacity of 1.5 liters were used at each sampling station. Water samples were taken in the contaminated zone according to the methodology of Devez (2004) as follows:

- The vials were carefully rinsed three times with the water to be analyzed, each time filling the vial until the volume of water had been renewed three times.
- After sample collection, vials were immediately resealed to minimize the formation of air bubbles inside.
- Each sample was accurately labeled to avoid any subsequent confusion, indicating the place and date of sampling, among other relevant information.
- Sample vials were kept in a cool box at a constant temperature of 4˚C from the start of sampling to their arrival at the laboratory.
- Prior to analysis, samples were stored at a temperature below 4˚C and protected from light to guarantee their integrity.

2.2.3. Sample Preparation

➢ **Acidification**

To optimize sample preservation, each sample was acidified by adding 5 mL of nitric acid to 200 mL of test water. The aim of this procedure was to lower the pH of the sample to less than 2, since concentrated nitric acid is a powerful oxidizing agent capable of dissolving most common metals in accordance with the method of [21].

➢ **Filtration**

After acidification, all samples were subjected to filtration through 0.45 µm porosity filter membranes using glass filtration apparatus, operating under vacuum. The filtrate thus obtained was collected in clean vials for determination of the total content of Arsenic (Ar), Cadmium (Cd), Chromium (Cr), Copper (Cu), Iron (Fe), Mercury (Hg), Nickel (Ni) and Lead (Pb).

2.2.4. Heavy Metals Analysis Technique

Heavy metals were determined using Atomic Absorption Spectrophotometry with Flame (AASF), in accordance with the method described by [22]. Analyses were carried out at the Pesticide Residues Laboratory of Ghana Standards Authority of the University of Lagon and the Laboratoire Analyses de Geochimie Environnementale of the University of Lomé.

2.2.5. Sample Analysis Methods

Atomic Absorption Spectrophotometry is the method used for the quantitative analysis of chemical elements. It is based on the principle that an atom, in its ground state, can change to an excited state by absorbing energy in the form of electromagnetic radiation at a specific wavelength. Measurement of the decrease in light intensity, under specific conditions, is directly linked to the concentration of the element to be measured, as described in the study by [23].

2.2.6. World Health Organization (WHO) Recommended Standards

For toxic substances, the WHO recommended in 2006 the standards required for uncontaminated surface water (**Table 2**).

2.2.7. Technique for Extracting Pesticides from Water Samples

- Filter the sample through a filter paper to remove debris and solid particles.

Table 2. WHO standards for toxic substances in good quality water.

Toxic substances	Standards (WHO, 2006)
Arsenic	0.01 mg/L
Cadmium	0.003 mg/L
Chromium	0.05 mg/L
Copper	2 mg/L
Iron	0.3 mg/L
Mercury	0.006 mg/L
Nickel	0.07 mg/L
Lead	0.01 mg/L

Ar = Arsenic; Cd = Cadmium; Cr = Chromium; Cu = Copper; Fe = Iron; Hg = Mercury; Ni = Nickel; Pb = Lead.

- Transfer 1 L of the water sample to a 2 L separatory funnel and add 30 ml of saturated sodium chloride solution.
- Separate the water sample with 100 ml dichloromethane by vigorously shaking the separating funnel containing the sample for 2 - 3 minutes, releasing the pressure intermittently.
- Allow the layers to separate and drain off the dichloromethane extract layer.
- Repeat the separation process twice more, collecting the organic phase in a round-bottomed flask each time.
- Ensure that the sample is filtered through filter paper containing sufficient sodium sulfate to trap any moisture that may have leached out with the organic phase.
- Combine the three dichloromethane layer extracts and concentrate to approx. 2 ml using a vacuum rotary evaporator for gas chromatography.

2.2.8. Purification of Extract

- Condition a silica cartridge (1000 mg/6 ml) containing a layer of 0.3 g sodium sulfate with precisely 10 ± 0.2 ml dichloromethane, then load the sample extract onto the cartridge. Collect the eluent in a 100 ml round-bottomed flask.
- Elute the column with 20 ml dichloromethane, taking care to recover all the eluent, and concentrate the collected eluent to dryness using the rotary evaporator. Ensure that the temperature remains below 40˚C during this process.
- Once the sample extract is almost dry, dissolve it again in 1 ml ethyl acetate. To improve the accuracy of the analysis, add 20 µl of 1% polyethylene glycol in ethyl acetate (v/v) to the extract. Now transfer the prepared extract to a 2 ml standard opening vial. This extract is ready for pesticide quantification by gas chromatography coupled with electron capture spectrometry detection (GC-ECD) and flame photometry detection (GC-PFPD).

2.2.9. Sample Analysis Methods: Chromatographic Conditions for Organophosphorus Pesticides

The gas chromatography (GC) system used in this study is a Varian CP-3800 equipped with a CombiPAL autosampler, allowing efficient automation of sample introduction. A 0.25 µm thick VF-1701ms film-coated fused silica analytical column from Varian, offering high separation efficiency, was used. The injector is configured in splitless mode with a temperature of 270˚C, ensuring efficient sample vaporization. Compounds are detected using a Pulsed Flame Photometry Detector (PFPD) set at a temperature of 280˚C.

- **Data analysis**

Metallic Trace Element (MTE) content data were subjected to statistical analysis to explore relationships and correlations between the various stations and MTE. Similarly, a Principal Component Analysis (PCA) was performed using R software version 3.5.0. The pesticide active ingredient values obtained were carefully interpreted to assess their presence and concentration in the water samples. Histograms were produced to illustrate the distribution of pesticides in the various stations, highlighting spatial and temporal variations.

3. Results

The results of the study of the measured levels of Metallic Trace Element (MTE) show that the surface waters analyzed during the flood period contain different concentrations of arsenic (Ar), cadmium (Cd), chromium (Cr), copper (Cu), iron (Fe), mercury (Hg), nickel (Ni) and lead (Pb), as well as the active ingredients of the pesticides studied at each station.

3.1. Okpara Station

The levels of Metallic Trace Element (MTE) measured in the water of Okpara station show that the values obtained for Ar = 2×10^{-4} mg/L; Cd = 4.4×10^{-5} mg/L; Cr = 0 mg/L; Cu = 7×10^{-4} mg/L; Hg = 0 mg/L; Ni = 0 mg/L; Pb = 0 mg/L are all below the standard recommended by the World Health Organization (WHO, 2006) for surface water, except for mercury, nickel, chromium and lead which were not detected except for Fe = 1.51 mg/L. The values recommended by the WHO are Ar = 10^{-2} mg/L; Cd = 3×10^{-3} mg/L; Cr = 5×10^{-2} mg/L; Cu = 2 mg/L; Fe = 0.3 mg/L; Hg = 6×10^{-3} mg/L; Ni = 7×10^{-2} mg/L; Pb = 10^{-2} mg/L. **Figure 2** shows the trace metal content of Okpara Station water.

3.2. Térou Station

Metallic Trace Element (MTE) levels measured in water from the Térou station show the following values: Ar = 2.2×10^{-1} mg/L; Cd = 1.1×10^{-2} mg/L; Cr = 0 mg/L; Cu = 3×10^{-3} mg/L; Fe = 6.4×10^{-1} mg/L; Hg = 0 mg/L; Ni = 0 mg/L; Pb = 0 mg/L. In fact, arsenic, cadmium and iron have higher values than the standard recommended by the World Health Organization [24] for uncontaminated surface water. According to the WHO, the recommended values are respectively: Ar = 10^{-2} mg/L; Cd = 3×10^{-3} mg/L; Cr = 5×10^{-2} mg/L; Cu = 2 mg/L; Fe = 0.3 mg/L;

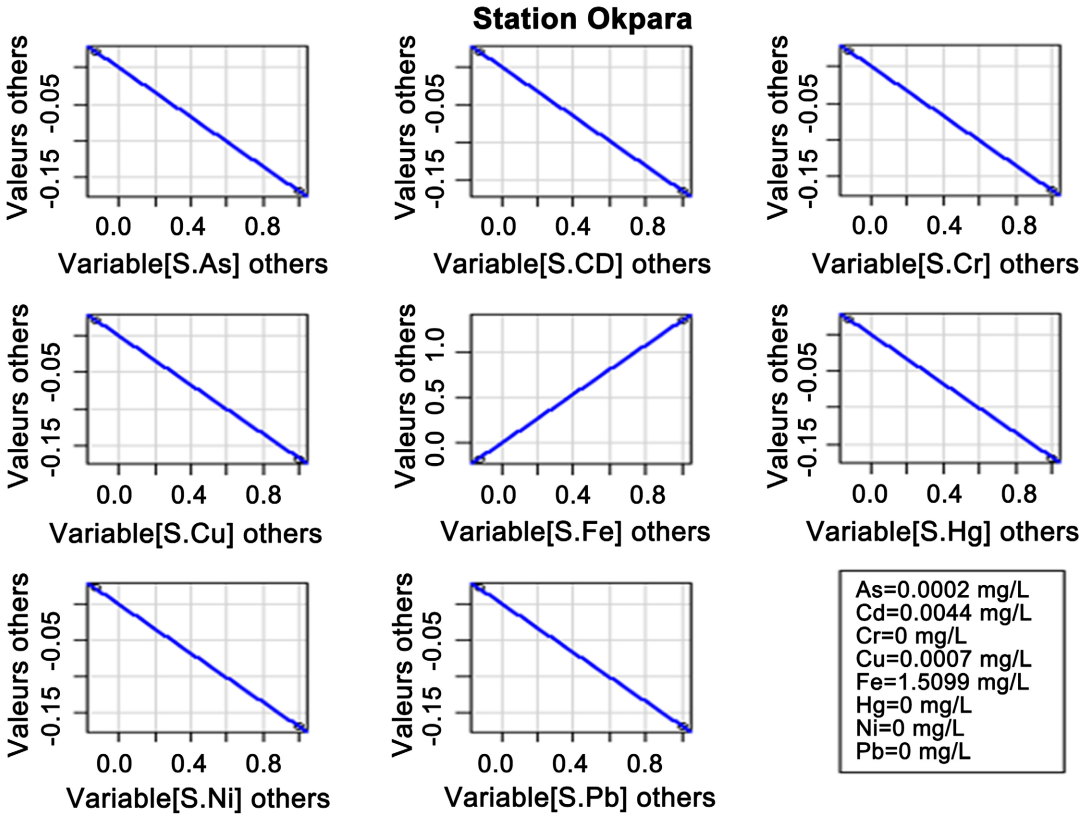

Figure 2. Trace metal content of Okpara station water.

Hg = 6×10^{-3} mg/L; Ni = 7×10^{-2} mg/L; Pb = 10^{-2} mg/L. **Figure 3** shows the trace metal content of water from the Térou station.

3.3. Affon Station

Metallic Trace Element (MTE) levels measured in water from the Affon station give the following values: Ar = 1.2×10^{-4} mg/L; Cd = 10^{-4} mg/L; Cr = 0 mg/L; Cu = 7×10^{-4} mg/L; Hg = 0 mg/L; Ni = 0 mg/L; Pb = 1.5×10^{-3} mg/L. These values are all below the standard recommended by the World Health Organization [24] for uncontaminated surface water, with the exception of Fe = 2.0012 mg/L. The WHO recommended values are respectively: Ar = 10^{-2} mg/L; Cd = 3×10^{-3} mg/L; Cr = 5×10^{-2} mg/L; Cu = 2 mg/L; Fe = 0.3 mg/L; Hg = 6×10^{-3} mg/L; Ni = 7×10^{-2} mg/L; Pb = 10^{-2} mg/L. **Figure 4** shows the trace metal content of Affon station water.

3.4. Adjiro Station

Metallic Trace Element (MTE) levels obtained in water from the Adjiro station show that the values obtained for Ar = 2×10^{-4} mg/L; Cd = 4×10^{-4} mg/L; Cr = 0 mg/L; Cu = 1×10^{-4} mg/L; Fe = 2.9×10^{-1} mg/L; Hg = 0 mg/L; Ni = 0 mg/L; Pb = 1.5×10^{-3} mg/L are all below the standard recommended by the World Health Organization [24] for uncontaminated surface water, except for chromium, nickel and mercury, which were not detected. The WHO recommended values

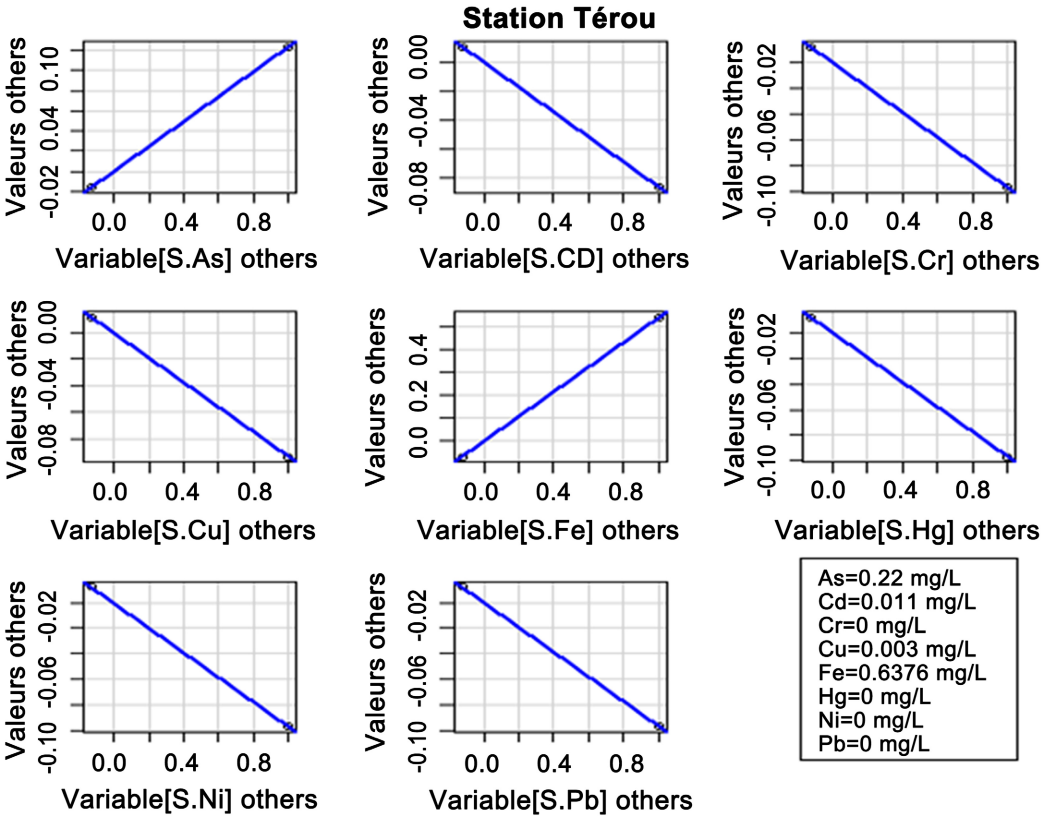

Figure 3. Trace metal content of water from the Térou plant.

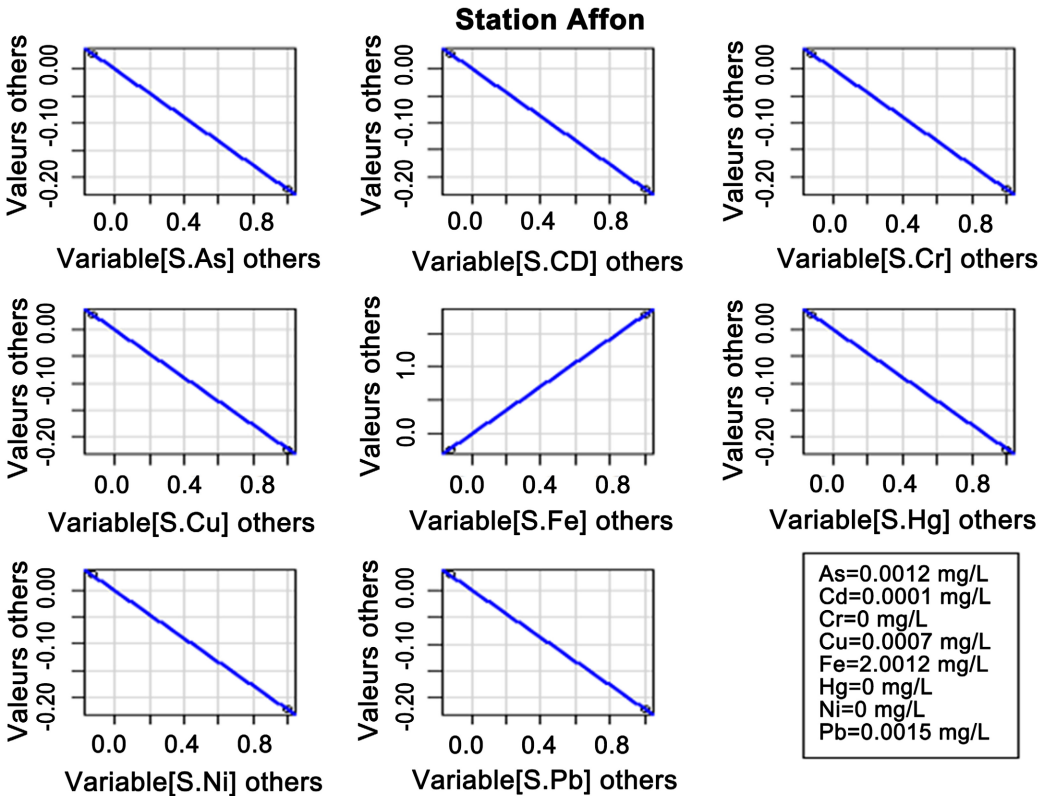

Figure 4. Trace metal content of water from Affon plant.

are respectively: Ar = 10^{-2} mg/L; Cd = 3×10^{-3} mg/L; Cr = 5×10^{-2} mg/L; Cu = 2 mg/L; Fe = 0.3 mg/L; Hg = 6×10^{-3} mg/L; Ni = 7×10^{-2} mg/L; Pb = 10^{-2} mg/L. Figure 5 shows the trace metal content of water from the Adjiro station.

4. Principal Component Analysis

4.1. Correlation Circle

A Principal Component Analysis (PCA) was carried out in R software version 3.5.0 in order to describe the relationships between the Metallic Trace Element (MTE) in the various stations and to give the characteristics of each hydrochemical group. The results of this analysis show that the two principal components account for 71.33% and 19.84% respectively, *i.e.* a total of 91.17% of the variations in the initial table, which is sufficient to guarantee excellent accuracy of interpretation. However, correlation analysis shows that Trace Metals (TMEs) such as Iron move in the same direction at the different stations. Copper, arsenic, lead and cadmium are also moving in the same direction. Finally, Mercury, Zinc, Nickel and Chromium are not represented in the various stations and tend towards the origin. Figure 6 shows the correlation circle for Metallic Trace Element (MTEs).

4.2. Correlation between Stations and Trace Metal Elements (TMEs)

Metallic Trace Element (MTE) such as iron are better represented at the Okpara and Affon stations. On the other hand, Copper, Arsenic, Lead and Cadmium are

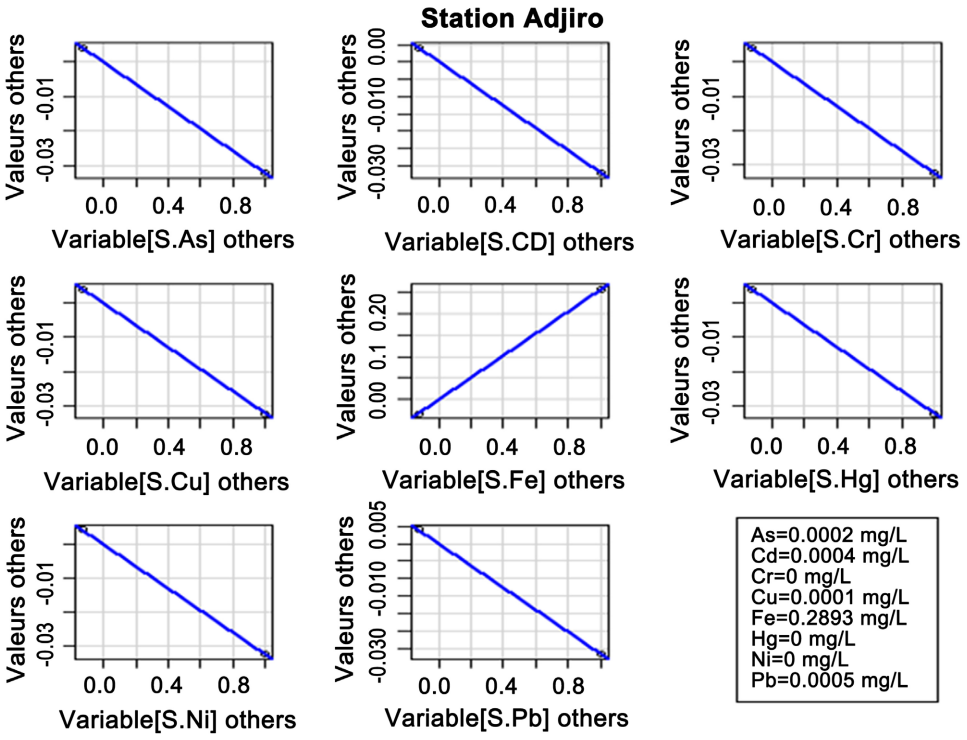

Figure 5. Trace metal content of water from the Adjiro plant.

more represented at the Térou station. Mercury, zinc, nickel and chromium are poorly represented at the Adjiro station. Figure 7 shows the distribution of stations in the Axis 1 and 2 system.

4.3. Pesticide Content

The stations of Okpara, Térou, Affon and Adjiro as indicated in Table 3 show the presence of a number of active ingredients in surface waters, including cyfluthrin, endosulfan-alpha, endosulfan-beta, profenosfos, tihan, atrazine, gala super and glycel, indicating the state of agricultural contamination by pesticides.

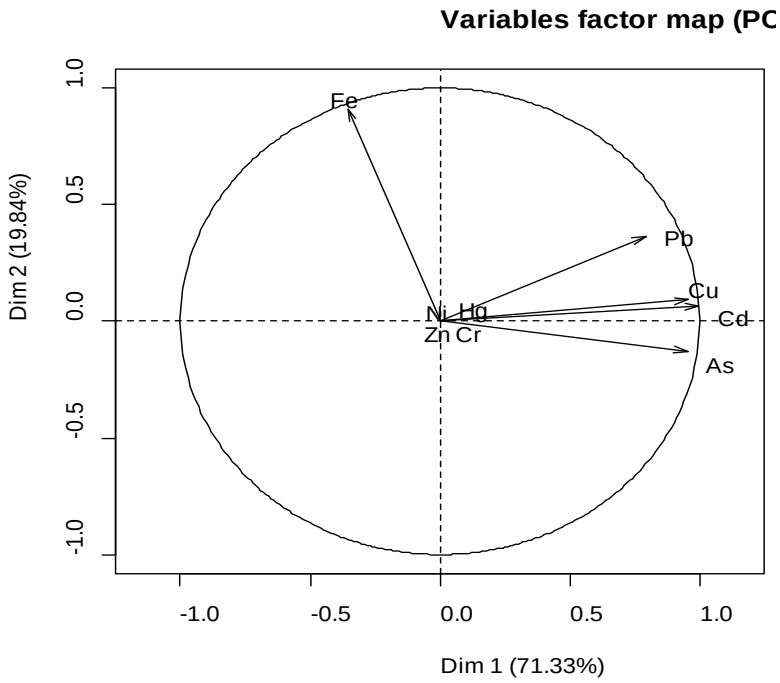

Figure 6. Correlation circle for Trace Metal Elements (TMEs).

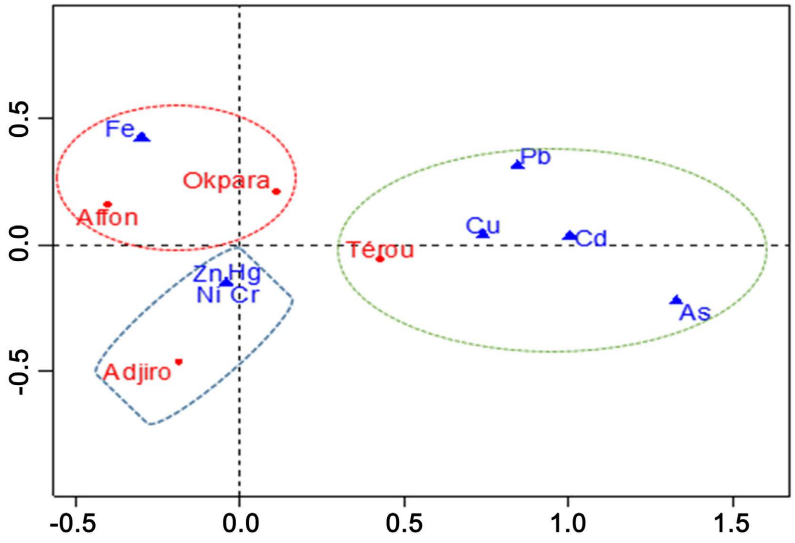

Figure 7. Distribution of stations in the Axis 1 and 2 system.

Table 3. Pesticide levels in surface water at surveyed sites.

	Pesticides	Unit	Résults			
			Station Okpara	Station Térou	Station Affon	Station Adjiro
Insecticides	Aldrin	µg/L	nd	nd	nd	nd
	Allethrin	µg/L	nd	nd	nd	nd
	Trans-Chlordane	µg/L	nd	nd	nd	nd
	Chlorpyrifos	µg/L	nd	nd	nd	nd
	Cyfluthrin	µg/L	1.7×10^{-2}	4.7×10^{-2}	4×10^{-3}	1.1×10^{-2}
	DDD-p,p'	µg/L	nd	nd	nd	nd
	Deltamethrin	µg/L	nd	nd	nd	nd
	Dieldrin	µg/L	nd	nd	nd	nd
	Endosulfan-alpha	µg/L	6.4×10^{-2}	3.4×10^{-2}	1×10^{-2}	1.8×10^{-2}
	Endosulfan-beta	µg/L	6×10^{-2}	3.2×10^{-2}	1.3×10^{-2}	2.1×10^{-2}
	Heptachlor	µg/L	nd	nd	nd	nd
	Fanofos	µg/L	nd	nd	nd	nd
	Profenosfos	µg/L	7×10^{-2}	2.4×10^{-2}	1.5×10^{-2}	7×10^{-2}
Herbicides	Ametryne	µg/L	nd	nd	nd	nd
	Atrazine	µg/L	4×10^{-3}	1.3×10^{-2}	2.6×10^{-2}	8×10^{-3}
	Butachlor	µg/L	nd	nd	nd	nd
	Fluazifop-p-butyl	µg/L	nd	nd	nd	nd
	Gala super	µg/L	1×10^{-2}	1.7×10^{-2}	4.9×10^{-2}	4×10^{-2}
	Glycel	µg/L	5.5×10^{-3}	3.4×10^{-3}	5.2×10^{-2}	4.6×10^{-2}
	Oxyfluorifen	µg/L	nd	nd	nd	nd
	Terbutryne	µg/L	nd	nd	nd	nd
Fungicides	Boscalid	µg/L	nd	nd	nd	nd
	Difenoconazole	µg/L	nd	nd	nd	nd
	Kresoxim-methyl	µg/L	nd	nd	nd	nd
	Tebuconazole	µg/L	nd	nd	nd	nd

nd = not determined.

4.4. Spatial Distribution of Active Ingredients

The active ingredients found in surface water showed the effective use of pesticides. Endosulfan-alpha (R^2 = 0.7687), Endosulfan-beta (R^2 = 0.7311) and Gala super (R^2 = 0.7253) were strongly correlated in the different stations (Okpara, Térou, Affon, Adjiro). On the other hand, Cyfluthrin (R^2 = 0.0342), Profenosfos (R^2 = 0.0016) and Glycel (R^2 = 0.0157) were weakly correlated. The low values obtained could be explained by the collection period. Figure 8 shows the spatial distribution of pesticides at the various stations.

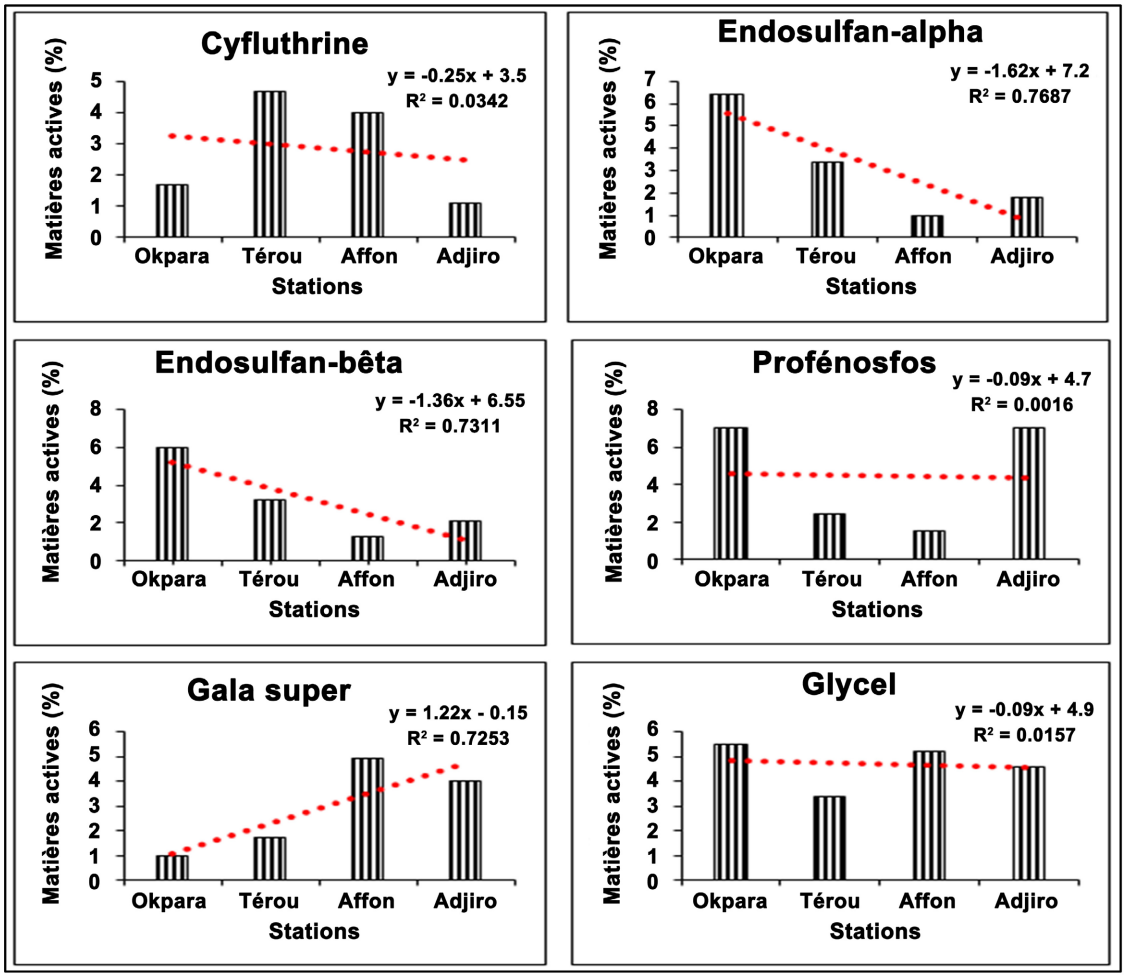

Figure 8. Spatial distribution of pesticides at different stations.

5. Discussion

Analysis of the results for Metallic Trace Element (MTE) measured in surface waters from the four stations: Okpara, Térou, Affon and Adjiro shows little variation from one station to another. In fact, total levels of Arsenic (Ar), Cadmium (Cd), Chromium (Cr), Copper (Cu), Mercury (Hg), Nickel (Ni) and Lead (Pb) are below the World Health Organization [24] recommended standards for surface waters. On the other hand, iron (Fe) levels in sampled waters exceeded the normal [24] limit of 0.3 mg/L: 1.51 mg/L; 6.4×10^{-1} mg/L; 2.0012 mg/L at Okpara, Térou and Affon respectively. In terms of the aforementioned standard, this situation indicates that these waters may be contaminated with Metallic Trace Element (MTE). Furthermore, the values obtained for cadmium and lead at the various sampling stations (Okpara, Térou, Affon and Adjiro) are respectively: 4.4×10^{-5} mg/L; 1.1×10^{-2} mg/L; 10^{-4} mg/L; 4×10^{-4} mg/L for cadmium and 0 mg/L; 0 mg/L; 1.5×10^{-3} mg/L; 10^{-2} mg/L for Lead. These values corroborate those reported by [19] in their study of heavy metals and pesticides in drinking water, soils and sediments in the cotton belt of Gogounou, Kandi and Banikoara in Benin. The protection of these waters against various contamina-

tions is necessary and imperative if they are to continue to be used in agriculture without risk of contamination by [25]. Certain toxic environmental contaminants, such as trace metals, accumulate in the tissues of humans and livestock and are then transferred to the food chain [26]. Freshwater ecosystems are therefore vulnerable to metals, as insoluble metal compounds accumulated in sediments can be released into pore water, increasing the concentration of soluble or suspended metals.

In terms of pesticide test results, organophosphorus contamination was fairly regular but low in the water sampled at the four (04) sampling stations: Okpara, Térou, Affon and Adjiro. The presence of the active ingredient Cyfluthrin was higher at the Adjiro station (1.1×10^{-2} µg/L) than at the other stations (1.7×10^{-2} µg/L; 4.7×10^{-2} µg/L; 4×10^{-2} µg/L) in Okpara, Térou and Affon, respectively. Active ingredients such as Endosulfan-alpha, beta, Profenosfos and Tihan were found in surface waters at low doses at the different stations, reflecting the use of these products by farmers and gardeners. The values obtained for endosulfan-alpha (6.4×10^{-2} µg/L; 3.4×10^{-2} µg/L; 1×10^{-2} µg/L; 1.8×10^{-2} µg/L), endosulfan-beta (6×10^{-2} µg/L; 3.2×10^{-2} µg/L; 1.3×10^{-2} µg/L; 2.1×10^{-2} µg/L) and profenosfos (7×10^{-2} µg/L; 2.4×10^{-2} µg/L; 1.5×10^{-2} µg/L; 2.5×10^{-2} µg/L) in the different stations (Okpara, Térou, Affon and Adjiro) show the state of contamination of surface waters by chemicals (insecticides). On the other hand, active ingredients such as Atrazine, Gala super and Glycel are also present in surface waters. The values obtained for Atrazine (4×10^{-3} µg/L; 1.3×10^{-2} µg/L; 2.6×10^{-2} µg/L; 8×10^{-2} µg/L), Gala super (1×10^{-2} µg/L; 1.7×10^{-2} µg/L; 4×10^{-2} µg/L; 2.5×10^{-2} µg/L) and Glycel (5.5×10^{-2} µg/L; 3.4×10^{-2} µg/L; 5.2×10^{-2} µg/L; 4.6×10^{-2} µg/L) respectively at the different stations (Okpara, Térou, Affon, and Adjiro) also show the state of contamination of surface waters by chemicals, particularly herbicides. The use of endosulfan in soils poor in organic matter presents a significant threat to water resources and food crops, particularly in the event of heavy rainfall [27]. This potential threat jeopardizes water, a vital resource essential to economic development. To ensure the health of consumers and preserve the integrity of this crucial resource, it is imperative to monitor water quality in accordance with established standards [28]. It is therefore essential to identify the sources of pollution in hydrological systems, which is key to better understanding the ecological consequences of such pollution [29]. Furthermore, watersheds have particular characteristics that can have significant negative impacts on water resources, accumulating various forms of pollution [30]. It is therefore essential to implement effective monitoring and management measures to protect water resources, taking into account the specific features of each watershed.

6. Conclusions

In summary, the concentration of metallic trace elements and pesticides poses significant risks to human health and the environment.

Exceeding a certain threshold can result in hazardous chemical molecules. Various pollution indicator parameters demonstrate the dangers of utilizing surface water for agricultural purposes, specifically market gardening. The transfer of trace metals and pesticides from the soil into surface water imposes a significant threat to the well-being of aquatic life and the aquatic environment. Controlling the quality of agricultural inputs used in farming and market gardening is crucial, as well as the obligation to establish application periods before harvest. Continuous monitoring of surface water quality through an alert system is essential for public health reasons.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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