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Geochemical contribution to now know underground waters quality of former toxic waste zones

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Abstract

Around 540 m^3 of toxic liquid waste from Probo Koala Boat, were dumped in 13 zones, of the Abidjan district during the night of 20th to 21st August 2006. The abrupt character of the situation and insufficient knowledge about the risks of this high magnitude pollution has made it difficult to solve quickly this environmental problem. Therefore this work aims to improve technical knowledge about the management of underground waters analysis results from contaminated toxic waste in the sustainable development context.

To make this work, an environmental sampling program to determine the presence or absence of potential contaminants in groundwater cause by the dumping of waste from the Probo Koala has been recommended to state of Côte d'Ivoire since 2015 by the UN Environment Program after the depollution work on the zones. 17 piezometers have been built to manage underground waters in Abidjan at the 13 toxic waste dumping zones.

The results permitted to identify the lithology of the crossed formations and the static level of each piezometer. The large crossed formations find are clay, sand and sandy clay. All these formations stay on the bed rock which was reached at Alépé, Anyama (reference zone) and Agboville. The decision matrices permitted to determine that the water of bad quality are the water from each piezometers of the zones: zone 1 Erymakouguié, zone 3 Dokui2, zone 4 Abobo Coco service, zone 5 AboboSagbé, zone 7 M'Badon, zone 9 Filtissac. There are 6 zones where the water are bad quality. Good quality water are the water from the piezometers of the zones: zone 6 Akouédo, zone 8 Koumassi, zone 10 Maca Cité ADO.

The aim of the decision matrices is to permit to the decision-makers "the public authorities" to find the quintessence of this work, as quickly as possible without necessary having to read it in full. Two color symbols have been used to characterize the water quality of the piezometers the green color shows that the underground waters is good quality, but the red color alerts that there are measures to be taken for the protection of the underground waters of concerned zones.

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Keywords: Toxic Waste; Quality; Underground Waters; Decision; Matrices

1. Introduction

This work aims to show the geochimical contribution to now know underground waters quality after the toxic waste. Around 540 m^3 of toxic liquid waste from Probo Koala Boat, were dumped in 13 zones, of the Abidjan district during the night of 20th to 21st August 2006. The pollutes compounds toxic waste were discharge in Abidjan distric made 30 000 cases of intoxication and the death of one hundred people (Dongo and *al.*, 2012) (Amnesty International, 2012). What about the quality of now know underground waters quality after the toxic waste? Therefore this work aims to improve technical knowledge about the management of toxic waste of underground waters analysis results. 17 piezometers have been built to manage underground waters in Abidjan at the 13 toxic waste dumping zones. The toxic waste compounds have carcinogenic, toxic, and mutagenic properties, some have been classified as priority pollutants by the US-EPA (Keith &Telliard, 1979). In the environment, PAHs contribute to the contamination of soil, water, and air worldwide (US-EPA, 1999). To study the underground water impact of these pollutants in Ivory Coast generally, and particularly, in the Abidjan district, groundwater samples were sent to the Wessling laboratory in France for analysis.

2. Materials and Methods

2.1. Samples

This study concerns the 13 toxic waste-contaminated zones in the southern region of Ivory Coast, located within the Abidjan district. The samples analysed were collected from 17 piezometers that have been built to manage underground waters in these 13 toxic waste dumping zones in Abidjan district. The geographical coordinates are presented in Table 1.

Table 1 The geographic position of 13 contaminated toxic waste zones

Zone	Unloading geographic position
Cocody: Akouédo	-AkouédoI : N 05°21.429’ - W 03°56.095’ -AkouédoII : N 05°21.077’ - W 03°56.206’ -AkouédoIII : N 05°21.425’ - W 03°56.028’
Abobo	-Abobo (Coco services) : N 05°24.092’ - W 04°01.167’ -AboboSagbé : N 05°24.409’ - W 04°01.593’ -Plateau DoduiI : N 05°23.403’ - W 04°00.367’
Abobo Alépé Road (Djibi Village)	-Alépé1 : N 05°27.373’ - W 03°58.344’ -Alépé2 : N 05°27.572’ - W 03°58.280’
Yopougon: Civile Prison Road (MACA)	-MACA I : N 05°23.354’ - W 04°04.710’ -MACA II : N 05°24.811’ - W 04°04.674’ -MACA III : N 05°25.309’ - W 04°04.405’
Koumassi	-Koumassi Industrial Zone : N 05°17.547’ - W 03°56.783’
Port-Bouet	-Vridi CAP Logistic : N 05°15.832’ - W 03°59.980’

Underground waters were sampled in 17 piezometers of these 13 zones. The extract contained PAHs, VACs, mercaptans, sulfur, heavy metals, and various organic compounds ranging from macromolecules (e.g., asphaltenes) to mono-aromatic units. These analyses were conducted using a photometer-equipped microscope to determine the proportion of volume occupied by different underground waters.

2.2. Hydrogeology of toxic waste tipping zone

The hydrogeology context of the survey zone is characterized by two types of acquiferes: the discontinuous acquiferes of the pedestal and the continuous acquifere of the inshore sedimentary basin that contain the continental terminal of Abidjan. In the formations of pedestal, the permeability is weak in clay reservoir, and strong to the discontinuous acquifere.

The conceptual diagram of this type of reservoir show that clay plays a role of storage (capacitive function) and as a broken reservoir role (conductive function) (Antea, 2007).

In non influenced system (out pumping) the two acquiferes are balance. The porosity would be there strong and the permeabilities are weak generally.

The works of these authors (Koffi and *al.,* 2013) showed also that these waters are generally of good chemical quality and that they are surmounted by reservoirs of clay generally exploited by villagers well whose depths fewer than 5 m. The transmissivity met on the set of the survey zone is consisted generally between 1,9 10^{-6} and 8,9 10^{-5} m^2/s in the schistose levels and 2,3 10^{-5} and 4,6 10^{-4} m^2/s in the levels granitiques.

On a card piezometrique achieved by the National office of the drinking water (ONEP) in June 2020, the points of tipping of the toxic waste have been projected in order to get a card (Figure 1). The isopiezes curves descended of this country leaves from the coast 55 to 0 m with a out-flow sense of NS and NW. The analysis of the isopiezes card show that the static level of the different works of Abidjan (LBTP, 2015) (Rockwell, 2021).

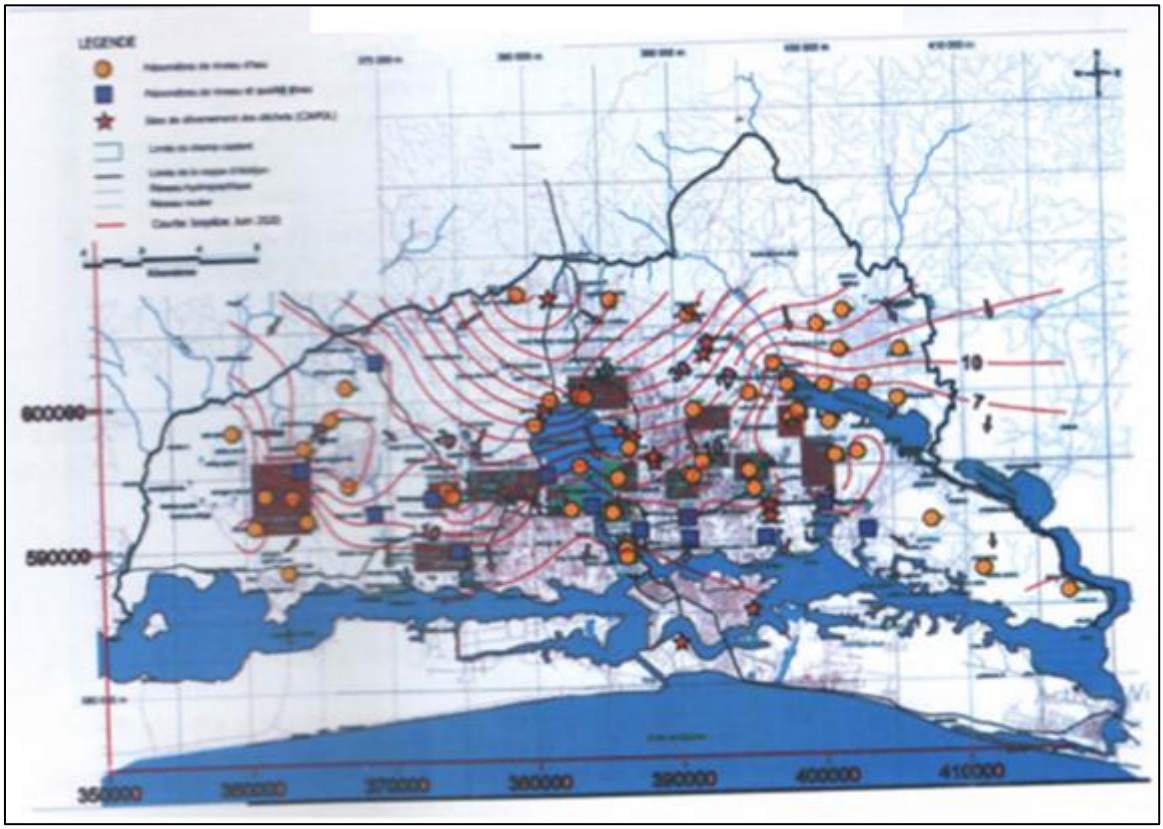

Figure 1 Piezometric card of Abidjan

2.3. Hydrochemistry of toxic waste

The table 2 show the minimal values, middle and maximal of physico-chemical analyzed parameters. The pH of groundwaters varies from 3,6 to 7,4 with an average of 5,6. The conductivity, when to it, oscillate between 42 µ S/cms and 4380 µ S/cms. The concentrations of ions ammonium vary from 0,11 mg/L to 16,77 mg/L, with an average of 2,75 mg/L. The shape oxidized of nitrogen (the nitrate ion) has some concentrations between 2,22 mg/L to 252,51 mg/L (correspondent to five more than the WHO norm) (Rockwell (2021).

Table 2 Physico-chemical parameters of the samples of the underground waters of Abidjan

Parameters	Minimum	Middle	Maximum	Standard-deviation
pH	3.6	5.6	7.4	0.91
Cond (µS/cm)	42	772.78	4380	589.97
TDS (mg/L)	19.8	388.87	2270	301.61
NH4+ (mg/L)	0.11	2.75	16.77	3.82
NO3+ (mg/L)	2.22	42.4	252.51	39.07
HCO3- (mg/L)	0.49	2.6	17.69	3.03
SO42- (mg/L)	1.77	30.83	131.43	26.81
Cl- (mg/L)	15.98	76.75	244.95	46.23
Ca2+ (mg/L)	4.53	40.18	125	25.67
Mg2+ (mg/L)	0.63	42.53	179.65	37.84
Na+ (mg/L)	10.45	47.23	98.94	20.43
K+ (mg/L)	0.59	28.99	105.68	17.36

2.4. Setting reglementation: Netherland international norms

The international norms of Netherland intervention for the dépollution of the underground waters are been used for this workas reference. These norms correspond to the limits of dépollution judged acceptable by Netherland and used in this situation by the government of Ivory Coast (UN Environment, 2017).

2.5. Analytical

2.5.1. Extraction-fractionation

A mixture of chloroform / methanol (50/50 v/v) are been used for the samples with a strong waters content (Biache, 2008). Aliphatic, aromatic, and polar fractions were separated by liquid chromatography on a silica column through successive elution with pentane and a pentane/dichloromethane mixture. Polar compound were recovered using a methanol/dichloromethane mixture. After each step, the recovered fractions were weighed and the mass differences were calculated.

2.5.2. Gas Chromatography-mass Spectrometry

Table 3 Parameters and analytical methods

Parameters	Norm	Technical	Laboratory
Benzene and aromatics (VAC -BTEX)	NF ISO 11423-1(#)	GC-MS	Wessling Lyon (F)
Volatile Halogenated Hydrocarbons Compounds (VHOC) on water	NF EN ISO 10301(#)	GC-MS	Wessling Lyon (F)
Polycyclics Aromatics Hydrocarbons (HAP)	Internal method HAP-PCB adapted de NF T90-115(#)	GC-MS GC-FID	Wessling Lyon (F)
Hydrocarbons Idication (GC) on water / leached (HCT)	NF EN ISO 9377-2(A)	GC-FID	Wessling Lyon (F)
Metals / Elements on water / leached	DIN EN ISO 11885 / DIN EN ISO 17294-2(A)	(ICP-MS)	Wessling Altenberge (D)
Metals on water / leached	NF EN ISO 17294-2(#)	(ICP-MS)	Wessling Lyon (F)
Metals on water / leached (ICP-MS)	NF EN ISO 17294-2(#)	(ICP-MS)	Wessling Lyon (F)
Mercaptans on water	WEX 100	(ICP-MS)	Partner Laboratory

Aliphatic and aromatic hydrocarbons, along with polar compounds, were analyzed by gas chromatography–mass spectrometry (GC–MS) using an HP 5890 Series II GC coupled to an HP 5971 mass spectrometer. An on-column injector, a 60 m DB-5 J&W fused silica column (0.25 mm i.d., 0.1 mm film thickness), and a temperature program of 40–300 °Cat 3 °C/min followed by an isothermal stage at 300 °C for 15 minutes (with constant helium flow at 1 ml/min) were employed. Due to the presence of carboxylic acids in the polar fractions, silylation using BSTFA + 1% TMCS (99/1) was performed to enhance chromatographic resolution (Biache et al., 2014). A small aliquot of the sample was dissolved in the derivatizing solution at a concentration of 4 mg/ml and heated for 15 minutes at 50 °C. One microliter of the solution was then directly injected into the gas chromatograph (Biache et al., 2014). Geochemical analytical techniques such as GC-FID and ICP-MS were also applied in this study. Details of all analytical methods are provided in Table 3.

3. Results

The results of this study concern underground water collected from toxic waste affected zones in Abidjan district. These samples were sent to the Wessling labolatory in France for analysis. The findings revealed that Polycyclics Aromatics Hydrocarbons (PAH), Volatile Aromatics Compound (VAC), mercaptans, sulfurs-containing molecules, and heavy metals were the primary pollutants present in the underground waters.

3.1. Concentrations of underground waters samples in Polycyclics Aromatics Hydrocarbons (PAH)

The Table 4 show the concentrations of underground waters samples in Polycyclics Aromatics Hydrocarbons (PAH). As the norms Netherlanders of the underground waters are not being defined for the 16 HAP, the concentrations of the waters of the piezometers measured on the 13 sites have been compared to the site 2 of Anyama, site of reference. For all, concentrations of the 16 HAP are equal the site 2 of Anyama, site of reference. Only the site 1 Erymakouguié show meaningful variations to site 2 of Anyama reference. Thus, the concentration of Pyrene is 0,06 µg/ls for this site 1 whereas it is 0,02 µg/ls for the site 2 of Anyama reference. Either, 0,04 µg/ls more than the site 2 of Anyama reference. The concentration of Benzo (a) anthracene is 0,03 µg/ls for this site 1 whereas it is 0,02 µg/ls for the site 2 of Anyama reference. Either, 0,01 µg/ls more than the site 2 of Anyama reference. The concentration of Chrysene is 0,91 µg/ls for this site 1 whereas it is 0,02 µg/ls for the site 2 of Anyama reference. Either, 0,89 µg/ls more than the site 2 of Anyama reference. The concentration of Benzo (b) fluoranthene is 0,11 µg/ls for this site 1 whereas it is 0,02 µg/ls for the site 2 of Anyama reference. Either, 0,09 µg/ls more than the site 2 of Anyama reference. The concentration of Benzo (k) fluoranthene is 0,14 µg/ls for this site 1 whereas it is 0,02 µg/ls for the site 2 of Anyama reference. Either, 0,12 µg/ls more than the site 2 of Anyama reference. The concentration of Benzo (a) pyrene is of 0,05 µg/ls for this site 1 whereas it is 0,02 µg/ls for the site 2 of Anyama reference. Either, 0,03 µg/ls more than the site 2 of Anyama reference. The concentration of Dibenzo (a,h) anthracene is 0,03 µg/ls for this site 1 whereas it is 0,02 µg/ls for the site 2 of Anyama reference. Either, 0,01 µg/ls more than the site 2 of Anyama reference.

Table 4 Concentrations of underground waters samples in Polycyclics Aromatics Hydrocarbons (PAH)

Sample number	Sample name	Naphtalene	Acenaphtylene	Acenaphtene	Fluorene	Phenanthrene	Anthracene	Fluoranthene	Pyrene	Benzo(a)anthracene	Chrysene	Benzo(b)fluoranthene	Benzo(k)fluoranthene	Benzo(a)pyrene	Dibenzo(a,h)anthracene	Indeno(1,2,3,c,d)pyrene	Benzo(g,h,i)perylene
23-001385-01	SITE 1. ERYMAKOUGUIE (point 1 et 15 et 16)	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.06	0.03	0.91	0.11	0.14	0.05	0.03	0.02	0.02
23-001385 03	SITE 3. Dokui 2 (point 3 et 35 et 36)	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
23-001385-04	SITE 4. ABOBO COCO SERVICE (point 4 et 45 et 46)	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
23-001385-05	SITE 5. ABOBO SAGBE (point 5 et 55 et 56)	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
23-001385-06	SITE 6. AKOUEDO (point 6 et 55 et 66)	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
23-001385-07	SITE 7. M'BADON (point 7 et 75 et 76)	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
23-001385-08	SITE 8. KOUMASSI 1 (point 8 et 85 et 86)	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
23-001385-09	SITE 9. FILTISSAC (point 9 et 95 et 96)	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
23-001385-10	SITE 10. MACA CITE ADO (point 10 et 105 et 106)	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
23-001385-11	SITE 11. 4.CROIX (point 11 et 115 et 116)	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
23-001385-12	SITE 12. ALEPE 1 (point 12 et 125 et 126)	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
23-001385-13	SITE 13. VRIDI LDC (point 13 et 135 et 136)	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
23-001385-02	SITE 2. ANYAMA REFERENCE (point 2 et 25 et 26	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
	Netherland international norms (µg/l)	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

All these variations measured to the level of this site reveal the bad quality of waters to the site 1 Erymakouguié. All these variations are presented on the Figure 2.

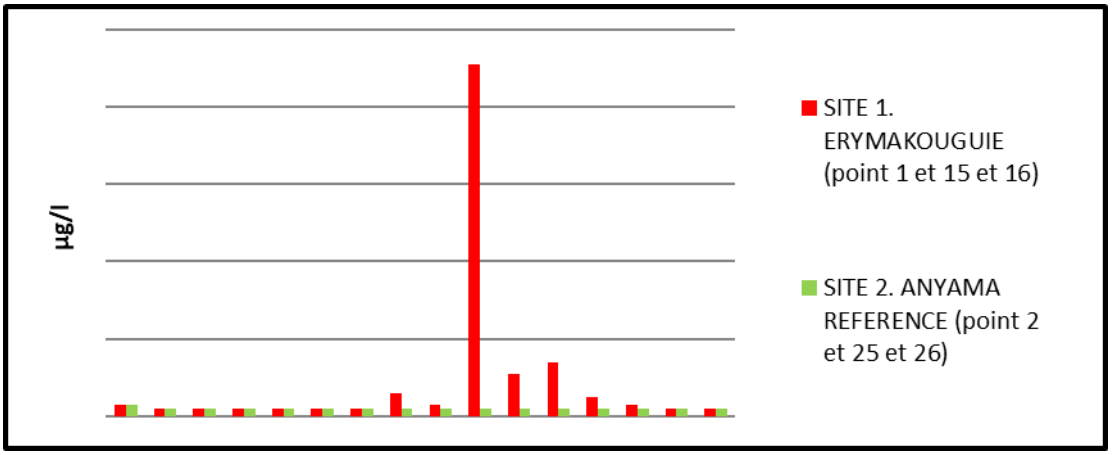

Figure 2 Comparison between HAP concentrations of the Site 1 Erymankoudguié and Site 2 of Anyama reference

3.2. Concentrations of underground waters samples in Benzene, Ethylbenene, Toluene, Ethyltoluene, Xylene (BETEX)

The table 5 show the concentrations of underground waters samples in Benzene, Ethylbenene, Toluene, Ethyltoluene, Xylene (BETEX). For all BETEX, the concentrations of the waters of the piezometers measured to the 13 sites are equal to the site 2, site of Anyama reference. Besides, the parameters for which, the Netherlanders norms are defined that are: Benzene, Toluene, Ethylbenzene, o-xylene, m-p-xylene, has some concentrations extensively under this side of the concentrations of this norms. These results suggest that the concentration of the BETEX respects the Netherlanders norms.

Table 5 Concentrations of underground waters samples in Benzene, Ethylbenene, Toluene, Ethyltoluene, Xylene (BETEX)

Sample number	Sample name	Benzene	Toluene	Ethylbenzene	o-Xylene	m-, p-Xylene	Cumene	Mesitylene	o-Ethyltoluene	m-, p-Ethyltoluene	Pseudocumene
23-001385-01	SITE 1. ERYMAKOUGUIE (point 1 et 15 et 16)	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
23-001385-03	SITE 3. Dokui 2 (point 3 et 35 et 36)	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
23-001385-04	SITE 4. ABOBO COCO SERVICE (point 4 et 45 et 46)	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
23-001385-05	SITE 5. ABOBO SAGBE (point 5 et 55 et 56)	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
23-001385-06	SITE 6. AKOUEDO (point 6 et 55 et 66)	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
23-001385-07	SITE 7. M'BADON (point 7 et 75 et 76)	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
23-001385-08	SITE 8. KOUMASSI 1 (point 8 et 85 et 86)	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
23-001385-09	SITE 9. FILTISSAC (point 9 et 95 et 96)	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
23-001385-10	SITE 10. MACA CITE ADO (point 10 et 105 et 106)	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
23-001385-11	SITE 11. 4.CROIX (point 11 et 115 et 116)	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
23-001385-12	SITE 12. ALEPE 1 (point 12 et 125 et 126_	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
23-001385-13	SITE 13. VRIDI LDC (point 13 et 135 et 136)	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
23-001385-02	**SITE 2. ANYAMA REFERENCE (point 2 et 25 et 26)**	**0.5**	**0.5**	**0.5**	**0.5**	**0.5**	**0.5**	**0.5**	**0.5**	**0.5**	**0.5**
	Netherland international norms (µg/l)	**30**	**150**	**1000**	**70**	**70**	**ND**	**ND**	**ND**	**ND**	**ND**

3.3. Concentrations of underground waters samples in Aliphatic Hydrocarbons

The table 6 show the concentrations of underground waters samples in Aliphatic Hydrocarbons. All concentrations of the hydrocarbons aliphatic C10-C40 for the sites 4 Coco Services, site 5 AboboSagbé, site 6 Akouédo, site 8 Koumassi, site 9 Filtisac, site 10 Maca ADO city , site 11 Croix, site 12 Alépé 1 and site 13 Vridi LDC are under concentrations of the site 2 Anyama reference.

For the site 1, site of Erymankouguié, all concentrations of the hydrocarbons aliphatic C10-C40 are superior to the site 2 of reference of Anyama (Figure 3). These results suggest the bad quality of water. So, the concentration of the hydrocarbons aliphatic C10-C40 is 6,8 mg/l for this site 1 whereas she is of 0,39 mg/l for the site 2 of Anyama reference. Either, 6,41 mg/l more than the site 2 of Anyama reference. The concentration of the hydrocarbons aliphatic C10-C12 is 0,5 mg/l for this site 1 whereas she is 0,1 mg/l for the site 2 of Anyama reference. Either, 0,4 mg/l more than the site 2 of Anyama reference. The concentration of the hydrocarbons aliphatic C12-C16 is 0,5 mg/l for this site 1 whereas she is 0,1 mg/l for the site 2 of Anyama reference. Either, 0,4 mg/l more than the site 2 of Anyama reference. The concentration of the hydrocarbons aliphatic C16-C21 is 0,5 mg/l for this site 1 whereas she is of 0,1 mg/l for the site 2 of Anyama reference. Either, 0,4 mg/l more than the site 2 of Anyama reference. The concentration of the hydrocarbons aliphatic C21-C35 is 6 mg/l for this site 1 whereas she is 0,35 mg/l for the site 2 of Anyama reference. Either, 5,65 mg/l more than the site 2 of Anyama reference. The concentration of the hydrocarbons aliphatic C35-C40 is 0,7 mg/l for this site 1 whereas she is 0,1 mg/l for the site 2 of Anyama reference. Either, 0,6 mg/l more than the site 2 of Anyama reference.

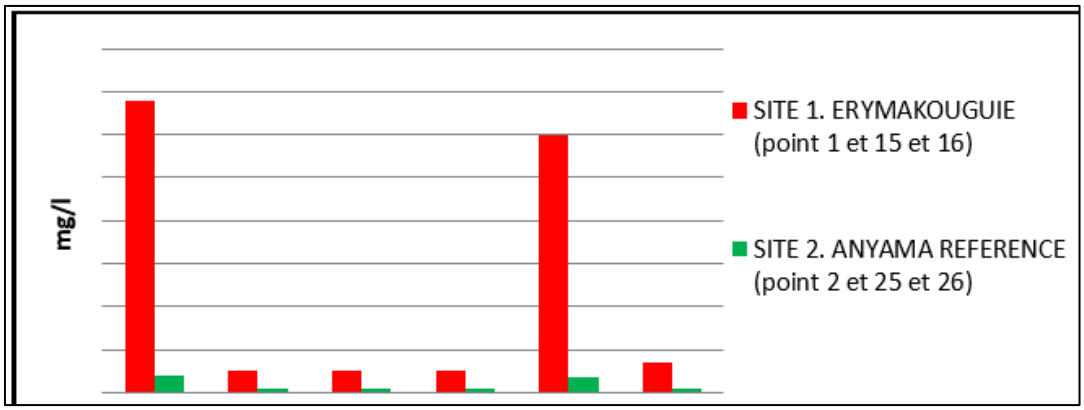

Figure 3 Comparison between the concentrations of Aliphatic Hydrocarbons of the Site 1 Erymankoudguié and Site 2 of Anyama reference

For the site 3, site Dokui 2, the concentration of the hydrocarbons aliphatic C10-C40 is 0,99 mg/l for this site 1 whereas she is 0,39 mg/l for the site 2 of Anyama reference. Either, 0,6 mg/l more than the site 2 of Anyama reference. The concentration of the hydrocarbons aliphatic C21-C35 is 0,83 mg/l for this site 1 whereas she is 0,35 mg/l for the site 2 of Anyama reference. Either, 0,48 mg/l more than the site 2 of Anyama reference. The concentration of the hydrocarbons aliphatic C35-C40 is 0,12 mg/l for this site 1 whereas she is 0,1 mg/l for the site 2 of Anyama reference. Either, 0,02 mg/l more than the site 2 of Anyama reference. For the site 7, site M'Badon, the concentration of the hydrocarbons aliphatic C10-C40 is 0,7 mg/l for this site 7 whereas she is 0,39 mg/l for the site 2 of Anyama reference. Either, 0,31 mg/l more than the site 2 of Anyama reference. The concentration of the hydrocarbons aliphatic C21-C35 is 0,48 mg/l for this site 7 whereas she is 0,35 mg/l for the site 2 of Anyama reference. Either, 0,13 mg/l more than the site 2 of Anyama reference. The concentration of the hydrocarbons aliphatic C35-C40 is 0,2 mg/l for this site 7 whereas she is 0,1 mg/l for the site 2 of Anyama reference. Either, 0,1 mg/l more than the site 2 of Anyama reference.

Table 6 Concentrations of underground waters samples in Aliphatic Hydrocarbons

Sample number	Sample name	Hydrocarbon indication C10-C40	Hydrocarbon > C10-C12	Hydrocarbon > C12-C16	Hydrocarbon > C16-C21	Hydrocarbon > C21-C35	Hydrocarbon > C35-C40
23-001385-01	SITE 1. ERYMAKOUGUIE (point 1 et 15 et 16)	6.8	0.5	0.5	0.5	6	0.7
23-001385-03	SITE 3. Dokui 2 (point 3 et 35 et 36)	0.99	0.05	0.05	0.05	0.83	0.12
23-001385-04	SITE 4. ABOBO COCO SERVICE (point 4 et 45 et 46)	0.09	0.05	0.05	0.05	0.07	0.05
23-001385-05	SITE 5. ABOBO SAGBE (point 5 et 55 et 56)	0.05	0.05	0.05	0.05	0.05	0.05
23-001385-06	SITE 6. AKOUEDO (point 6 et 55 et 66)	0.05	0.05	0.05	0.05	0.05	0.05
23-001385-07	SITE 7. M'BADON (point 7 et 75 et 76)	0.7	0.05	0.05	0.05	0.48	0.2
23-001385-08	SITE 8. KOUMASSI 1 (point 8 et 85 et 86)	0.15	0.05	0.05	0.05	0.11	0.05
23-001385-09	SITE 9. FILTISSAC (point 9 et 95 et 96)	0.05	0.05	0.05	0.05	0.05	0.05
23-001385-10	SITE 10. MACA CITE ADO (point 10 et 105 et 106)	0.05	0.05	0.05	0.05	0.05	0.05
23-001385-11	SITE 11. 4.CROIX (point 11 et 115 et 116)	0.05	0.05	0.05	0.05	0.05	0.05
23-001385-12	SITE 12. ALEPE 1 (point 12 et 125 et 126)	0.05	0.05	0.05	0.05	0.05	0.05
23-001385-13	SITE 13. VRIDI LDC (point 13 et 135 et 136)	0.05	0.05	0.05	0.05	0.05	0.05
23-001385-02	**SITE 2. ANYAMA REFERENCE (point 2 et 25 et 26)**	**0.39**	**0.1**	**0.1**	**0.1**	**0.35**	**0.1**
	Netherland international norms (mg/l)	**600000**	**ND**	**ND**	**ND**	**ND**	**ND**

The Figure 4 show the concentrations of the aliphatic hydrocarbons of the sites 3, Dokui 2 and site 7 M'Badon in relation to the site 2 of Anyama reference.

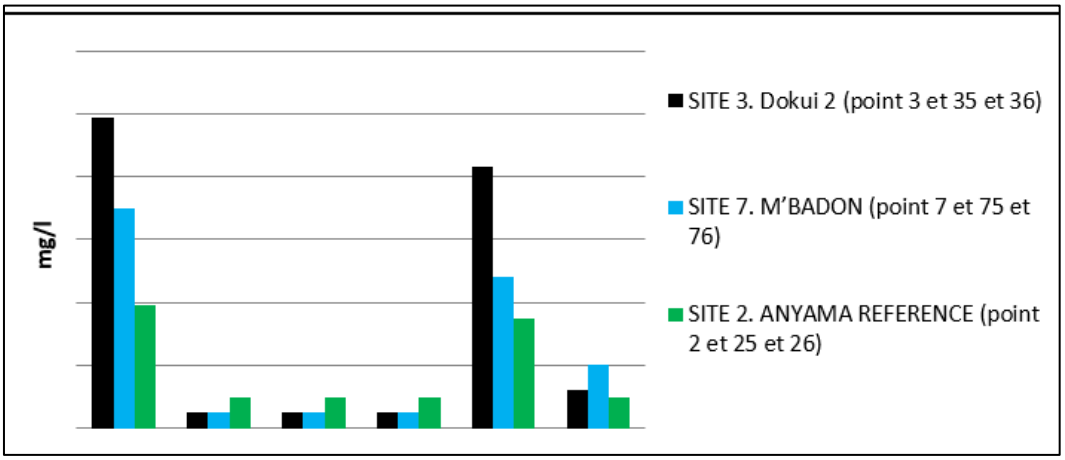

Figure 4 Comparison between concentrations of the Aliphatic Hydrocarbons of the Site 1 Erymankoudguié and Site 2 of Anyama reference

3.4. Concentrations of underground waters samples in Mercaptans

The table 7 show the concentrations of underground waters samples in Mercaptans. For all mercaptans, the concentrations of the waters of the piezometers measured to the 13 sites are equal to the one of the site 2 Anyama reference. Without the sites 5 of Abobo Coco services, site 6 Abobo Sagbé and site 9 Filtissac where concentrations 0,6 µg/ls and 0,4 µg/ls and 0,5 µg/ls have been found respectively for mercury, this concentration are of 0,2 µg/ls for the site2 Anyama reference. Either, 0,4 µg/ls, 0,2 µg/ls and 0,3 µg/ls more than the site 2 Anyama reference. These three concentrations are over to the site 2 Anyama reference and to the concentration of mercury of the Netherlander norm which is of 0,3 µg/ls, only concentration determine by this norm for the mercaptans.

Table 7 Concentrations of underground waters samples in Mercaptans

Sample number	Sample name	Mercury (Hg)	Mehyl mercaptan	Ethyl mercaptan	Propyl mercaptan	n-Butyl mercaptan	n-Pentyl mercaptan	Dimethyle Sulfure (DMS)	Dimethyle Disulfure (DMDS)	Diehylsulfure	sec-Butyl mercaptan	Isobutyl mercaptan	tert-Pentyl mercaptan	tert-Butyl mercaptan	Diethyldisulfure	Isopropyl mercaptan
23-001385-01	SITE 1. ERYMAKOUGUIE (point 1 et 15 et 16)	0.2	10	10	10	10	10	10	10	10	10	10	10	10	10	10
23-001385-03	SITE 3. Dokui 2 (point 3 et 35 et 36)	0.2	10	10	10	10	10	10	10	10	10	10	10	10	10	10
23-001385-04	SITE 4. ABOBO COCO SERVICE (point 4 et 45 et 46)	0.6	10	10	10	10	10	10	10	10	10	10	10	10	10	10
23-001385-05	SITE 5. ABOBO SAGBE (point 5 et 55 et 56)	0.4	10	10	10	10	10	10	10	10	10	10	10	10	10	10
23-001385-06	SITE 6. AKOUEDO (point 6 et 55 et 66)	0.2	10	10	10	10	10	10	10	10	10	10	10	10	10	10
23-001385-07	SITE 7. M'BADON (point 7 et 75 et 76)	0.2	10	10	10	10	10	10	10	10	10	10	10	10	10	10
23-001385-08	SITE 8. KOUMASSI 1 (point 8 et 85 et 86)	0.2	10	10	10	10	10	10	10	10	10	10	10	10	10	10
23-001385-09	SITE 9. FILTISSAC (point 9 et 95 et 96)	0.5	10	10	10	10	10	10	10	10	10	10	10	10	10	10
23-001385-10	SITE 10. MACA CITE ADO (point 10 et 105 et 106)	0.2	10	10	10	10	10	10	10	10	10	10	10	10	10	10
23-001385-11	SITE 11. 4.CROIX (point 11 et 115 et 116)	0.2	10	10	10	10	10	10	10	10	10	10	10	10	10	10
23-001385-12	SITE 12. ALEPE 1 (point 12 et 125 et 126)	0.2	10	10	10	10	10	10	10	10	10	10	10	10	10	10
23-001385-13	SITE 13. VRIDI LDC (point 13 et 135 et 136)	0.2	10	10	10	10	10	10	10	10	10	10	10	10	10	10
23-001385-02	**SITE 2. ANYAMA REFERENCE (point 2 et 25 et 26)**	**0.2**	**10**	**10**	**10**	**10**	**10**	**10**	**10**	**10**	**10**	**10**	**10**	**10**	**10**	**10**
	Netherland international norms (µg/l)	**0.3**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**

3.5. Concentrations of underground waters samples in Metallic Traces Elements (MTE)

The table 8 show the concentrations of underground waters samples in Metallic Traces Elements (MTE). All concentrations of the MTE waters of the piezometers measured on the site 2 Anyama reference are lower or equal to the Netherlander norms. It reveals the good quality of the underground waters of this reference site 2 for what concerns the MTE. The concentration of sulfur is not defined by the norms Netherlanders, but the concentrations of all others chemical elements of the MTE of the 17 piezometers are lower to the securities defined by this norm. Except the concentration of lead of the site 9, Filtissac that is 130 µg/ls whereas it is 75 µg/ls for the Netherlander norm. Either, 55 µg/ls more than the Netherlander norm.

Table 8 Concentrations of underground waters samples in Metallic Traces Elements (MTE)

Sample number	Sample name	Arsenic (As)	Lead (Pb)	Cadmium (Cd)	Chromium(Cr)	Cobalt (Co)	Copper (Cu)	Nickel (Ni)	Sulfur (S)	Zinc (Zn)	Mercury (Hg)
23-001385-01	SITE 1. ERYMAKOUGUIE (point 1 et 15 et 16)	15	12	0.5	5	5	10	11	230	120	0.2
23-001385-03	SITE 3. Dokui 2 (point 3 et 35 et 36)	15	10	0.5	5	5	10	10	1400	61	0.2
23-001385-04	SITE 4. ABOBO COCO SERVICE (point 4 et 45 et 46)	15	31	0.5	5.8	5	10	10	1700	150	0.6
23-001385-05	SITE 5. ABOBO SAGBE (point 5 et 55 et 56)	15	10	0.5	5	5	10	10	57	84	0.4
23-001385-06	SITE 6. AKOUEDO (point 6 et 55 et 66)	15	10	0.5	5	5	10	10	1800	92	0.2
23-001385-07	SITE 7. M'BADON (point 7 et 75 et 76)	15	16	0.5	5	5	10	10	900	75	0.2
23-001385-08	SITE 8. KOUMASSI 1 (point 8 et 85 et 86)	15	37	0.5	5	5	10	11	21000	87	0.2
23-001385-09	SITE 9. FILTISSAC (point 9 et 95 et 96)	39	130	0.5	11	5	80	73	1700	200	0.5
23-001385-10	SITE 10. MACA CITE ADO (point 10 et 105 et 106)	15	13	0.5	5	5	10	18	9800	78	0.2
23-001385-11	SITE 11. 4.CROIX (point 11 et 115 et 116)	15	10	0.5	5	5	10	10	140	50	0.2
23-001385-12	SITE 12. ALEPE 1 (point 12 et 125 et 126)	15	10	0.5	5	5	10	10	1500	70	0.2
23-001385-13	SITE 13. VRIDI LDC (point 13 et 135 et 136)	20	10	0.5	20	5	10	10	1700	24	0.2
23-001385-02	**SITE 2. ANYAMA REFERENCE (point 2 et 25 et 26)**	**15**	**12**	**0.5**	**5**	**5**	**10**	**10**	**260**	**74**	**0.2**
	Netherland international norms (µg/l)	**60**	**75**	**6**	**30**	**100**	**75**	**75**	**ND**	**800**	**0.3**

However, the comparison of piezometers waters of the different sites 1 to 13 has been achieved and permitted to show that the concentrations of arsenic, lead, cadmium, chromium, cobalt, copper, sulfur and mercury of piezometers waters measured on the site 1, site of Erymakouguié is equal to the one of the site 2 of Anyama reference. But nickel and zinc 11 µg/ls and 120 µg/ls respectively of the site 1, site of Erymakouguié are over to the one of the site 2 Anyama reference 10 µg/ls and 74 µg/ls respectively. Either, 1 and 46 µg/ls more than the site 2 of Anyama reference. All concentrations of the MTE of piezometers water measured on the site 3, site of the Dokui 2 is lower or equal to the one of the site 2 Anyama reference, only the sulphur which the concentration of 1400 µg/ls measured on the site 3 passes from 1140 µg/ls of the reference site that is of 260 µg/ls. The concentrations of the arsenic, cadmium, cobalt, copper, nickel of the piezometers waters measured on the site 4, site of Abobo Coco Service is equal to the one of the site 2 of Anyama reference. But those of lead, chromium, sulfur, zinc and mercury respectively of 31 µg/ls, 5,8 µg/ls, 1700 µg/ls, 150 µg/ls and 0,6 µg/ls of the site 4, site of Abobo Coco Service is respectively over to the one of the site 2 of Anyama reference of 12 µg/ls, 5 µg/ls, 260 µg/ls, 74 µg/ls, 0,6 µg/ls. Either, 19 µg/ls, 0,8 µg/ls, 1440 µg/ls, 76 µg/ls and 0,4 µg/ls respectively more than the site of reference. But those of nickel and zinc respectively of 11 µg/ls and 120 µg/ls of the site 1, site of Erymakouguié is respectively over to the site 2 of Anyama reference of 10 µg/ls and 74 µg/ls. Either, 1 and 46 µg/ls more than the site 2 of Anyama reference. The concentrations of arsenic, lead, cadmium, chromium, cobalt, copper, nickel and sulfur of the piezometers waters measured on the site 5, site of Sagbé Abobo is lower or equal to the one of the site 2 of Anyama reference. But those of zinc and mercury respectively of 84 µg/ls and 0,4 µg/ls of the site 5, site of Sagbé Abobo are respectively over to the one of the site 2 of Anyama reference of 74 µg/ls and 0,2 µg/ls. Either, 10 µg/ls and 0,2 µg/ls more than the site 2 of Anyama reference. The concentrations of arsenic, lead, cadmium, chromium, cobalt, copper, nickel and the mercury of the piezometers waters of measured on the site 6, site of Akouédo is lower or equal to the one of the site 2 of Anyama reference. But those of sulfur and zinc and respectively of 1800 µg/ls and 92 µg/ls of the site 6, site of Akouédo are respectively over to the one of the site 2 Anyama reference of 260 µg/ls and 74 µg/ls. Either, 1540 µg/ls and 18 µg/ls more than the site 2 Anyama reference. The concentrations of arsenic, cadmium, chromium, cobalt, copper, nickel and mercury of the piezometers waters measured on the site 7, site of M'Badon is lower or equal to the one of the site 2 Anyama reference. But those of lead, sulfur and zinc of 16 µg/ls, 900 µg/ls and 75 µg/ls of the site 6, site of Akouédo are over to the one of the site 2 Anyama reference respectively of 12 µg/ls, 260 µg/ls and 75 µg/ls. Either, 4 µg/ls, 640 µg/ls and 1 µg/l more than the site 2 Anyama reference.

The concentrations of arsenic, of cadmium, of chromium, cobalt, copper and mercury of the piezometers waters measured on the site 8, site of Koumassi are lower or equal to the one of the site 2 Anyama reference. But those of lead, of the nickel of sulfur and zinc respectively of 37 µg/ls, 11 µg/ls, 21000 µg/ls and 87 µg/ls of the site 8, site of Koumassi are respectively over to the one of the site 2 Anyama reference of 12 µg/ls, 10 µg/ls, 260 µg/ls, 87 µg/ls. Either, 25 µg/ls, 1 µg/l, 20740 µg/ls and 13 µg/ls more than the site 2 of Anyama reference. The concentrations of cadmium and cobalt of the piezometers waters measured on the site 9, site of Filtissac is lower or equal to the one of the site 2 of Anyama reference. But those of arsenic, lead, chromium, copper, nickel, sulfur, zinc and mercury are respectively 39 µg/ls, 130 µg/ls, 11 µg/ls, 80 µg/ls, 73 µg/ls, 1700 µg/ls, 200 µg/ls and 0,5 µg/ls of the site 9, site of Filtissac are respectively over to the one of the site 2 Anyama reference of 15 µg/ls, 12 µg/ls, 5 µg/ls, 10 µg/ls, 10 µg/ls, 260 µg/ls, 74 µg/ls and 0,2 µg/ls. Either, 24 µg/ls, 118 µg/ls, 6 µg/ls, 70 µg/ls, 63 µg/ls, 1440 µg/ls, 126 µg/ls and 0,3 µg/ls more than the site 2 Anyama reference. The concentrations of arsenic, cadmium, chromium, cobalt, copper, and of mercury of the waters of piezometers measured on the site 10, site of Maca ADO City is lower or equal to the site 2 Anyama reference. But those of lead, nickel, sulfur and zinc respectively of 13 µg/ls, 18 µg/ls, 9800 µg/ls and 78 µg/ls of the site 10, site of Maca ADO City are respectively over to the one of the site 2 of Anyama reference of 12 µg/ls, 10 µg/ls, 260 µg/ls and 74 µg/ls. Either, 1 µg/l, 8 µg/ls, 9540 µg/ls, 4 µg/ls more than the site 2 of Anyama reference. All concentrations of the MTE measured on the piezometers waters of the site 11, site of Croix are lower or equal to the one of the site 2 Anyama reference. This reveals the good quality of the underground waters of this site. All concentrations of the MTE of the piezometers waters measured on the site 12, site of Alepé 1 is lower or equal to the one of the site 2 of Anyama reference, only the sulfur of which the concentration of 1500 µg/ls measured on the site 3 passes from 1240 µg/ls the one of the reference site that is of 260 µg/ls. The concentrations of lead, cadmium, cobalt, copper, nickel, zinc and mercury of of the piezometers waters measured on the site 13, site of Vridi is lower or equal to the one of the site 2 Anyama reference. But those of arsenic, chromium and sulfur of 20 µg/ls, 20 µg/ls and 1700 µg/ls of the site 13, site of Vridi are respectively over to the one of the site 2 Anyama reference of 15 µg/ls, 5 µg/ls and 260 µg/ls. Either, 5 µg/ls, 15 µg/ls and 1440 µg/ls more than the site 2 Anyama reference.

4. Discussion

The results of the analyses of the underground waters of 17 piezometers surroundings the 13 sites of toxic waste show that the chemical compounds are: the global parameters of indications of hydrocarbons, the heavy metals, the volatile halogenated hydrocarbons (COHV), the benzene and the aromatic (CAV-BETEX), the polycyclic aromatic hydrocarbons (HAP), the mercaptans rich in sulphides. These results have been compared to the Netherland international norms of

underground waters depollution. These norms correspond to the limits of depollution judged acceptable by Ivory Coast government. The results show that the underground waters have not been generally affected by this episode of contamination by the toxic waste.

4.1. Decision matrix of the Polycyclic Aromatic Hydrocarbons (PAH)

The table 9 show the decision matrix of the Polycyclic Aromatic Hydrocarbons (HAP). The decision matrix of the PAH show that the only one site that puts more problems is the site 1, Erymakoudjé site where the chemical element are over the site 2, Anyama reference: the pyrene, the benzo (a) anthracene, the chrysene, the benzo (b) fluoranthene, the benzo (k) fluorenthene, the benzo (a) pyrene; the dibenzo (a,h) anthracene, therefore it is bad quality water. The underground waters of the other piezometers don't pose a problem with regard to the HAP, this show that they are good quality water.

Table 9 Decision matrix of the Polycyclic Aromatic Hydrocarbons (PAH)

Sample number	Sample name	Naphtalene	Acenaphtylene	Acenaphtene	Fluorene	Phenanthrene	Anthracene	Fluoranthene	Pyrene	Benzo(a)anthracene	Chrysene	Benzo(b)fluoranthene	Benzo(k)fluoranthene	Benzo(a)pyrene	Dibenzo(a,h)anthracen	Indeno(1,2,3,c,d)pyren	Benzo(g,h,i)perylene
23-001385-01	SITE 1. ERYMAKOUGUIE (point 1 et 15 et 16)	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.06	0.03	0.91	0.11	0.14	0.05	0.03	0.02	0.02
23-001385-03	SITE 3. Dokui 2 (point 3 et 35 et 36)	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
23-001385-04	SITE 4. ABOBO COCO SERVICE (point 4 et 45 et 46)	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
23-001385-05	SITE 5. ABOBO SAGBE (point 5 et 55 et 56)	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
23-001385-06	SITE 6. AKOUEDO (point 6 et 55 et 66)	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
23-001385-07	SITE 7. M'BADON (point 7 et 75 et 76)	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
23-001385-08	SITE 8. KOUMASSI 1 (point 8 et 85 et 86)	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
23-001385-09	SITE 9. FILTISSAC (point 9 et 95 et 96)	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
23-001385-10	SITE 10. MACA CITE ADO (point 10 et 105 et 106)	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
23-001385-11	SITE 11. 4.CROIX (point 11 et 115 et 116)	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
23-001385-12	SITE 12. ALEPE 1 (point 12 et 125 et 126)	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
23-001385-13	SITE 13. VRIDI LDC (point 13 et 135 et 136)	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
23-001385-02	SITE 2. ANYAMA REFERENCE (point 2 et 25 et 26)	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
	Netherland international norms (µg/l)	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

4.2. Decision matrix of Benzene, Ethylbenene, Toluene, Ethyltoluene, Xylene (BETEX)

The table 10 show the decision matrix of Benzene, Ethylbenene, Toluene, Ethyltoluene, Xylene (BETEX). The decision matrix of the BETEX show that underground waters of the other piezometers don't pose a problem with regard to the BETEX, this don't show that they are good quality water.

Table 10 Decision matrix of Benzene, Ethylbenene, Toluene, Ethyltoluene, Xylene (BETEX)

Sample number	Sample name	Benzene	Toluene	Ethylbenzene	o-Xylene	m-, p-Xylene	Cumene	Mesitylene	o-Ethyltoluene	m-, p-Ethyltoluene	Pseudocumene
23-001385-01	SITE 1. ERYMAKOUGUIE (point 1 et 15 et 16)	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
23-001385-03	SITE 3. Dokui 2 (point 3 et 35 et 36)	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
23-001385-04	SITE 4. ABOBO COCO SERVICE (point 4 et 45 et 46	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
23-001385-05	SITE 5. ABOBO SAGBE (point 5 et 55 et 56)	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
23-001385-06	SITE 6. AKOUEDO (point 6 et 55 et 66)	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
23-001385-07	SITE 7. M'BADON (point 7 et 75 et 76)	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
23-001385-08	SITE 8. KOUMASSI 1 (point 8 et 85 et 86)	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
23-001385-09	SITE 9. FILTISSAC (point 9 et 95 et 96)	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
23-001385-10	SITE 10. MACA CITE ADO (point 10 et 105 et 106)	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
23-001385-11	SITE 11. 4.CROIX (point 11 et 115 et 116)	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
23-001385-12	SITE 12. ALEPE 1 (point 12 et 125 et 126)	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
23-001385-13	SITE 13. VRIDI LDC (point 13 et 135 et 136)	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
23-001385-02	**SITE 2. ANYAMA REFERENCE (point 2 et 25 et 26)**	**0.5**	**0.5**	**0.5**	**0.5**	**0.5**	**0.5**	**0.5**	**0.5**	**0.5**	**0.5**
	Netherland international norms (µg/l)	**30**	**150**	**1000**	**70**	**70**	**ND**	**ND**	**ND**	**ND**	**ND**

4.3. Decision Matrix of Aliphatic Hydrocarbons

Table 11 Decision matrix of the Aliphatic Hydrocarbons.

Sample number	Sample name	Hydrocarbon indication C10-C40	Hydrocarbon > C10-C12	Hydrocarbon > C12-C16	Hydrocarbon > C16-C21	Hydrocarbon > C21-C35	Hydrocarbon > C35-C40
23-001385-01	SITE 1. ERYMAKOUGUIE (point 1 et 15 et 16)	6.8	0.5	0.5	0.5	6	0.7
23-001385-03	SITE 3. Dokui 2 (point 3 et 35 et 36)	0.99	0.05	0.05	0.05	0.83	0.12
23-001385-04	SITE 4. ABOBO COCO SERVICE (point 4 et 45 et 46)	0.09	0.05	0.05	0.05	0.07	0.05
23-001385-05	SITE 5. ABOBO SAGBE (point 5 et 55 et 56)	0.05	0.05	0.05	0.05	0.05	0.05
23-001385-06	SITE 6. AKOUEDO (point 6 et 55 et 66)	0.05	0.05	0.05	0.05	0.05	0.05
23-001385-07	SITE 7. M'BADON (point 7 et 75 et 76)	0.7	0.05	0.05	0.05	0.48	0.2
23-001385-08	SITE 8. KOUMASSI 1 (point 8 et 85 et 86)	0.15	0.05	0.05	0.05	0.11	0.05
23-001385-09	SITE 9. FILTISSAC (point 9 et 95 et 96)	0.05	0.05	0.05	0.05	0.05	0.05
23-001385-10	SITE 10. MACA CITE ADO (point 10 et 105 et 106)	0.05	0.05	0.05	0.05	0.05	0.05
23-001385-11	SITE 11. 4.CROIX (point 11 et 115 et 116)	0.05	0.05	0.05	0.05	0.05	0.05
23-001385-12	SITE 12. ALEPE 1 (point 12 et 125 et 126)	0.05	0.05	0.05	0.05	0.05	0.05
23-001385-13	SITE 13. VRIDI LDC (point 13 et 135 et 136)	0.05	0.05	0.05	0.05	0.05	0.05
23-001385-02	**SITE 2. ANYAMA REFERENCE (point 2 et 25 et 26)**	**0.39**	**0.1**	**0.1**	**0.1**	**0.35**	**0.1**
	Netherland international norms (mg/l)	**600000**	**ND**	**ND**	**ND**	**ND**	**ND**

The table 11 show the decision matrix of the Aliphatic Hydrocarbons. Decision matrix of the Aliphatic Hydrocarbons show that the three sites poses problems are: the site 1, Erymakoudjé site, the site 3 Dokui 2 and the site 7 M'Badon. The chemical element over the reference site 2, Anyama site are: the family of the C10-C12 hydrocarbons, C12-C16 hydrocarbons, C16-C21 hydrocarbons, C21-C35 hydrocarbons and C35-C40 hydrocarbons for the site 1 Erymakouguié, the family of the C21-C35 hydrocarbons and C35-40 hydrocarbons for the site 3 Dokui 2 and also for the family of the C21-C35 hydrocarbons C21-C35 hydrocarbons for the site 7 M'Badon. The underground waters of the other piezometers don't pose a problem with regard to the Aliphatic Hydrocarbons, this don't show that they are good quality water.

4.4. Decision matrix of Mercaptans

The table 12 decision matrix of Mercaptans. The decision matrix of Mercaptans show that the three sites that put more problems are: the site 4, Abobo Coco Service, the site 5 AboboSagbé and the site 9, Filtissac. The chemical elements over the reference site 2, Anyama site for these three sites is mercury. The underground waters of the other piezometers don't pose a problem with regard to the Mercaptan, this show that they are good quality water.

Table 12 Decision matrix of Mer-captans

Sample number	Sample name	Mercury (Hg)	Methyl mercaptan	Ethyl mercaptan	Propyl mercaptan	n-Butyl mercaptan	n-Pentyl mercaptan	Diméthyle Sulfur (DMS)	DiméthyleDisulfur (DMDS)	Diethylsulfure	sec-Butyl mercaptan	Isobutyl mercaptan	tert-Pentyl mercaptan	tert-Butyl mercaptan	Diethyldisulfure	Isopropyl mercaptan
23-001385-01	SITE 1. ERYMAKOUGUIE (point 1 et 15 et 16)	0.2	10	10	10	10	10	10	10	10	10	10	10	10	10	10
23-001385-03	SITE 3. Dokui 2 (point 3 et 35 et 36)	0.2	10	10	10	10	10	10	10	10	10	10	10	10	10	10
23-001385-04	SITE 4. ABOBO COCO SERVICE (point 4 et 45 et 46)	0.6	10	10	10	10	10	10	10	10	10	10	10	10	10	10
23-001385-05	SITE 5. ABOBO SAGBE (point 5 et 55 et 56)	0.4	10	10	10	10	10	10	10	10	10	10	10	10	10	10
23-001385-06	SITE 6. AKOUEDO (point 6 et 55 et 66)	0.2	10	10	10	10	10	10	10	10	10	10	10	10	10	10
23-001385-07	SITE 7. M'BADON (point 7 et 75 et 76)	0.2	10	10	10	10	10	10	10	10	10	10	10	10	10	10
23-001385-08	SITE 8. KOUMASSI 1 (point 8 et 85 et 86)	0.2	10	10	10	10	10	10	10	10	10	10	10	10	10	10
23-001385-09	SITE 9. FILTISSAC (point 9 et 95 et 96)	0.5	10	10	10	10	10	10	10	10	10	10	10	10	10	10
23-001385-10	SITE 10. MACA CITE ADO (point 10 et 105 et 106)	0.2	10	10	10	10	10	10	10	10	10	10	10	10	10	10
23-001385-11	SITE 11. 4.CROIX (point 11 et 115 et 116)	0.2	10	10	10	10	10	10	10	10	10	10	10	10	10	10
23-001385-12	SITE 12. ALEPE 1 (point 12 et 125 et 126)	0.2	10	10	10	10	10	10	10	10	10	10	10	10	10	10
23-001385-13	SITE 13. VRIDI LDC (point 13 et 135 et 136)	0.2	10	10	10	10	10	10	10	10	10	10	10	10	10	10
23-001385-02	**SITE 2. ANYAMA REFERENCE (point 2 et 25 et 26)**	**0.2**	**10**	**10**	**10**	**10**	**10**	**10**	**10**	**10**	**10**	**10**	**10**	**10**	**10**	**10**
	Netherland international norms (µg/l)	**0.3**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**

4.5. Decision matrix of Traces Metallic Elements (TME)

The table 13 show decision matrix of Traces Metallic Elements (TME). The matrix of decision of the TME show that the three sites that put more problems are: the site 4, Abobo Coco Service, the site 5 AboboSagbé and the site 9, Filtissac. The chemical elements over the reference site 2, Anyama site for these three sites are mercury, lead and the copper for the site 9, Filtissac. The underground waters of the other piezometers don't pose a problem with regard to the Traces Metallic Elements (TME), this don't show that they are good quality water.

Table 13 Decision matrix of Traces Metallic Elements (TME)

Sample number	Sample name	Arsenic (As)	Lead(Pb)	Cadmium (Cd)	Chromium (Cr)	Cobalt (Co)	Copper (Cu)	Nickel (Ni)	Sulfur (S)	Zinc (Zn)	Mercury (Hg)
23-001385-01	SITE 1. ERYMAKOUGUIE (point 1 et 15 et 16)	15	12	0.5	5	5	10	11	230	120	0.2
23-001385-03	SITE 3. Dokui 2 (point 3 et 35 et 36)	15	10	0.5	5	5	10	10	1400	61	0.2
23-001385-04	SITE 4. ABOBO COCO SERVICE (point 4 et 45 et 46)	15	31	0.5	5.8	5	10	10	1700	150	0.6
23-001385-05	SITE 5. ABOBO SAGBE (point 5 et 55 et 56)	15	10	0.5	5	5	10	10	57	84	0.4
23-001385-06	SITE 6. AKOUEDO (point 6 et 55 et 66)	15	10	0.5	5	5	10	10	1800	92	0.2
23-001385-07	SITE 7. M'BADON (point 7 et 75 et 76)	15	16	0.5	5	5	10	10	900	75	0.2
23-001385-08	SITE 8. KOUMASSI 1 (point 8 et 85 et 86)	15	37	0.5	5	5	10	11	21000	87	0.2
23-001385-09	SITE 9. FILTISSAC (point 9 et 95 et 96)	39	130	0.5	11	5	80	73	1700	200	0.5
23-001385-10	SITE 10. MACA CITE ADO (point 10 et 105 et 106)	15	13	0.5	5	5	10	18	9800	78	0.2
23-001385-11	SITE 11. 4.CROIX (point 11 et 115 et 116)	15	10	0.5	5	5	10	10	140	50	0.2
23-001385-12	SITE 12. ALEPE 1 (point 12 et 125 et 126)	15	10	0.5	5	5	10	10	1500	70	0.2
23-001385-13	SITE 13. VRIDI LDC (point 13 et 135 et 136)	20	10	0.5	20	5	10	10	1700	24	0.2
23-001385-02	**SITE 2. ANYAMA REFERENCE (point 2 et 25 et 26)**	**15**	**12**	**0.5**	**5**	**5**	**10**	**10**	**260**	**74**	**0.2**
	Netherland international norms (µg/l)	**60**	**75**	**6**	**30**	**100**	**75**	**75**	**ND**	**800**	**0.3**

4.6. Synthesis of decisions matrixes and Netherlanders Norms

Table 14 Synthesis of decisions matrixes and Netherlanders Norms

Sample number	Sample name	PAH	BETEX	Aliphatic Hydrocarbons	Mercaptans	MTE
23-001385-01	SITE 1. ERYMAKOUGUIE (point 1 et 15 et 16)					
23-001385-03	SITE 3. Dokui 2 (point 3 et 35 et 36)					
23-001385-04	SITE 4. ABOBO COCO SERVICE (point 4 et 45 et 46)					
23-001385-05	SITE 5. ABOBO SAGBE (point 5 et 55 et 56)					
23-001385-06	SITE 6. AKOUEDO (point 6 et 55 et 66)					
23-001385-07	SITE 7. M'BADON (point 7 et 75 et 76)					
23-001385-08	SITE 8. KOUMASSI 1 (point 8 et 85 et 86)					
23-001385-09	SITE 9. FILTISSAC (point 9 et 95 et 96)					
23-001385-10	SITE 10. MACA CITE ADO (point 10 et 105 et 106)					
23-001385-11	SITE 11. 4.CROIX (point 11 et 115 et 116)					
23-001385-12	SITE 12. ALEPE 1 (point 12 et 125 et 126)					
23-001385-13	SITE 13. VRIDI LDC (point 13 et 135 et 136)					
23-001385-02	**SITE 2. ANYAMA REFERENCE (point 2 et 25 et 26)**					
	Netherland international norms (mg/l)					

The table 14 show Synthesis of decisions matrixes and Netherlanders Norms. Two symbols of color have been used to show the quality of the waters of the different piezometers, the green color show that the underground waters are good quality and red color show that it has some measures to take for the protection of the underground waters of the concerned sites.

The waters of bad qualities are the waters of the piezometers of: site1 Erymakouguié, site 3 Dokui 2, site 4 Abobo Coco service, site 5 AboboSagbé, site 7 M'Badon, site 9 Filtissac. Either 6 sites where waters are of bad qualities. This bad quality of waters cannot be due to a recent pollution like toxic waste. The waters of good qualities are the waters of the piezometers of: site 6 Akouédo, site 8 Koumassi, site 10 Maca ADO City, site 11 Croix, site 12 Alépés 1, site 13 Vridi LDC and site 2 Anyama reference. Either 7 sites where waters are of good qualities.

However, Netherlanders international norms of underground waters depollution exist only for a small part of the chemical compounds present in the superficial and underground waters. Chemical elements can't represent risk for the different possibilities of uses of the sites affected by these dangerous waste? It is about: cumen, mésitylène, ô-éthyltoluène, m-,-p-éthyltoluène for Polycyclic Aromatic Hydrocarbons (HAP), pseudocumene for BETEX, the set of the aliphatic hydrocarbons, out set the C10-C40 hydrocarbons, the set of the mercaptans, out set mercury and finally sulfur for what concerns the TME. All these chemical elements aren't completely determined by Netherlanders norms.

The Netherlanders international norms of intervention of fixed and accepted by the government of Coast of Ivory don't represent a sure shelter concerning sanitary risk, in this sense that the concentrations of the chemical elements remaining on the sites after depollution can constitute a sanitary risk according to the "decontaminated" practices possible of these different sites. Besides, the Netherlanders norms seem a lot more adapted for a country to moderate climate, or even Mediterranean, rather than for a tropical climate as the one of the Coast of Ivory. Indeed, the temperature dependences and of the parameters as the pH could constitute the limiting factors reliability of the Netherlanders international norms of intervention in tropical climate.

However, according to Kouamé and al., (2009), three capturing fields were threatened medium-term in Abidjan. These are the capturing fields of North Adjamé, North Zone and West Zone. The global transfer time of the pollutant has been estimated on average to 2 years. A regular follow-up of the water quality captured from these works of catchment belonging to these capturing fields is wished. This follow-up has been achieved by the Ciapol (2019), and, 17 years after the pollution bound to the toxic waste, the gotten results permit to put a term on a possible contamination of these three fields capturing as well as the one of the watertable of the district of Abidjan by the toxic waste. These works dating 2009, it would be today 2025, 17 years later, it will be interesting to make sampling again in these three capturing fields seen some of analyses for confirmation or invalidation of these results.

5. Conclusion

The results of analyses of the underground waters of the 17 piezometers arround the 13 "decontaminated" sites are on under the depollution limit of Netherlanders international norms of underground waters (used, in this setting by Ivory Coast government) when they are defined by this norm. However, the Netherlanders international norms of intervention for the depollution of the underground waters take in account, or exist only for a small part of the present chemical compounds in the underground waters. Chemical elements no take account by this norm can't represent a risk for the different uses possibilities of these sites affected by these dangerous waste? The waters of bad qualities are the waters of the piezometers of site1 Erymakouguié, site 3 Dokui 2, site 4 Abobo Coco service, site 5 AboboSagbé, site 7 M'Badon, site 9 Filtissac. Either 6 sites where waters are bad qualities. The waters of good qualities are the waters of the piezometers of site 6 Akouédo, site 8 Koumassi, site 10 Maca ADO City, site 11 Croix, site 12 Alépés 1, site 13 Vridi LDC and site 2 Anyama reference. Either 7 sites or waters are of good qualities. The global transfer time of the pollutant has been estimated on average to 2 years (Kouamé, 2009). 17 years after the pollution by the toxic waste, the results of analyses gotten permit to put a term on a possible contamination of the three fields capturing (Adjamé Nord, North Zone and West Zone) as well as the one of the water table of the district of Abijan by the toxic waste. However, it would be today 2025, after 17 years interesting to make sampling again in these three capturing fields seen some of analyses for confirmation or invalidation these results.

Compliance with ethical standards

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Disclosure of conflict of interest

The authors have no conflict of interests about the content of this article.

Statement of ethical approval

All of authors approved the ethical content of this article and they accepted to participate.

Statement of informed consent

All of authors declare that they have been informed and consent for the work submitted for publication. All authors have read and approved the final version manuscript.

References

[1] Amnesty International (2012). A toxic truth: about Trafigura, the Probo Koala and the unloading of toxic waste in Abidjan (Ivory Coast).

[2] Antea (2007)." Environmental technical advice of Ivory Coast republic in the context of tipping of the toxic waste in Abidjan in August 2006: post-accidental modelling of the atmospheric scattering, cutoff of impacted zones". Report n° 4789/B, 24 p.

[3] Biache, C., Mansuy-Huault, L., Faure, P., Munier-Lamy, C., &Leyval, C. (2008).Effects of thermal desorption on the composition of two cokingplant soils: impact on solvent extractable organic compounds andmetal bioavailability. Environ Pollut 156(3):671–677.

[4] Biache, C., Kouadio, O., Hanna, K., Lorgeoux, C., & Faure, P. (2014a). Role of goethite during air-oxidation of PAH-contaminated soils. Chemosphere.117 : 823-829.

[5] Biache, C., Kouadio, O., Lorgeoux, C., & Faure, P. (2014b). Impact of clay mineral on airoxidation of PAH-contaminated soils. Environ. Sci. Pollut. Res., 1–10.

[6] Ciapol (2019). "Biogenie works controlled and environmental follow-up of the impacted sites by the toxic waste: Period of March 2010 to September 2017: Minedd-ciapol convention". Synthesis Report , n°1- 03 / 2019.

[7] Dongo K., Tiembré I., Koné B.A., Zurbrügg C., Odermatt O., Tanner M., & Jakob Zinsstag J. and Cissé G. (2012). "Exposure to toxic waste containing high concentrations of hydrogen sulphide illegally dumped in Abidjan, Côte d'Ivoire". Environmental Science and Pollution Research 19:3192–3199.

[8] Koffi Y. B., Ahoussi K. E., Kouadio K. E., Kouassi A. M., Kouassi O., Kpangui L. C. and Biémi J. (2013). " Survey of the vulnerability of an acquifere broken in a context of implantation of a technical storage center: Application of the remote detection and the géotechnique on the site of Kossihouen in Coast of Ivory (West Africa) ". ISSN : 2028-9324 Vol.2 No. 4.

[9] Keith, LH. &Telliard, WA. (1979). Priority pollutants: I. A perspective view.Environ Sci Technol 13(4):416–423.

[10] Kouamé K. J., Jourda j. P., Leblanc Y., Deh S. K., Anani A. T. et Biémi J. (2009). "Implication of Hydrogeologic Modeling in the Estimate of Pollutants Transfer Time Towards Groundwater of Abidjan District: Case of Toxic Waste". European Journal of Scientific Research ISSN 1450-216X Vol.32 No.1 (2009), pp.6-24.

[11] LBTP (laboratory of public works and building) (2015). " Consistent environmental of toxic waste sites in Abidjan district ". Geotechnic survey Report files n° 14/dgc/g/0553. 45 p.

[12] Rockwell (2021). "Works of seventeen (17) piezometers realization for the follow-up of waters quality of watertable around toxic waste dumped sites from Probo Koala boat in the district of Abidjan". geophysical and hydrogeological survey Report, 52 p.

[13] Rockwell (2021). "Works of seventeen (17) piezometers realization for the follow-up of waters quality of watertable around toxic waste dumped sites from Probo Koala boat in the district of Abidjan". Final technical report, 54 p.

[14] UN Environment (2017). "Environmental Audit of toxic waste dumped from "probo koala". Program of the United Nations for the environment, 108 p.

[15] US-EPA (1999). Use of monitored natural attenuation at superfund, RCRAcorrective action, and underground storage tank sites. USEPA,Office of Solid Waste and Emergency Response : Washington (DC).

[16] VagnyLab (2017). "Survey of physical and biologic matrixes quality (trophic chain follow-up) in the Djibi village and the site of corn spoiled treatment in Erymakoudjé". Survey report of the project of complementary dépollution of toxic waste dumped from Probo Koala in Abidjan district Ivory Coast 80 p.