Analysis of Bacterial Pollution of Banks-Near Waters on the Petit-Bassam Island and its Impact on Populations' Health

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Abstract

The Ebrié lagoon is a place where domestic effluents are abusively dumped without being treated previously; particularly in the Petit-Bassam island's bays where the discharges are estimated to more than 60.000 m³ of waste, using microbiological data acquired from nine measurement stations located in the island bays and a transversal survey resorting to 1.023 households. On the one hand, this study aims at evaluating the bacterial pollution level of banks-near waters on the Petit-Bassam island and on the other hand, analyzing the impact of this pollution on the waterside populations health. The ascending hierarchical analysis that has been implemented using five indicators defined as fecal contamination telltales (coliforms F., enterococcus F., streptococcus F., E. coli and clostridium P.) shows that the most polluted areas are located in the island's southern and northwestern parts. It is in those spaces that we have notified the highest prevalence rates of diarrhea, cholera and malaria.

Keywords: Petit-Bassam Island, Ebrié lagoon, bacterial pollution, waterside population, health

Introduction

Lagoons are shallow water areas located between the continent and the sea. Due to their geographic situation, these milieus' coasts are very privileged places in most of African biggest urban agglomerations. They endure a strong anthropical pressure which is justified by an important human concentration and intense economic activities that strongly favor their pollution (Briton et *al*., 2007). As it happens, it is all about tourist, agricultural activities and aquacultural resources exploitation (Hauhouot, 2004).

Moreover, those milieus constitute a place where industrial and domestic effluents are abusively dumped without being treated previously (Saab et *al*., 2007; Kambiré and *al*., 2012).

In Morocco, 60% of waste are dumped into the Oualidia lagoon without any prior treatment (Fatta et *al*., 2004 cited by Chedad and *al*., 2007).

In Côte d'Ivoire, as far as Abidjan city is concerned, the Ebrié lagoon receives about 40.000 m³ of domestic waste per day (Affian, 2002; Koné and *al*., 2007a; Kambiré and *al*., 2012). According to the Ivoirian antipollution center (CIAPOL), those wastes are more worrying in the Ebrié lagoon waters on the Petit-Bassam island side. The CIAPOL estimates at more than 60.000 m³ the volume of diverse urban effluents discharges (domestic waste, septic tanks effluent, etc.) poured out every day, without being treated, into that part of the lagoon (CIAPOL, 2009). Those different repulses are at the basis of bacterial production because the island waters bays are 500 times more charged in *E. coli* and 70 times with fecal enterococcus than the one of a referential estuarine area (CIAPOL, 2009).

Indeed, several studies, namely by Hassen and *al*. (2002) and Aboulkacem and *al*. (2007), have shown that lagoon milieus are places of intense bacterial activities because of continental and marine inputs. Besides, the lagoon hydro-chemical characteristics (salinity) and the climatic conditions (temperature) would favor the bearing and the proliferation of pathogenic bacterias which give an endemic feature to some diseases (Kouassi and *al*., 1990).
As a matter of fact, some pathogenic microorganisms have been found in halieutic products, namely the crustaceans and fish sold in the local markets of the Petit-Bassam island's neighborhoods and those products are very appreciated by the population (Koffi-Nevry and *al*., 2008). They can constitute a major sanitary risk for the population, namely diarrheic syndromes after consuming them. A transversal household survey implemented in 2003 revealed a 15% prevalence of diarrheic diseases in three lagoon villages (Koné and *al*., 2007b). Previous studies had already incriminated the lagoon about cholera-like infections epidemics (Duchassin and *al*., 1973; Dosso and *al*., 1984; Kouassi and *al*., 1990).

Many studies on the Ebrié lagoon were about the physicochemical characteristics and pollution of the lagoon. Those different studies evaluated the pollution degree of those waters and their consequences on natural resources in general (Anoh, 2001; Dufour and *al*., 1975, Durand et *al*., 1994). Some of them were interested in lagoon fishing (Kablan, 2002). A few studies were focused on hydrology (Girard and *al*., 1971; Lehay, 1984; Guiral and Fehri, 1988; Ramany, 1980; Arfi and *al*., 1989), bathymetry (Tastet, 1979), sedimentology (Debyser, 1955), geochemistry (Debyser, 1959; Guiral, 1983; Carmouze and Caumette, 1985; Dufour and Slépoukha, 1975), biology (Binder, 1968; Daget and Durand, 1968) and benthos (Zabi, 1982). However, no recent study on the risk level of bacterial contamination carried by waste, and to which waterside users is exposed, has been undertaken to understand the effects of current fecal pollution on the Abidjan population growth.

Thus, the objective of our study is, on one hand, to evaluate the bacterial pollution level (evaluated by the densities of the five bacterias-tests of fecal contamination, namely the fecal coliforms, fecal enterococcus, fecal streptococcus, E. coli, and perfringens clostridium) of waters near the lagoon shores of the Petit-Bassam island; and on the other hand, to analyze its impact on the waterside populations health. The analysis is based on the CIAPOL's data banks of the lagoon waters quality and site inquiries implemented by resorting to the waterside populations of the Petit-Bassam island. Several statistical processing have been used to seek the correlation between the prevalence rates of diseases mentioned by the waterside population and the pollution levels of the island waters.

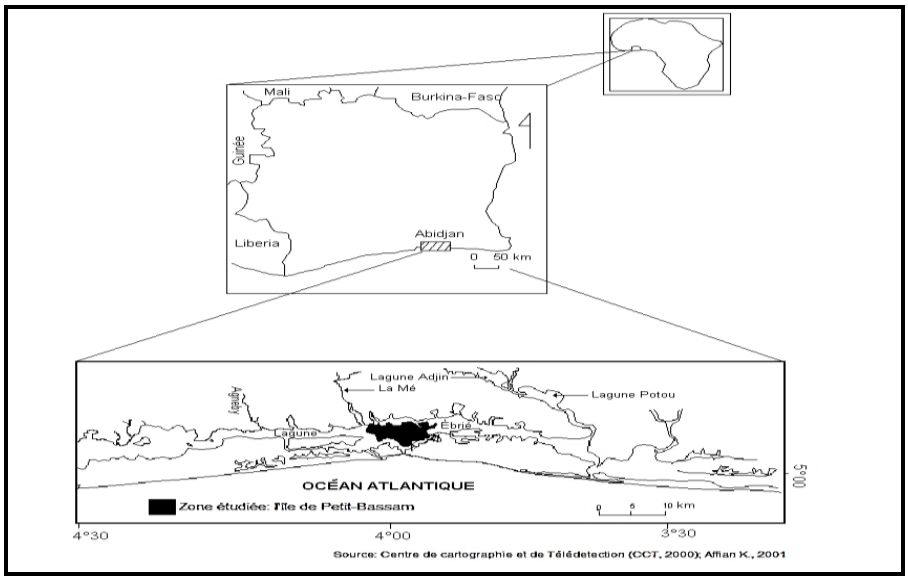
1. Materials and methods

1.1. Presentation of the study area: Petit-Bassam island

The Petit-Bassam island is located between the latitudes 5°00 and 5°18 north, and the longitudes 3°30 and 4°30 west in the southern part of Abidjan city (Figure 1). Surrounded by the Ebrié lagoon, it represents an area of 23.18 km² which amounts to about 4% of Abidjan city's terrestrial superficies. The Petit-Bassam island comprises the Koumassi, Treichville and Marcory municipalities which are part of the ten townships of Abidjan city. It benefits from both a mild climatic condition (26°C versus 34°C for Abidjan city) and a homogenous relief characterized by a lowland.

Adjacent to the Atlantic Ocean thanks to the Vridi's artificial waterway open in July 1950 and bordered by the Ebrié lagoon, the Petit-Bassam island is beneficially located as far as economic exchanges are concerned. The favorable situation for the human populations and economic activities settlements made the area one of the most densely populated and the most industrialized in Abidjan. As economic lung of the city, the island comprises the most important parts of industrial, commercial and port activities of the country which are precisely set up around the lagoon. Indeed, it comprises about 70% of the Ivorian industry and ensures 60% of the modern sector employments (Kablan, 2002). In 2014, the Petit-Bassam island had 887.805 inhabitants, that is, 22% of the Abidjan's population (SNI, 2014). It comprises seventy habitation sites, but we were only interested in its nineteen perilagoonal neighborhoods. Those areas' population represents 35%, and is one of the strongest densities in Abidjan city (21.170 hts/ km²). The Petit-Bassam island is rich because of its economic activities and these resources have a negative impact on the island water quality, and yields several challenges for the preservation of this brackish water.

Figure 1: Geographic location of the Ebrié lagoon and the Petit-Bassam island



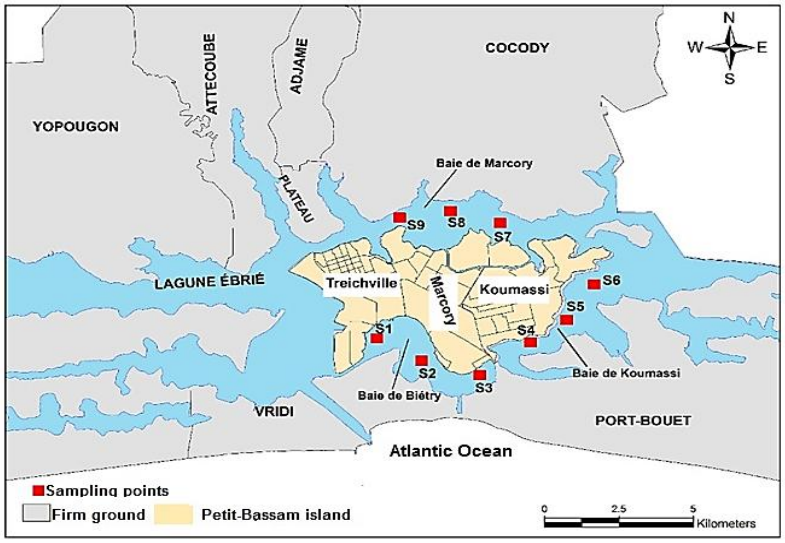
1.2. Acquisition of microbiological data

The data used to evaluate the bacterial pollution level of banks-near waters on the Petit-Bassam island stem from the Ivorian Anti-Pollution Center's data bank (CIAPOL).

In 2015, within the framework of the project « decontamination of the Ebrié lagoon's bays » financed by the Ivorian government and the World Environment Fund (WEF), the CIAPOL proceeded to several samples in the lagoon's different urban areas in order to evaluate the different types of pollution. The evaluations were done during six study explorations implemented between February and November 2015 in nine measurement stations located in Koumassi, Treichville and Marcory bays (Figure 2). Two samples measurements have been implemented during dry season (February-March), two others during rainy season (June-July), and two others again during the short rainy season and fluvial flood (September-October).

In the nine sites, all samples have been taken during each exploration *in situ* between 10:55 am and 11:45 am. For each exploration, two water samples per station have been taken from 20 cm below the water surface by means of sterile flacons with 500 ml glass plug; then, conserved in a 4°C cooler. Altogether, 108 water samples were taken during those six explorations by CIAPOL's agents.

Figure 2: Location of sample stations in Koumassi, Marcory and Treichville bays on the Petit-Bassam island



On each sample, five fecal contamination telltale bacterias which are normally absent in non-polluted waters have been sought. They are the fecal coliforms, fecal streptococcus, fecal enterococcus, E. coli, and perfringens clostridium (Table 1).

Table 1: Variables and indicators selected for the bacterial pollution level evaluation

Variables	Indicators	Sources
Clostridium	Perfringens clostridium density ≥100 germs /l	WHO/PNUE, 1977
Coliforms	Fecal coliforms density or thermotolerants≥100 germs/l	WHO/PNUE, 1977
Enterococcus	Fecal enterococcus density≥100 germs/l	WHO/PNUE, 1977
Streptococcus	Fecal streptococcus density≥100 germs/l	WHO/PNUE, 1977
E.coli	E.coli density ≥100 germs/l	WHO/PNUE, 1977

The densities of colony bacterias have been expressed under the form of Colony Formant Unity (CFU) for 100 ml after logarithmic transformation (CFU> logo (CFU + 1) in conformity with the recommendations established by WHO/PNUE (1977).

1.3. Microbiological data processing

Statistical analyses concerning the average density of fecal coliforms, fecal streptococcus, fecal enterococcus, E. coli and perfringens clostridium distributions counted in surface waters near lagoon banks on the Petit-Bassam island have been calculated. The typical gap among those distributions has been determined.

Furthermore, an ascending hierarchical classification (aggregation index: centered moment order 2; partition algorithm: reducible neighbors method) of diverse stations has been realized for the six sample explorations with XLSTAT. In this analysis, only the variables which permit a bacterial pollution estimation (fecal bacterias density: E. coli, perfringens C., etc.) have been taken into account to map the bacterial pollution levels observed on the lagoon banks of the Petit-Bassam island. As a result, the perilagoonal neighborhoods which are most exposed to contamination risks of hydric diseases have been identified.

1.4. Demographic data acquisitions

A transversal survey to the households through questionnaire was implemented to analyze the effects of bacterial pollution on the Petit-Bassam island's waterside population. It is based on the simple random sampling technique. The sample size (number of households) depends on the rates to measure and the expected precision, as expressed in the equation 1 (WHO, 1991):

$N = PQ / [E/L] 2 \quad N = P (1-P) / [E / 1.96]2$

With:

N: minimal size of the necessary sample;
P: estimation of the expected proportion (prevalence rate) for the phenomenon under study;
Q: value of (1-P);
E: tolerated margin of error (statistical risk in %);
L: reduced gap for the statistical risk admitted (1.96 for the risk 5%).

The validity of equation [1] lies in the value choice dexterity of the prevalence rate. The prevalence rate of diarrheal diseases has been considered in this study. Nationally, this rate is of 15% (Koné et *al*., 2007). This choice is linked to the fact that diarrheal diseases constitute a public health problem, and, after malaria, they are the second cause for consultation in Ivorian health centers.

The equation [1] application with an allowable risk of 5%, led to a sample of 1.023 households necessary to cover the 19 selected neighborhoods. The choice of the households under study was made randomly. A 6 lots survey step was determined by means of a Digital Globe Incorporation's Quick-Bird satellite image of Abidjan city on November 17th 2005 in order to cover the whole study area. The spatial resolution of that image is 60 centimeters.

In the selected lots, the household was eligible if and only if the householder was living in the neighborhood since more than 3 years. From the moment that we wished to measure the pollution influence on individuals' health, the inclusion of minimal duration of residence in the neighborhood proved essential.

The questionnaire is structured into 3 sections: 1, 2 and 3. Firstly, the section 1 is concerned with the identification and the basic information about the household in terms of socioeconomic and demographic characteristics of households. Secondly, the section 2 is concerned with the concession state. As for the section 3, it analyzes the diseases contracted by the household during the 15 days preceding the survey.
The variables extracted from those three themes are presented in the Table 2.

During two months (June to July 2015), in each neighborhood, 2 trained surveyors submit the questionnaire to different households (householder or any other person capable of answering questions helpfully).

Table 2: Variables presentation and households survey indicators

Variables	Indicators
Demographic and socioeconomic characteristics of the household.	Sex, age, the marital status, level of instruction, residence place, residence duration, socioprofessional category and income, basic apparatus level (kitchen, toilet, modern bath), drinking water's supplying mode, storage mode and household refuse management, waste evacuation mode;
Morbidity	Diseases prevalence,
Consumption of products from the lagoon	Type of consumed products, purchase place ;
Frequentation of the lagoon	Type of practiced activities, (activities, walk, fishing, etc.).

1.5. Processing of the survey data

The filled questionnaires about the household transversal inquiry were subject to a quality-check process. Next, the data were collected in an elaborate gathering mask in Epi Data, then, transferred into the XLSTAT software for processing and analyzing. A data auditing was carried out in order to reinforce the quality of those ones. The double collection exploitation (25%) contributed to it, and permitted to appreciate the collection quality as very satisfying.

First, a descriptive analysis of data about the households put under study and the diseases prevalence rates were done to evaluate the questioned households' health condition.
Besides, a non-parametric correlation analysis was carried out using the XLSTAT software. The Spearman's rho coefficient and Kendall's tau coefficient (Field, 2009) were used to measure the association between the diseases prevalence rates and the factors capable of influencing their distribution as far as perilagoonal neighborhoods on the Petit-Bassam island are concerned.

The analysis examined about the illiteracy rate as indicator of the level of instruction and the following percentages: the households consuming lagoon products or well water, the households visiting the lagoon banks or having an activity related to the lagoon, the households having a residence duration ≥ 3 years, as well as those having basic equipments such as a kitchen, a toilet and a modern bath as indicator of housing healthiness. As for the environmental factor, we assumed that people living near strongly polluted areas had a higher risk of diseases contamination than those living far from polluted areas. The environmental indicator is defined by the repartition of microorganisms' density, telltale of bacterial pollution.

2. Results and discussion

2.1. Descriptive analysis of data on the bacterial contamination level of banks-near waters on the Petit-Bassam Island

The Table 3 presents the average densities of bacterial pollution indicators (expressed log CFU/100 ml) obtained from the different stations. The average bacterial densities of fecal coliforms, fecal enterococcus, fecal streptococcus, E. coli, and clostridium correspond to the counting realized for surface waters near the lagoon banks.

The results indicate an important density of bacterias in the surface waters on the Petit-Bassam island. The E. coli, the fecal coliforms, and the fecal streptococcus respectively reach up to ($5.09\ 10^5$; $4.20\ 10^5$; $4.22\ 10^4$ CFU/100 ml) in the measurement stations 2, 3 and 4 located in the south-eastern part of the Biétry bay. Among those three stations, the stations 2 and 4 showed the highest bacterial charges indicating fecal contamination. That difference might stem from a contamination through sanitation structures built on the lagoon near each of those stations that would significantly participate in the input of a large number of fecal contamination germs.

The clostridiums densities and the enterococcus are much stronger in the Marcory bay, located in the North-western part of the island. That remarkable bacteriologic pollution level in the island's bays had already been mentioned in several studies (Lanusse, I987, Pages et *al*., 1978; Guiral and Kouassi, 1992; Adingra et *al*., 1998; Koné et *al*., 2007a).

Table 3: Average densities of E. coli, fecal clostridium, fecal coliforms, fecal enterococcus and fecal streptococcus in the surface waters near lagoon banks on the Petit-Bassam island

Measurement stations	Enterococcus		Clostridium		E.coli		Streptococcus		Coliforms	
	D 50	σ	D 50	σ	D 50	σ	D 50	σ	D 50	Σ
Station 1	3.09	1.32	2.74	0.30	4.60	1.25	3.05	1.35	2.27	1.18
Station 2	3.55	1.17	3.32	0.33	5.00	0.60	4.15	1.13	2.39	1.10
Station 3	3.55	1.17	3.32	0.33	5.00	0.85	2.37	1.17	2.69	1.31
Station 4	3.20	1.21	3.58	0.73	5.09	0.40	3.04	1.43	4.20	1.21
Station 5	1.97	0.84	3.58	0.73	3.11	1.80	3.69	1.15	2.37	1.05
Station 6	1.97	0.92	3.84	0.75	3.39	1.62	2.62	1.15	3.55	1.14
Station 7	3.45	1.21	2.77	0.84	4.33	1.60	4.22	1.11	3.05	1.25
Station 8	3.09	1.34	3.62	0.81	3.61	1.67	2.05	1.08	3.58	0.73
Station 9	3.95	1.37	3.18	1.10	3.39	1.62	2.67	1.16	3.61	167

Respective averages of E. coli, enterococcus and clostridium (log CFU for 100 ml); D50: representing the bacterial densities which correspond to 50% of the counting realized for the surface waters; σ: standard deviation; Ivorian Antipollution Center (CIAPOL, 2015).

For a surface water to be considered as bacteriologically satisfying, concerning the WHO/PNUE norms, it must not present more than 100 germs for 100 ml in 50% of the analyzed samples (Table 1).

According to that norm and regarding the average concentrations observed about E. coli, coliform, clostridium, enterococcus, and streptococcus, the sampled lagoon banks-near waters are unsuited to any resort activities, and this is applicable to the six explorations implemented. The bacterias density averages are significantly different for the 3 stations which have been studied (Table 4) with maximal values during rainy and flood seasons. Those periods correspond to a stronger bacterial contamination of waters by E. coli, clostridium and enterococcus. Indeed, those bacterias live longer during rainy and flood seasons (Kambiré et *al*., 2012).

The bacterial seasonal enrichment had already been observed in the Ebrié lagoon's bays (Lanusse and Guiral, 1988; Kouassi et *al*., 1990). Those densities' increase of E. coli, clostridium and enterococcus has been interpreted as the result of inputs' increase related to flowing waters and strong oceanic influences of those bacterias' failure to develop themselves on a selective milieu after its transition into a high salinity milieu (Kouassi et *al*., 1990).

Table 4: Statistical parameters of E. coli, coliform, clostridium, enterococcus, and streptococcus distributions to the 3 hydroclimatic seasons

Periods		Dry season [February-March]	Rainy season [June-July]	Short rainy season and fluvial flood [September-October]
E.coli	EC 50 σ IC	3.55 0.70 3.41-3.69	4.40 0.85 4.19-4.61	3.85 0.65 3.67-4.03
Enterococcus	ENT 50 σ IC	2.70 0.95 2.51-2.89	3.20 0.95 2.97-3.43	2.70 0.70 2.51-2.89
Clostridium	CL 50 σ IC	2.75 0.60 2.63-2.87	3.20 0.80 3.00-3.40	2.55 0.55 2.40-2.70
Coliforms	CO 50 σ IC	2.15 0.45 2.05-2.22	2,25 0,70 2,20-2,35	2,40 0,60 2,35-2,45
Streptococcus	ST50 σ IC	1.95 0.55 2.15-1.88	2.15 0.75 2.05-2.22	2.55 0.55 2.40-2.70

σ : standard deviation; EC 50, ENT 50, CL 50, CO 50 and ST 50 : respective averages of E. coli, enterococcus, clostridium, coliforms, and streptococcus (log CFU for 100 ml) representing the bacterial densities that correspond to 50% of the counting realized for surface waters; C: certitude gap (5%). Ivorian Antipollution Center (CIAPOL, 2015).

Generally speaking, the sites show a strong charge characterized by a high bacterial contamination no matter the period. The densities of the five bacterias selected as bacterial contamination test-organisms indicate a high pollution of banks. That enrichment stems from the proximity between the sampled stations and the wastes sites. Since the percentage of connection to the city's sanitation system is very low, the enteric bacterias constitute a diffused pollution source for the lagoon milieu. Those bacterias are carried by flowing waters, and lead to a more important contamination of lagoon banks and, particularly, those located within bays in those milieus. Hydro-dynamism is less active in them as well as the massive existence of bacterial pollution. The lagoon is a brackish milieu that hardly defends itself against bacterias because of the high temperature of waters (25.5°C and 34°C) (Affian et *al*., 1997).

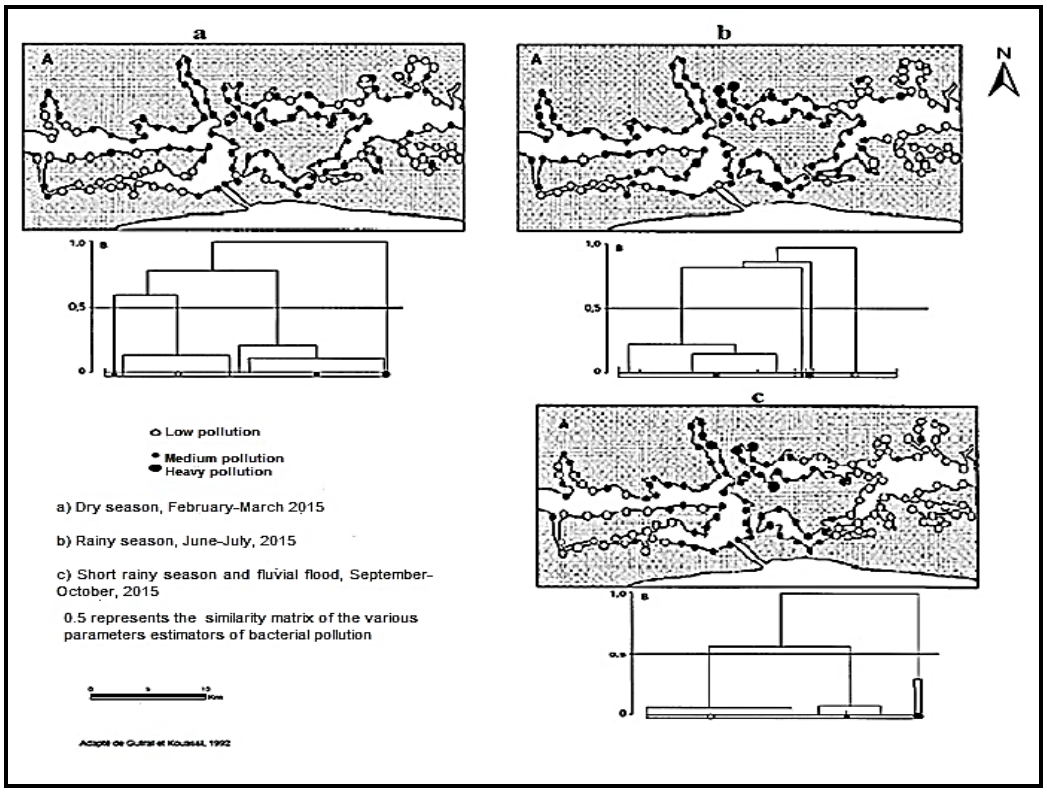
Besides, the bays extremity display the emergence of a new rainwater which constitutes, an additional factor to pollution. Thus, in the bed of those bays, values superior to 10^6 E. coli for l00 ml were determined (Affian et *al*., 1997) during period of maximal bacterial contamination (big rainy seasons). Since several years, during that period in the Abidjan region, the appearance of diverse choleric infections is noted (Duchassin et *al*., 1973) or cholera-like forms caused either by Vibrio parazaemolyticus (Dosso et *al*., 1983) or by other vibrio (Dosso, 1984) of pathogenic bacterias identified in the lagoon (Guiral et *al*., 1993). Those diverse observations confirm the very crucial sanitary and bacteriological situation of the Ebrié lagoon at the level of Abidjan city. Without a sanitizing and water purification system, the lagoon banks permanently prove alarming and particularly amplified during strong rainy season. This observation calls for a rapid elaboration of a sanitation global diagram of Abidjan city allowing the improvement of the bacteriological quality of lagoon waters and, more specifically areas the waterside population can access.

2.2. Cartography of bacterial pollution levels on the island's lagoon banks

An ascending hierarchical analysis permitted to make a cartography of bacterial pollution levels concerning the lagoon banks. This analysis took into account the five variables corresponding to bacterial densities in terms of fecal coliforms, fecal enterococcus, streptococcus, E. coli, and clostridium; and was carried out for the six explorations related to the three hydroclimatic seasons of the Ebrié lagoon. The dendrograms from this analysis are represented in the figures 3a, 3b and 3c.

For the three exploration periods, it has been possible to individualize three groups (group 1: dry season; group 2: rainy season; group 3: flood season) whose statistical characteristics have enabled a graphic representation of the diverse sampled sites according to an increasing pollution scale particular to each season. That analysis shows that waters with strong pollution occupy the central part of the Ebrié lagoon island no matter the period. In dry season, one can observe an important extension of polluted areas towards the north-eastern part of the lagoon (Figure 3a) in comparison to the Vridi's waterway (south-west). The local precipitations cause a generalization of strong pollution areas that thereby affect the set of stations located in the north of the lagoon's Western branch and in the south-east (Figure 3b). After the flood season, the number of strong pollution sites is considerably reduced particularly in the Western sector which is more directly influenced by the passage of fluvial waters (Figure 3c). The effect of climatic variation on the distribution of the lagoon's waters pollution level with a notable increase during rainy periods has been reported in many studies (Cheng and *al*., 2013; Dewan and *al*., 2013; Corner and *al*., 2013).

Figure 3: Cartography of pollution levels for the Petit-Bassam island's lagoon banks made through the dendrogram representing the similitude matrix of the five parameters of bacterial pollution in 2015



It is also important to precise that the southern and north-western areas are occupied, for most of them, by crowded and precarious neighborhoods where there is no sanitation and domestic waste collection (Affian et *al*., 1997). This situation compels the populations to evacuate their waste and other substantial wastes (household refuse) directly into the lagoon.

The island's lagoon banks have become dumping places of any type of substantial waste. As we could observe on site, dangerous objects such as syringes and sharp materials are found in those places. Throughout the banks of some neighborhoods (Yobourt-Lambert, Anoumabo, Ancien-Koumassi, etc.), one can observe the presence of toilets on stilts where human excrements are dumped directly into the ponds that serve for fishing, swimming, practicing informal activities, and walking.

Therefore, one must be aware of the fact that in a community where there is an important reservoir of potential diseases, the evacuation of the infectious excrements into the lagoon milieu constitutes a serious threat for the heath of waterside populations. Two major contamination modes are suspected: either through the direct contact with the body during toilet or swimming activities, or through the consumption of contaminated fish, crustaceans or mollusks. Those daily practices that may endanger the waterside population's health, have been described several times in studies (Dufour and *al*.; Affian and *al*., 1997).

In 1998, a few epidemiologic data were even published by the Public Health National Institute, data predicting a possible involvement of the lagoon milieu and its hydroclimatic variations in the endemic retention of some diseases (PHNI, 1998).

2.3. Recurrent diseases prevalence

Before the survey, over a two-week recall period, three recurrent hydric diseases were revealed: malaria, diarrhea and cholera. The malaria's general prevalence rate, assessed within the framework of this study, on the basis of the household inquiry answers is of 49% in the studied peri-lagoon neighborhoods. That rate is higher than the national one (30%) and the one of the cities of Côte d'Ivoire's (40%) (PNLP, 2003). It represents the double of the one revealed by Dagnan and *al*., (2002) whose studies, throughout the whole Petit-Bassam island, give a rate of 23.3%. This study shows that the malarial prevalence in the peri-lagoon neighborhoods is higher than the one on the Petit-Bassam island. The perilagoonal neighborhoods are more exposed to malarial contamination. In the Yobourt-lambert (North-west), Kouassi-Lenoir (South), Abia-Abety and Ancien-Koumassi (South-east) neighborhoods, the malarial prevalence displays the highest rates (>51%). The lowest rate (25.6%) is noted in the Residential-estate and Biétry neighborhoods (Figure 4).

Recurrent consultations in the peri-lagoon neighborhoods are also due to diarrheal diseases. Those diseases display order prevalences of 23% on average, basing on answers from studied households. As far as the less than 5 years old are concerned, that prevalence was of 14.0%.Yet, this study confirms that the less than 5 year-old cohort is the most vulnerable concerning diarrheic diseases (Al-ghamdi and *al*., 2009; Barreto and *al*., 2006; WIerzba and *al*., 2006; WHO, 1999).

The situation remains particularly alarming in the crowded and precarious neighborhoods located in the south and the north of the Petit-Bassam island (Figure 4). Those neighborhoods display the highest rates (>20%) unlike the south-east and north-west neighborhoods that display the lowest rates (16%). This result is pointed out in the studies implemented by Cissé and *al*. (1998), Bartlett (2003) and WHO (2005) which showed that the poor milieus in developing countries are the most affected by diarrheal diseases, mostly the fringe of children less than 5 years old. Those diseases kill millions of people every year, preventing other millions of them from living healthily and undercut the efforts made in terms of development (Nash, 1993; Olshansky and *al*. 1997). This situation also goes along with the results of recent studies implemented in the Abidjan's precarious neighborhoods (PHNI, 1998; Obrist and *al*. 2006).

The cholera's prevalence rate was on average of 19% order. The most stricken neighborhoods are located in the southern and eastern parts of the island (>16.5%).Cholera frequently occurs on the island where several cases have been notified (Kouassi and *al*., 1990). Thus, between 1985 and 1993, during the cholera epidemics that stroke Abidjan, the morbidity prevalence rate was respectively 44%, 32% and 25% in the Koumassi, Marcory and Treichville townships and 2% for most of the other townships located in the north of the Abidjan agglomeration. A few years later, the same observation was made during a typhoid fever epidemic (Kouamé and *al*., 1995).
The study is based on the last morbid episode declared by individuals fifteen days prior to our passage. Even if this fifteen-day recall period permits to avoid the declaration bias (Kroeger, 1985; Timaeus and *al*., 1988), it limits the number of declared morbid episodes. This study must be completed by field inquiries resorting to health services of the island's peri-lagoon neighborhoods in order to compare the morbidity declared by individuals with the morbidity diagnosed by a health professional.

2.4. Analysis of the non-parametric correlation between the mentioned diseases and the bacterial pollution levels

The Table 5 clusters the coefficients of non-parametric correlation that measures the association between the diseases prevalence rate from the households and the factors associated with its distribution on the Petit-Bassam island. We use only diarrheal diseases because it's constitute one most important water-borne disease related to water pollution.

Table 5: Results of coefficients of non-parametric correlation between the diseases rate and the associated factors

Factors associated with diarrheal diseases	Coefficients of non-parametric correlation	
	Rho of tau-b of Kendall	Spearman (ρ)
Proximity with very strong pollution sectors : South, North-west	- 0.428*	- 0.298**
Proximity with strong pollution sectors : North	- 0.674**	- 0.467**
Proximity with medium pollution sectors : East	- 0.551**	- 0.390**
Proximity with low pollution sectors : North-east	- 0.353*	- 0.269*
Percentage of households consuming well water	- 0.313*	- 0.209*
Percentage of households consuming lagoon products	- 0.278*	- 0.289*
Percentage of households with a residence duration ≥3 years	- 0.341*	- 0.269*
Illiteracy rate	- 0.019	- 0.004
Percentage of households having toilets	- 0.198	- 0.101
Percentage of households attending the lagoon banks	- 0.048	- 0.075
Percentage of households having an activity related to the lagoon	- 0.049	- 0.125
*The correlation is significant at the level of 0.05; **The correlation is significant at the level of 0.01		

These results show a negative association which is highly significant ($p<0.01$) between the mentioned diarrheal diseases and the proximity with the three sectors of the most polluted banks on the Petit-Bassam island. The analysis of the same association, with sectors taken in pairs, revealed negative associations of which the strongest is located in the southern and north-western sectors.

Furthermore, the analysis of the non-parametric correlation coefficients shows a strong correlation with the proximity of sectors less polluted in the east, and the percentages of households consuming well water, lagoon products and having a residence duration ≥3 on the Petit-Bassam island. No statistical association was found with the illiteracy rate and the percentages of households having toilets, attending the lagoon banks and having a lagoon-related activity. While no statistical association was found with the illiteracy rate and the percentage of basic apparatus, this highly significant and negative association that has been found between the diarrheal diseases prevalence and the proximity of polluted lagoon banks on the Petit-Bassam island, supports the hypothesis about the contamination risk increase through hydric diseases as far as the populations living near the polluted lagoon waters are concerned.

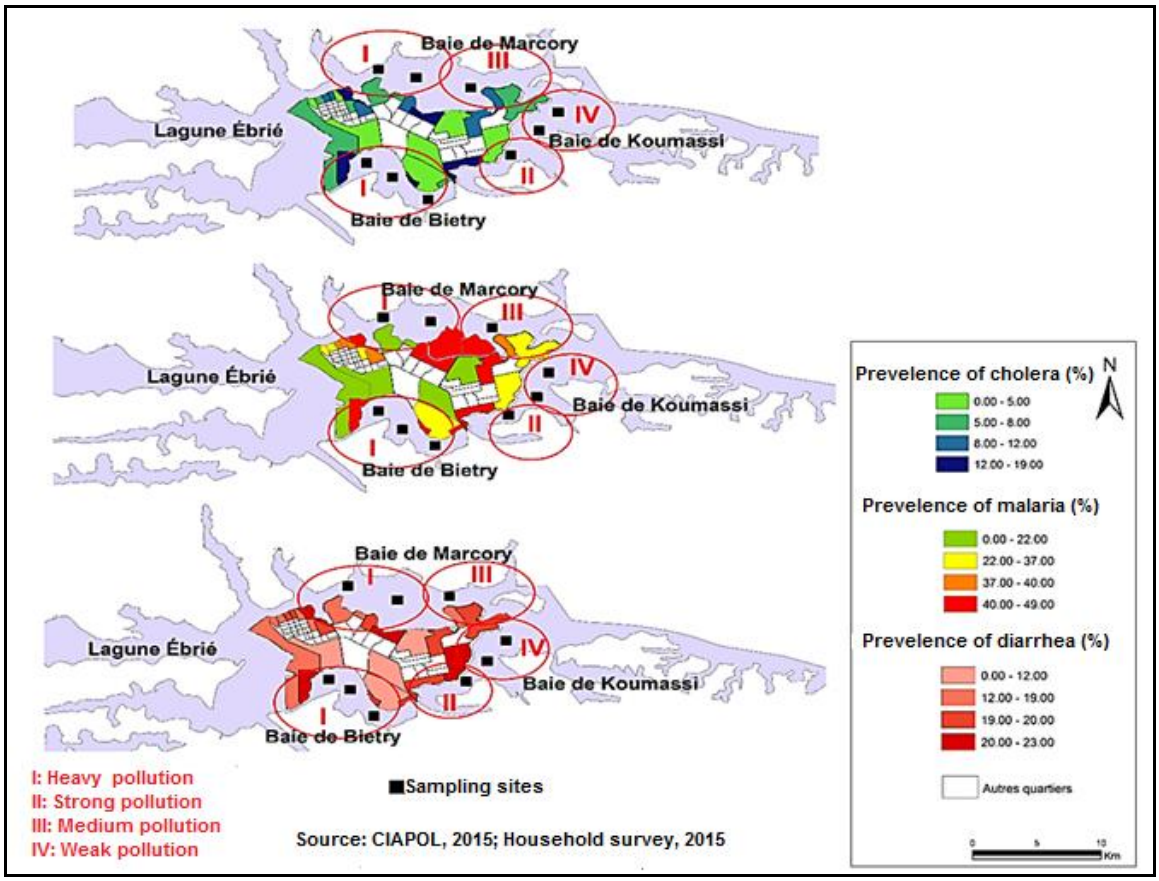
Prior studies by Dosso and *al.* (1984) had mentioned a high prevalence rate of cholera in the Southern lagoon areas. In 1985, the epidemic of diarrheas appeared during June and July months, was mainly caused by viruses found in the lagoon. Between 1985 and 1990, many cholera-like infections involving other vibrionaceans were periodically signaled in inhabited areas bordering the lagoon (Kouassi and *al*., 1990). The Ebrié lagoon on the Petit-Bassam island's side is a deposit shelter for several organisms which are very dangerous for human beings insofar as they are responsible for many diseases. Consequently, it has been reported that the higher the pollution level the more important the declarations of diseases prevalence rates (Figure 4).

Besides, the strong correlation with the proximity of weakly polluted sectors in the east shows that the lagoon pollution is not the only relevant factor in the diseases contamination risks on the island. Several hypotheses have been put forward to explain this unexpected situation. As regards sanitation, the deficit of neighborhoods' drainage and domestic waste evacuation observed in those precarious peri-lagoon neighborhoods is a disease factor, namely the pseudo-diarrheic and pseudo-malarial syndromes. As a matter of fact, poor-quality waters, precarious sanitation and bad hygiene greatly contribute to deterioration of the populations' health (Ersey and *al*., 1991). The diarrheal diseases are caused by several parasites such as salmonellas (the most encountered) which are located in unhealthy milieus with no adequate modern sanitation system and associated with hygiene deficit (Farthing, 2000). That rate is high in very poor milieus because of bad hygienic conditions, malnutrition and precarious sanitary environment. The significant association ($p<0.01$) between the mentioned diseases and the percentage of households consuming well water on the Petit-Bassam island shows that the shallow ground waters are linked to the lagoon water which is strongly polluted by bacterias and pathogenic agents causing hydric diseases. This result is in accordance with the one from Konan and *al*. (2009).

An important quantity of raw fruits and vegetables and other lagoon products are commercialized in the peri-lagoon neighborhoods' local markets. Despite the existing risks, it is 35% of the questioned households that frequently buy and consume the lagoon products. That behavior might explain the significant association between the percentage of households consuming the lagoon products and the diseases prevalence. That observation about the marketing of fishing products and vegetables irrigated by lagoon waste water at the level of local markets was reported by inquiring studies on urban farmers and fishermen of Abidjan city (Kouamé 2009; Affian, 2002). The consumption of fishing products from polluted waters or foodstuffs irrigated by waste water is sanitarily risky since they can be vectors of pathogens associated with excreta (whose bacterias are responsible for diarrhea or cholera), salmonella, or vibrio (Bos et *al*.,2011; WHO, 2012).

The prevalence rates of recurrent diseases (malaria, cholera and diarrhea) evaluated in this study are furnished indicatively and cannot represent the epidemiologic reality witnessed in these neighborhoods. To get this study completed, clinical investigations would be essential to set up an effective link between diseases and the bacterial pollution of those neighborhoods' lagoon. These study results constitute an important current database for the future actions to be undertaken in those neighborhoods. They will enable the sensitization of the government about the sanitary risks which the populations living on the verge of the Petit-Bassam island's lagoon are facing.
The study of factors associated with the mentioned diseases is limited to the level indicators of banks pollution, the level of instruction, socio-demographic factors, and housing healthiness; the environmental data concerning the neighborhoods have not been called up in this study. The strong prevalence rate of diseases in the eastern neighborhoods shows the necessity to complete this study with environmental inquiries.

Figure 4: Distribution of the most frequent diseases in the households of perilagoonal neighborhoods on the Petit-Bassam island



The classification method that has been used is the 'Natural Breaks of Jenks'. The gathering of sites pollution level has been inferred through the ascending hierarchical analysis (Figure 3).

Conclusion

This study has permitted to assess the bacteriologic pollution level of the banks-near lagoon waters on the Petit-Bassam Island during the three seasons that characterize the lagoon hydroclimate. During rainy seasons, the densities of the five bacterias (fecal coliforms, fecal enterococcus, streptococcus, E. coli, and perfringen clostridium) selected as test-organisms of fecal contamination indicate a strongly high pollution particularly on the island's lagoon banks. That period, in this study space, corresponds to a strong prevalence rate of malaria, cholera and diarrhea in the questioned households. The calculation of non-parametric correlation coefficients associates the strong prevalence rates of diseases recorded from the households living near very polluted banks; which permits to determine the populations exposed to high risk of diarrhea contaminations, mainly located in the south and north-west. Moreover, the local distinctions of percentages of households consuming lagoon products, well water, having a residence duration ≥3 years have been identified as the other factors of influence on the geographic distribution of diseases, and the illiteracy rates and the basic apparatus level as probable factors.

This analysis constitutes an important step in the implementation of local programs specific to the prevention and the control of the lagoon pollution too often involved in the infections of diseases such as cholera, typhoid fever, malaria as far as the Petit-Bassam island is concerned. In order to be successful, the programs that will be established must take into account the waterside populations' demographic and cultural profiles, and neighborhoods' environmental characteristics.

References

Affian K., 2002, "Étude par télédétection aéroportée d'un environnement lagunaire en zone tropicale :cas de la lagune Ébrié en Côte d'Ivoire", in Télédétection, vol. 2, No.4, 233-242.

Affian K., Biemi J., Gioan P., 1997, "Exemple de traitement numérique de données auxiliaires du type photographie aérienne : étude de la dynamique côtière en liaison avec le canyon du trou Sans Fond à la droite du port d'Abidjan", In Dubois J.-M., Bernier M, Fortin J.-P., Boivin F, "La réalité de terrain en télédétection : pratiques et méthodes", AUF, 209-216.

Al-Ghamdi A., Bentham G., Hunter P., 2009, "Environmental risk factors for diarrhea among male schoolchildren in Jeddah City, Saudi Arabia", Journal of Water and Health, Vol 7, No.3, 380-391.

Anoh K., 2001, "Lagune Ébrié de 1995 à 1998, Pollution des eaux et encombrement des baies urbaines de l'agglomération d'Abidjan", in Géotrope, Presse universitaire de Côte d'Ivoire, No.3, 6278.

Arfi R., Guiral D., Torreton J., 1989, "Cycle hydrologique annuel d'une baie lagunaire eutrophe : la baie de Biétri (lagune Ébrié, Côte d'Ivoire), Revue d'Hydrobiologie Tropicale, Vol 22 : No.4, 263273.

Bartlett S., 2003, "Water, sanitation and urban children: the need to go beyond "improved provision", Environment and Urbanization, No.15, 57-70.

Binder E., 1968, "Répartition des mollusques dans la lagune Ébrié (Côte d'Ivoire)", Cahier de l'ORSTOM, Série hydrobiologie, Vol 2 : No4, 3-34.

Bohle H.G., 2001, "Vulnerability and criticality: perspectives from social geography", In: IHDP update 3, 3-5.

Bollig M., 2003, "Vulnerability and Resilience in Africa: The creation of resilience in two African herder societies", In: IHDP update 5, 8-9.

Carmouze P., Caumette P., 1985, "Les effets de la pollution organique sur les biomasses et activités de phytoplancton et des bactéries hétérotrophes dans la lagune Ébrié (Côte d'Ivoire)", Revue d'Hydrobiologie Tropicale, Vol 18, 183-211.

Castro L., 2000, "Public spending on health care in Africa: do the poor benefit? » Bulletin of the world Health Organization, Vol 78, No1, 66- 74.

Cheng J., Tang Y., Bao J., Zhu F, Liang Q., 2013, "Spatial analyses of typhoid fever in Jiangsu province, People's Republic of China", Geospatial Health, Vol 7, No.2, 279-288.

CIAPOL (Centre Ivoirien Anti-pollution), 2015, Synthèse de suivi des eauxlagunairesd'Abidjan2015, Abidjan, CIAPOL.

CIAPOL (Centre Ivoirien Antipollution), 2015, Synthèse de suivi des eaux lagunaires d'Abidjan 2000-2015, Abidjan, CIAPOL.

Cissé G., Mayestre L., Odermatt P., Tanner T., 1998, Spatial distribution of diarrhoea and risk factors among children under five in Ouagadougou (Burkina Faso), Proceeding of the 1st World congress of Health and Urban Environment, Madrid, Spain, Juillet 6-10, p 340.

Daget J., Durand J.R., 1968, "Étude du peuplement des poissons d'un milieu saumâtre tropical poikilohalin: la baie de Cocody en Côte d'Ivoire", Cahier de l'ORSTOM, Série océanographie, Vol 11, No.4, 431-454.

Dagnan N. S., Koné A., Tiembre I., Ekra K., Benié V., Ndoutabe M., Tagliante S., 2002, "Étude de la prévalence du paludisme dans la commune de Yopougon Abidjan- Côte d'Ivoire, Médecine d'Afrique Noire", Vol 49, No.11, 507-510.

Debyser J., 1955, "Étude sédimentologique du système lagunaire d'Abidjan", Revue de l'Institut Français du Pétrole, Vol 10, 319-334.

Debyser J., 1959, Contribution à l'étude géochimique des vases, Thèse de doctorat ès sciences naturelles, Paris, 251 p.

Dosso M., Duchassin M., Lombardo A., Koné M., Edoh V., 1984, "Cassporadiques ou début d'une nouvelle épidémie de choléra", in Bulletin de la Société de Pathologie Exotique, No.76, 121-125.

Dufour P., Slépoukha M., 1975, "L'oxygène dissous en lagune Ébrié: influence de l'hydroclimat et des pollutions", Document Scientifique du Centre de Recherche Océanographique, Abidjan, Vol 6, 75-118.

Dufour P., Kouassi A.M., Lanuisse A., 1994, "Les pollutions", Durand J.P., Dufour P., Guiral D., Zabi F. in Environnement et ressources aquatiques de Côte d'Ivoire – les milieux lagunaires, Paris, ORSTOM, Tome II, 309-333.

Durand J.R., Guiral D., 1994, "Hydroclimat et hydrochimie", Dans Environnement et ressources aquatiques de Côte d'Ivoire: Les milieux lagunaires, Tome 2, Orstom, 59-90.

Ersey S.A., Potach J.B., Robert L., Shiff C. 1991. "Effects of improved water supply and sanitation on ascariasis, diarrhoea and trachoma", Bulletin of world health organization, No.69, 609-621.

Girard G., Sircoulon J., Touche boeuf P., 1971, "Aperçu sur les regions hydrologiques: le milieu naturel de Côte d'Ivoire", in mémoire de l'ORSTOM, No50, 109-156.

Guiral D., 1983, "Physico-chimie et bio géochimie des eaux et des sédiments à la station d'aquaculture de Layo (lagune Ébrié, Côte d'Ivoire)", Document Scientifique du Centre de Recherche Océanographique, Abidjan, Vol 14, 1-29.

Institut National de la Statistique (INS) Côte d'Ivoire., 2014, Synthèse des résultats définitif du Recensement Général de la Population et de l'Habitat (RGPH, 2014), 232p.

Kambire O., Adingra A., Kakou C et Koffi-Nevry C., 2012, "Indicateurs de pollution fécale dans une lagune tropicale a forte influence continentale (lagune Aby, Côte d'Ivoire) ", in Agronomie Africaine, Vol 24, No.2, 89 – 100.

Koné B., Cissé G., Houenou P.V., Obrist B., Wyss K., Odermatt P., Tanner M. 2006., "Vulnérabilité et résilience des populations riveraines liées à la pollution des eaux lagunaires de la metropole d'Abidjan, Côte d'Ivoire", in Revue électronique en sciences de l'environnement Vertigo, Hors-série 3.

Kouassi A.T., 1985, L'eau et les problèmes d'aménagement de la ville d'Abidjan, Mémoire de D.E.A. Université de Cocody. I.G.T, 86 p.

Kouassi A.M., Guiral D., Dosso M. 1990. "Variations saisonnières de la contamination microbienne de la zone urbaine d'une lagune tropicale estuarienne. Cas de la ville d'Abidjan (Côte d'Ivoire)", in Revue Hydrobiologie Tropicale, ORSTOM-IRD Paris. No.23 (3), 181-194.

Kouassi A., Kba N., Metongo B., 1995, "Land based sources of pollution and environmental quality of the Ébrié lagoon waters", In Marine pollution bulletin, Vol 30, 295-300.

Institut National d'Hygiène Publique (INHP). 1998, Stratégie de lute contre les maladies diarrhéiques. Rapport d'étude, Abidjan, 12-16.

Kablan N.J., 2002, Les arrières pays des ports ivoiriens, Thèse de Doctorat de Géographie, Université de Cocody, Abidjan, IGT, 342 p.

Kroegr A., 1985, "Reponses errors and other problems of health interview surveys in developping countries", World Health Statistical Quart, Vol 38, 15-37.

Lehay D., 1984, Système lagunaire Ébrié (Abidjan, Côte d'Ivoire): synthèse des données, modélisation de la courantométrie, dispersion, Mémoire de DEA, Université de Brest, 111 p.

Lanusse A., Guirald, 1987, Suivi annuel de la contamination bactérienne et virale des eaux et des sediments lagunaires au niveau d'Abidjan, 87p.

Metongo B.S., 1991, "Concentration des métaux toxiques chez Crassostreagasar (huître des mangroves) en zone urbaine lagunaire d'Abidjan", J Ivoir. Océanol. Limnol, Vol 1, No.1, 33-45.

Obrist B.G., Cissé B., Koné K., Dongo S., Granado., Tanner M., 2006, "Interconnected Slums: Water, Sanitation and Health in Abidjan, Côte d'Ivoire", European Journal of Development Research, Vol 18, No.2 319-336.

OMS/PNUE, 1977, Directives applicables à la surveillance sanitaire de la qualité des eaux littorales, Rapport Bureau Régional de l'Europe, Copenhague, 172 pp. Pages

J., Lemasson L., Dufour P., 1980, La pollution bactérienne de la lagune et de la mer autour d'Abidjan, Doc. Sci. CRO, Abidjan – Côte d'Ivoire, 43-50.

Programme Nationale de Lutte contre le Paludisme (PNLP), 2003, Rapports annuels d'activités 2001, 2002, 2003, Document technique, 27p.

Ramany B.P., 1980, Les systems lagunaires Ébrié en Côte d'Ivoire: fonctionnement hydrodynamique et salinité, Thèse de doctorat, Université d'Abidjan, 247 p.

Tastet J.P., 1979, Environnements sédimentaires et structuraux quaternaires du littoral du Golf de Guinée (Côte d'Ivoire, Togo, Bénin), Thèse de doctorat, Université de Bordeaux I, 181 p.

World Health Organization (WHO), 2005, Communicable diseases surveillance and response (CSR), Diseases outbreak report, Yellow fever in Côte d'Ivoire,

WHO, Geneva, 196p. WHO, 2003, Guidelines for safe recreational water environments, Vol 1: Coastal and fresh water, Geneva, WHO, 253 p.

WHO, 1999, The World Health Report 1999: Making a difference, WHO, Geneva, 136p.

Zabi S.G., 1982, Répartition et abondance des espèces de la macro faune benthique de la lagune Ẻbrié (Côte d'Ivoire), In Documents scientifiques du centre de Recherches Océanographiques, Abidjan, 151.