

Assessment of Heavy Metals (As, Cd, Hg, Pb) in Sources of Water for Human Consumption in Sub-Saharan Africa: A Literature Review

Alassane Youssao Abdou Karim^{1,2,*}, Emmanuel Azokpota^{1,2}, Léonce Firmin Dovonon¹, Abdoul Kader Alassane Moussa^{1,2}, Alphonse Sako Avocefohou², Daouda Mama², Dominique Codjo Koko Sohounhloue¹

¹Research Unit in Ecotoxicology and Quality Study (UREEQ), Laboratory for Study and Research in Applied Chemistry (LERCA), Polytechnic School of Abomey-Calavi, University of Abomey-Calavi, Cotonou, Benin

²Hydrology Laboratory (LHA), Faculty of Science and Technology, University of Abomey-Calavi, Cotonou, Benin

Email address:

yousaaoalassane@gmail.com (Alassane Youssao Abdou Karim), azokpotaemmanuel75@gmail.com (Emmanuel Azokpota), ldovonon@yahoo.fr (Léonce Firmin Dovonon), almokano@gmail.com (Abdoul Kader Alassane Moussa), alphasakoav@gmail.com (Alphonse Sako Avocefohou), mkdaouda@yahoo.fr (Daouda Mama), csohoun@gmail.com (Dominique Codjo Koko Sohounhloue)

*Corresponding author

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Abstract: In the world and particularly in Africa, the supply of drinking water by rural communities is still a challenge to be met due to the unavailability of water in quality and quantity. Indeed, 76% of the population in sub-Saharan Africa does not have access to drinking water. This situation is more pronounced in rural and peri-urban communities than in urban areas. Some communities, particularly in rural areas, are therefore condemned to consume surface water, rainwater and well water of dubious quality due to the contamination of this water and especially the lack of a drinking water distribution network. Several research studies on metal contamination of surface water, groundwater and rainwater have reported high levels of metals. This review article focuses on the contamination of waters in sub-Saharan Africa by cadmium, lead, mercury and arsenic, because of their toxicity and the health and ecotoxicological consequences linked to their presence in water. These are heavy metals at the origin of several dangerous diseases such as lead poisoning, hydrargyrius, Itai Itai disease, etc. This article reviews the problems of accessibility to drinking water in communities in terms of quantity and quality, the origins and levels of water contamination by metals as well as analytical methods for metals and the consequences related to the consumption of these waters.

Keywords: Toxic Metals, Drinking Water, Rivers, Ponds, Underground, Rainwater

1. Introduction

Water is essential to all forms of life and there is no known substitute for it; It is essential for eradicating poverty and is closely linked to health, agriculture, energy and biodiversity [1-3]. The United Nations has recognized the right to safe and clean water as a fundamental human right, essential to the full exercise of the right to life and all human rights [4].

Unfortunately, the water is frequently contaminated by pollutants due to the lack of sanitation measures, the management method and the socio-cultural constraints of the populations [5].

In recent decades, the contamination of water by metallic pollutants has become more and more recurrent and is a topic addressed by many researchers around the world and particularly in sub-Saharan Africa. Toxic metals are among the most formidable contaminants, but unfortunately water

quality control analyzes are rare even for public bodies responsible for the supply of drinking water. This state of affairs is even more accentuated in rural areas where people obtain their drinking water from nature, from unsanitary traditional wells, rivers, ponds, etc. [6, 7].

The problem of toxic metals such as mercury, cadmium, lead and arsenic is not only linked to water for human consumption. They are ubiquitous in aquatic ecosystems where they not only accumulate in sediments but also concentrate in water and aquatic living organisms [8-16] with the possibility that the latter are transformed into molecules still more toxic such as methylmercury [17-19]. From the sediments, these metals are remobilized in the water through water currents and other anthropogenic activities [20].

This article aims to take stock of the contamination of sources of water for human consumption with cadmium, mercury, lead and arsenic in sub-Saharan Africa and to ask the major questions related to water supply in this part of the world where people are most vulnerable because of the great ambient poverty.

2. Problem of Supply in Drinking Water

In Africa, around 1.1 billion people have no access whatsoever to an improved source of safe water [21].

In sub-Saharan Africa, only 24% of the population has access to a safe source of drinking water. (World Water Development Report [4], 39% of inhabitants do not have access to basic water access services and one hundred and thirty-five (135) million people make more than (30) minutes of travel per day to have access to drinking water. The proportion of the population with access to drinking water is 68%. Between 1990 and 2016, the performance index calculated in relation to the average annual progression of households that have access to an improved source of drinking water is as follows [22]:

- 1) Rwanda, Burkina-Faso and Ethiopia achieved the best performances (more than 2 points);
- 2) Zambia and Zimbabwe have seen no substantial progress;
- 3) Côte d'Ivoire, Madagascar, Tanzania, Senegal and Cameroon experienced a slight increase (less than 1 point);
- 4) Benin, Kenya, Ghana, Niger, Malawi, Mozambique, Namibia and Uganda experienced substantial progress (more than 1 point).

Despite the efforts made, the issue of access to water arises repeatedly in developing countries, particularly in rural areas, due to demography and uncontrolled urbanization [23].

While some Maghreb countries such as Algeria, Morocco and Tunisia have respectively 79%, 61% and 83% access to drinking water in rural areas, other countries such as Ethiopia, Mozambique and Uganda are still at a rate of less than 50% access to drinking water; 86% of rural populations in Cameroon, 30% of the population and 3 out of 5 people in rural areas in Benin do not have access to drinking water with strong disparities between departments [24]. Faced with this not very rosy situation and the fact that the supply of priced water is

developing in Africa and concerns the minority of populations able to pay for a connection and a subscription, the majority of Africans resort to multiple solutions, which are often dangerous expedients, to meet their water needs: drawing from rivers, lakes, backwaters, even puddles of putrid water. Supplying hundreds of millions of people with clean drinking water is very expensive at all levels, whether in terms of investments and maintenance of facilities. This is why, in sub-Saharan Africa, surface water is consumed directly in rural areas in the absence of public water supply or when public boreholes are out of service. This is the case for example in Niakhar (Senegal), and Oumako, Kpanroun and Hèvié (Benin), in rural areas in Cameroon, in Burkina-Faso where the ponds are used by the villagers either for laundry, dishes, washing, cooking or drinking [25-27, 21]. This is also the case in certain villages of Agbangnizoun and Za-kpota in southern Benin where people use surface water for drinking and domestic purposes. Apart from surface water, wells, boreholes and developed springs constitute the different types of groundwater supply on the one hand and the common means of supplying drinking water in the event of a deficit in the drinking water network in the most developing countries on the other [27-30].

3. Problems Related to Inaccessibility to Water

Throughout the world, the difficulties of access to water are the cause of many diseases that lead to the loss of human lives. Africa is the most disadvantaged continent, particularly in rural areas. Up to 80% of diseases encountered in developing countries and more than a third of deaths are attributable to the quality of water, first affecting the poorest and most marginalized sections of the population [21]. The unavailability of water continues to hamper economic activities and waterborne diseases continue to plague especially in rural areas [31]. Of the 37 major diseases that plague developing countries, 27 are waterborne (cholera, diarrhoea, dysentery, hepatitis A, typhoid fever and poliomyelitis, etc.) and 15 million children die every year from drinking unclean water [32]. In these countries, because of the low rate of access to drinking water, especially in rural areas, populations depend on natural water resources for their survival. However, around these resources, we note the poor management of solid and liquid waste and the development of human activities which contribute to the enrichment of these environments in pollutants and other undesirable or potentially dangerous elements for health. Water resources are therefore threatened by pollution linked to solid waste, wastewater, agricultural and even industrial waste [33]. The pollution of water resources compromises the quality of water, which itself depends on the state of sanitation and human activities carried out in the surrounding territory. Contaminated water can pose a serious threat to human health in rural areas where treatment systems and technologies are almost non-existent; and the main causes of disease and poor health of populations in sub-Saharan Africa are related to water [5]. Industrialization, the non-rational use of fertilizers and pesticides, as well as the lack of awareness of the population for the

protection of the environment, lead as much to an imbalance of the ecosystem and generate polluting elements which can affect the quality physico-chemical waters. These pollutants are not without risks for the local population, with the persistence of exposure to pollutants, the possible migrations towards surface or underground waters, responsible for a degradation of drinking water resources. Surface water and traditional wells are, for the most part, unfit for consumption because of their level of contamination and may contain toxic pollutants for humans [5].

In developing countries, human activity, whatever its origin, industrial, urban or agricultural, produces a quantity of polluting substances of all kinds which generate different types of pollution. These pollutants can be permanent (domestic discharges from a large city, for example), periodic or even accidental or acute [34].

4. Origin and Distribution of Metals in the Environment

4.1. Synthesis

Unlike most organic contaminants, heavy metals are natural constituents in rocks and mineral deposits. Thus, these elements are normally present at low levels (in trace amounts,

less than 0.1%) in soils, sediments, surface waters and living organisms [35]. These low concentrations of heavy metals constitute the geochemical background of a certain environment. To assess the impact of a heavy metal in the environment, its mere presence is not sufficient. This impact is potential if the given metal is found at abnormally high concentration levels relative to the geochemical background [35]. This is why a good knowledge of the geochemical background is essential to determine heavy metal contamination caused by anthropogenic activity [36].

These natural metals are found in the various compartments of the environment by degassing of the earth's crust and/or by the alteration of rocks.

Due to their different specific characteristics, heavy metals have been widely used in new technologies (metallurgical and electronic). As a result, their anthropogenic sources (Table 1) are extensive and their introduction to the environment is rather recent. Among the anthropogenic sources of heavy metals we can point out: mining activity, the metallurgical and iron and steel industry, fertilizers and pesticides applied in soil cultivation, incinerators and ashes from waste incineration, medical waste, most urban waste, city dumps, factory and combustion engine emissions, sewage effluent and sewage sludge [37-45, 35].

Table 1. Industrial and agricultural sources of metals in the environment.

Uses (sources)	Metals
Batteries and other electrical devices	Cd, Hg, Pb, Zn, Mn, Ni.
Pigments and paints	Ti, Cd, Hg, Pb, Zn, Mn, Sn, Cr, Al, As, Cu, Fe
Alloys and solders	Cd, As, Pb, Zn, Mn, Sn, Ni, Cu
Biocides (pesticides, herbicides, preservatives)	As, Hg, Pb, Cu, Sn, Zn, Mn
Catalytic agents	Ni, Hg, Pb, Cu, Sn
Glass	As, Sn, Mn
Fertilizer	Cd, Hg, Pb, Al, As, Cr, Cu, Mn, Ni, Zn
Plastic materials	Cd, Sn, Pb
Dental and cosmetic products	Sn, Hg
Textiles	Cr, Fe, Al
Refineries	Ni, V, Pb, Fe, Mn, Zn
Fuels	Ni, Hg, Cu, Fe, Mn, Pb, Cd

Source: Biney et al. 1994 [46].

The main sources emitting these heavy metals are mining industries and foundries, processing industries (metallurgy, electroplating, etc.), incineration plants and the agricultural sector (phosphate fertilizers) [45].

Compared to the natural flow, the flow of heavy metals from human activities is significant. (Table 2).

Table 2. Heavy metals flows from natural and human activities.

Elements	Anthropogenic flow	Natural flow
As	150	90
Cd	43	4.5
Cr	7810	810
Cu	9162	375
Pb	3665	180
Hg	17.8	0.9
Ni	1134	255
Zn	7467	540

Source: Kabir et al., 2012 [47].

Thus, the highest concentrations of heavy metals are related to human activity. They are found in our daily environment in very diverse chemical forms, each of which can confer a particular property (solubility, toxicity, etc.) to the metal studied. In the aquatic environment, heavy metals can occur in various physical (dissolved, particulate) and chemical (mineral, organic) forms. In order to assess the bioavailability of the metal, it is necessary to know its speciation, that is to say its distribution with respect to its different physico-chemical forms. Among the very toxic heavy metals that can accidentally be found in water, we distinguish: lead, cadmium, cyanide, arsenic, chromium, nickel, antimony, selenium [48].

4.2. Lead

Lead is a chemical element of the crystallogens family, with symbol Pb and atomic number 82. It is a soft and heavy metal, bluish gray and with a sweet taste but no particular smell. Lead

is a natural product of the decay of uranium [49]. Pb has two oxidation states 2+ and 4+. The tetravalent state is a very strong oxidant, but it is not common in the environment; on the other hand, the divalent state is the most stable in the environment. The lead released into the atmosphere exists mainly in the form of particles. Small lead particles can travel considerable distances, while large particles ($>2.5 \mu\text{m}$) tend to leave the atmosphere quickly and settle relatively close to the emission source. Lead is removed from the atmosphere mainly by rain, but it can also precipitate by dry deposition. Organic and inorganic forms of Pb have toxic effects in humans. However, the toxicity of organic species is much greater than that of inorganic species; its preferred passage to humans is through the food chain. The World Health Organization also points out the serious risk produced by the form of inorganic Pb introduced into the human organism through the consumption of water. The pathological effects of lead poisoning are numerous and can be separated into two categories: physiological and neurological effects [38, 42].

4.3. Cadmium

Cadmium is a chemical element with symbol Cd and atomic number 48 [49]. It is a silvery-white, soft, ductile and malleable metal. It tarnishes on contact with air. Cadmium is present in almost all zinc ores (cadmium content varies from 0.01 to 0.05%). It is also present in lead and copper ores, as well as in natural phosphates [50]. The toxicity of cadmium has been known since the 1950s. Highly toxic in all its forms (metal, vapour, salts, organic compounds), cadmium is one of the rare elements with no known function in the human body or in humans. 'animal.

4.4. Mercury

Known for more than 2000 years, mercury, symbol Hg is the only liquid metal at room temperature (-10° and $+40^\circ\text{C}$). It is also the only metal whose boiling point is below 357°C . Characterized by extreme volatility and high density, it combines very easily with other metals (formation of amalgams), with inorganic or organic (carbon) sulfur compounds. Mercury is found naturally in the earth's crust at concentrations varying between 0.02 mg/kg and 0.625 mg/kg and in different forms: metallic mercury (Hg_0), inorganic mercury (Hg^+ and Hg^{2+}) whose mercury salts and organic mercury including methylmercury (MeHg). Most of the different complexes formed by mercury are insoluble with a few exceptions, including methylmercury and the mercuric ion Hg^{2+} . In an aqueous medium, two essential chemical reactions are in competition: reduction and methylation. The first favors atmospheric recycling, the second is at the origin of bioaccumulation. It is the reduction or methylation of Hg^{2+} in aquatic systems that will therefore modify its behavior and determine its mobility, its bioavailability and its toxicity.

4.5. Arsenic

Arsenic is a chemical element of the family of pnictogens, symbol As and atomic number 33, presenting properties

intermediate between those of metals and metalloids [49].

The electronic configuration of arsenic induces four possible oxidation states: (-3), (0), (+3), (+5). The arsenic compounds encountered in the environment mainly correspond to inorganic species, presenting the two oxidation states As(V) and As(III). The main chemical species of arsenic present in water are oxyanions or inorganic neutral compounds [51]. The toxicity of arsenic depends on its chemical nature: inorganic arsenic is more toxic than organic arsenic. The toxicity of arsenic depends on its degree of oxidation: $\text{As}(\text{O}) > \text{As}(\text{III}) > \text{As}(\text{V})$. Toxicity increases with the degree of arsenic methylation [38, 35, 52].

5. Summary of Metal Analysis Results (As, Cd, Hg, Pb) in the Waters

5.1. General Synthesis

Using chemical methods such as molecular absorption spectrophotometry [53], plasma mass spectrophotometry [54, 55], atomic emission spectrometry [56], emission spectroscopy with inductive coupling [57, 58], UV/visible spectrophotometry [59] and atomic absorption spectrophotometry [29, 60-62], concentrations of toxic metals such as arsenic, cadmium, mercury and lead, higher than the drinking water standards recommended by the WHO, are recorded in surface waters in sub-Saharan Africa. These concentrations vary from 0.1 mg/L to 20.49 mg/L for cadmium [53, 57, 56, 59, 63, 54]; they vary from 0.02 mg/L to 70.4 mg/L for lead [64, 53, 65, 60, 66, 57, 56, 67, 59, 63, 54, 58, 68, 69, 70]; 0.09 mg/L and 0.32 mg/L for arsenic [57, 54] and 0.001 mg/L to 0.38 mg/L for mercury [53, 57, 70].

These metals are also detected in groundwater where concentrations exceeding WHO standards vary from 0.02 mg/L to 0.23 mg/L for cadmium [61, 57, 71]; from 0.01 mg/L to 0.33 mg/L for mercury [57, 72]; from 0.03 mg/L to 4.8 mg/L for lead [61, 62, 57] and from 0.05 mg/L to 0.18 mg/L for arsenic [57]. No less significant values (0.017 mg/L) of cadmium and 0.078 mg/L of lead were also recorded in rainwater [73, 74].

The concentrations of toxic metals (As, Cd, Hg, Pb) obtained in the different sources (wells, cisterns and surface waters) by the different researchers vary from one source to another. The values obtained in surface water greatly exceed, in some cases, the values obtained in well water and rainwater. Indeed, while the average Cd concentrations vary from 0.002 to 20.49 mg/L in surface waters, those in well waters vary respectively from 0.006 to 0.23 mg/L. Average Pb concentrations in surface waters are 0.005 to 70.41 mg/L and 0.03 to 0.18 mg/L in well waters. The average values obtained relate to total metals. The forms and species of these metals are not addressed by these various researchers.

5.2. Case of Hg Analysis Results in Africa

The particular case of the contamination of water resources by mercury in Africa is presented in Table 3 below.

Table 3. Summary of mercury analysis results in water in Africa.

Authors, Years	Matrices and Hg form	Concentrations
Al-Asadi, (2018) [75]	Water	0.1 to 1.6 µg.L ⁻¹
Avocefohou et al. (2022) [76]	Water (THg)	<LOQ
Azokpota et al. (2022) [77]	Rainwater (THg)	<LOQ to 1,060 µg/L
Brunke et al. (2016) [78]	Rainwater (THg)	0.03 to 52.5 ng.L ⁻¹
Brunke et al. (2016) [78]	Rainwater (THg)	0.03 to 52.5 ng.L ⁻¹
Campbell et al. (2003) [79]	water (THg)	0.7 to 5.8 ng.L ⁻¹
Donkor et al. (2016) [80]	Water (THg)	0.145 to 1.078 µg.L ⁻¹
Donkor et al. (2006) [80]	Water (THg)	28.7 to 462.10 ng.L ⁻¹
Donkor et al. (2016) [81]	Waters (MeHg)	to 19.640 ng.L ⁻¹
Gichuki et al. (2013) [82]	Rainwater (THg)	10.6 ng.L ⁻¹ to 15.8 ng.L ⁻¹
Ikingura et al. (1997) [83]	Water	0.01 to 6.78 µg.L ⁻¹
Lusilao et al., (2016) [84]	Water (THg)	<0.02 to 26.65±3.53 ng.L ⁻¹
Lusilao et al., (2016) [84]	Water (MeHg)	0.05- 7.83 ng.L ⁻¹
Lusilao et al., (2016) [84]	Water (IHg)	0.006- 13.05 ng.L ⁻¹
Lusilao-Makiese et al. (2016) [84]	water (THg)	0.03 to 19.60 ng.L ⁻¹
Lusilao-Makiese et al. (2016) [84]	water (IHg)	0.003 to 13.05 ng.L ⁻¹
Lusilao-Makiese et al. (2016) [84]	water (MeHg)	0.01 to 7.83 ng.L ⁻¹
Lusilao-Malehase et al. (2016) [84]	water (THg)	0.004 to 0.070 µg.L ⁻¹
Ouedraogo and Amyot (2013) [85]	Water (THg)	0.04 to 21.38 ng.L ⁻¹
Ouedraogo et Amyot (2013) [85]	Water (DHg)	0.05 to 4 ng.L ⁻¹
Ouedraogo et Amyot (2013) [85]	Water (PHg)	0.04 to 19 ng.L ⁻¹
Ouedraogo et Amyot (2013) [85]	Water (MeHg)	0.01 ng.L ⁻¹ to 0.21 ng.L ⁻¹
Poste et al. (2015) [86]	Water (THg)	0.38 ± 0.01 to 1.30 ± 0.09 ng.L ⁻¹
Ugbidye et al. (2013) [87]	Water (THg)	0.00mg.kg ⁻¹
Williams et al. (2010) [88]	Water (THg)	0.06 to 26.65 ± 3.53 ng.L ⁻¹
Williams et al. (2010) [88]	Water (MeHg)	0.02 ng/L to 2.73 ± 0.10 ng.L ⁻¹
Youssao et al. (2018) [89]	Water (THg)	0.5 to 616.9 µg.L ⁻¹

Indeed, the day after the Minamata conference on mercury, the various African countries initiated research work with a very active participation of researchers and involvement of African States in the evaluation process of the Convention bearing its name [90]. This motivated the authors of this article to make mercury a special study.

5.3. Standard Values of Some Metals in Drinking Water

The table 4 shows the standard values of heavy metals in drinking waters.

Table 4. Standard values of heavy metals in drinking waters.

Element	Units	WHO	Benin	Canada	MSDA
Mg	mg/L		50		50-125
Ca	mg/L		100		200
Cr	µg/L	50	50	50	1 (Cr ⁶⁺ /l)
Mn	µg/L	400	0.1		20
Fe	µg/L		300		50
Ni	µg/L	70	20		
Cu	µg/L	2000	2000	1000	20 (Cu ²⁺ /l)
Zn	µg/L		3000		100
As	µg/L	10	50	10	2
Se	µg/L	40	10	10	1
Cd	µg/L	3	5	5	0.5
Al	µg/L	200			50
Ba	µg/L	700	1000	1000	1300
Hg	µg/L	6	1	1	0.1 (Hg ²⁺ /l)
Pb	µg/L	10	50	5	1 (Pb ²⁺ /l)
U	µg/L	30		20	

MSDA: Swiss food manual

5.4. Standard Values of Some Metals in Drinking Water

The table 5 below presents the pre-industrial levels of certain metals in the sediments of the Loire (France). This represents the geochemical background of this region.

Table 5. Geochemical background of some metals in the sediments of the Loire (France).

Metals	Concentrations (µg/kg)
As	20
Bi	0.7
Cd	0.4
Cr	99
Cu	20
Hg	0.02
Ni	28
Pb	35
Sb	0.4
Sn	7.5
U	8.2
W	6
Zn	94

Source: Grosbois et al. 2012 [91].

6. Consequences Related to the Consumption of Waters Containing Metals

Health effects linked to the presence of these toxic metals in drinking water are known. Mention may be made, for lead, of

lead poisoning, which results in clinical disorders, biological abnormalities and various histopathological alterations, cognitive and neurobehavioral damage, increased sensitivity to the toxic effects of lead in young children linked to blood-brain barrier permeability, anorexia, vomiting, irritability, behavioral disturbances, abdominal pain, coma, and death; in pregnant women, there is harm to the development of the central nervous system of the fetus [29, 92]. Poisoning by mercury salts (hydrargyrisms), characterized by lesions of the nerve centers results in tremors; irreversible renal failure due to long-term effects of mineral derivatives of mercury on the kidneys and effect of organic derivatives (organomercurials) on the central nervous system; the health effects linked to cadmium are: renal disorders, bone alterations and arterial hypertension; "Itai Itai" characterized by bone decalcification, proteinuria and glucosuria; Those linked to arsenic are: more or less pronounced gastrointestinal disorders, hepatic and renal disorders and cardiovascular manifestations; hypertension and tachycardia in the case of acute poisoning; digestive disorders, melano-dermal and neurological syndromes in the case of chronic intoxication [93, 34].

The presence of chromium in drinking water causes, in the case of acute poisoning, tubulonephritis sometimes complicated with toxic hepatitis with jaundice and in the case of chronic poisoning: skin and mucous membrane lesions with damage the respiratory system (bronchitis, asthma, bronchopulmonary cancers) [34, 94].

7. Conclusion

Through this literature review, it appears that the drinking water supply of rural and peri-urban communities in sub-Saharan Africa is a worrying issue in the scientific world. In the absence of drinking water, populations in disadvantaged areas, especially in developing countries of sub-Saharan Africa, consume water from alternative sources (surface water, well water and rainwater) contaminated by toxic metals (Pb, Cd, Hg, As) affecting the quality of these waters. These chemical pollutants generated by anthropogenic activities have harmful consequences on human health. However, the forms and the fate of the toxic metals which are the basis of the most toxic chemical pollution of waters, are fields of investigation to be furnished. It is therefore important to develop concrete actions aimed at protecting water resources for sustainable development.

References

- [1] Sylla I. 2011. Rumors and scares around water in the world. ICT4D ENDA Lead rica program. www.leadinafrica.org/sigp.7am
- [2] Amoussou E. 2010. Rainfall variability and hydro-sedimentary dynamics of the watershed of the Mono - Ahémé - Couffo fluvio -lagoon complex (West Africa). Doctoral thesis from the University of Burgundy. 315p. 2010DIJOL001.pdf – Theses.
- [3] Ehoulo, Y. 2003. Water resources management in the municipality of Zè: Diagnostic analysis and sustainable management strategy. Dissertation for obtaining the diploma of advanced studies. University of Abomey- Calavi, Benin. 76p.
- [4] UN. 2010. Access to drinking water recognized as a fundamental right by the UN. <https://www.actu-environnement.com/ae/news/eau-potable-droit-fondamental-onu-10787.php4> consulted on October 20, 2021 at 5:03 p.m.
- [5] Kpehounou KM. 2016. Water and Sanitation: Beliefs and Management Methods in the Commune of Houéyogbé. DEA. University of Abomey- Calavi. 101p.
- [6] Aïna PM, Degila H, Chikou A, Adjahatode F, Matejkag. 2012. Risk of Metal Poisoning heavy (Pb, Cd, Cu, Hg) linked to the consumption of certain species fisheries in Lake Nokoue: the case of Penaeus shrimp and Sarotherodon melanotheron. British Journal of Science 5 (2): 104118.
- [7] Sénouvo P. 2003. Study of the impact of heavy metal pollution (Pb, Cu and Zn) on the ecology of the Crassostrea oyster gasar in the lagoon areas of Cotonou (Benin) In Books of abstracts. African Fishes and Fisheries: Diversity and Utilization. Third International Conference of the Pan African Fisheries Association. Cotonou, Benin, 211 p.
- [8] Cossa D. 1989. A review of the use of Mytilus spp. as quantitative indicators of cadmium and mercury contamination in waters coastal, Oceanol. Acta 12 (1989) 417–432 Ullrich SM, Tanton TW, Abdrashitova SA. 2001. Mercury in the aquatic environment: a review of factors affecting methylation. Critical Reviews of Environmental Science and Technology, 31 (3), 241-293.
- [9] Ullrich SM, Tanton TW, Abdrashitova SA. 2001. Mercury in the aquatic environment: a review of factors affecting methylation. Critical Reviews of Environmental Science and Technology, 31 (3), 241-293.
- [10] Sirven J-B. 2006. Detection of heavy metals in soils by laser-induced plasma emission spectroscopy (LIBS). Atomic Physics. Thesis of the University of Sciences and Technologies - Bordeaux I, 2006. Français. NNT: tel-00122546.
- [11] Akele DG, Agadjihouede H, Gougbedji AUM, Laleye PA. 2017. Exploitation of the Crassostrea mangrove oyster gasar (Adanson, 1757) in Lake Nokoué, European Scientific Journal April 2017 edition Vol. 13, No. 12 ISSN: 1857 – 7881 (Print) e - ISSN 1857- 7431.
- [12] Boening, DW. 1999. An assessment of bivalves as metal pollution biomonitors heavy in marine waters. Environmental monitoring and assessment 55, 459–470.
- [13] Bogner D. 1996. Surface sediments and influence of characteristics physico - chemical sediments on the distribution of heavy metals in Kastela Bay, pp. 105. Doctoral thesis, University of Zagreb, Zagreb (Croatia).
- [14] Boust D, Jouanneau JM, Latouche C. 1980. Methodology and interpretation of total trace metal contents in estuarine and coastal sediments, Bull. Inst. Geol. Aquitaine Basin; 30 (1980) 71-86.
- [15] Compeau GC, Bartha R. 1987. Effect of salinity on mercury methylation activity of bacteria sulfate-reducing in estuarine sediments. Applied and Environmental Microbiology, 53, 261-265.

- [16] Rainbow PS. 1995. Biomonitoring of heavy metal availability in the marine environment. *Marine Pollution Bulletin* 31, p. 183-19.
- [17] Bartlett PD, Craig PJ. 1981. Total levels of mercury and methylmercury in sediment _ estuarine British - It. *Water Research*, 15, 37-47.
- [18] Belamie R, Phelippot S. 1982. CEMAGREF. Water Quality, Fisheries and Fish Farming Division; Rap. No. 16 (1982) 8.
- [19] Mikac N, Niessen S, Ouddane B, Wartel M. 1999. Speciation of mercury in sediments from the Seine estuary (France). *Applied Organometallic Chemistry*, 13, 715-725.
- [20] Maurice-Bourgoin L, Alanoca L, Fraizy P, Vauchel P. 2003. Mercury sources in surface waters of the upper erosive basins of Madeira, Bolivia. *Journal of Physics IV*, 107: 855-858.
- [21] Bagbonon CAA. 2015. Water perception and management of supply sources in rural areas of Abomey- Calavi. Doctoral thesis. University of Abomey- Calavi. 344p.
- [22] Djane KA, Olemba PF O. 2018. Inequality of access to sanitation services in sub-Saharan Africa: state of play and challenges for after 2015. Review of changes in Africa, Volume 2, Nos 1 & 2, 2017, pp 153-178. © CODESRIA & ECA 2018 (ISSN 2411-5002).
- [23] Amoussou E, Totin Vodounon SH, Hougni A, Vissin EW, Houndenou C, Mahe G and Boko M. 2016. Environmental changes and ecosystem vulnerability in the Benin basin of the Niger River. *Int. J. Biol. _ Chem. Sci.* 10 (5): 2183-2201.
- [24] Ngakomo ARP, Aghaindum AG, Abou Elnaga Z, Ngassam P. 2020. Physico-chemical and dynamic characteristics of the environmental forms of enteric coccidia in water from springs, wells and streams in the Commune of Akono (Cameroon, Central Africa). *European Scientific Journal* January 2020 Edition Vol. 16, No. 3 ISSN: 1857-7881 (Print) e- ISSN 1857-7431.
- [25] Chippaux JP, Houssier S, Gross P, Bouvier C, Brissaud F. 2002. Study of groundwater pollution in the city of Niamey, Niger. *Bull. Soc. Pathol. Exot*, 95 (2): 119-223.
- [26] Agassounon DTM, Ayi-fanou L, Lozes E, Fadonougbo R, Anago GDJ, Agbangla C, Ahanhanzo C. 2012. Health impacts related to the use of well water, sanitation and development in Gbôdjê in the district of Godomey in Benin. *Int. J. Biol. _ Chem. Sci.*, 6 (2): 592-602.
- [27] Hounsounou EO, Agassounon DTM, Kelome NC, Vissin EW, Mensah GA, Agbossou E. 2016. Domestic water pollution in underprivileged urban areas of developing countries: Bibliographic summary. *Int. J. Biol. Chem. Science*. 10 (5): 2392-2412, October 2016 ISSN 1997-342X (online), ISSN 1991-8631 (print). 21p.
- [28] Odoulami L. 2009. The problem of drinking water and human health in the city of Cotonou (Republic of Benin), Unique Doctoral Thesis, University of Abomey - Calavi, p. 230.
- [29] Degbey C, Makoutode M, Fayomi B, Brouwer C. 2010. The quality of drinking water in the workplace in Godomey, Benin, *Journal Internationale de Santé et Travaux*, Vol 1, PP: 15-22.
- [30] Ahoudi H, Gnandi K, Tanouayi G, Ouro-Sama K. 2015. Physico-chemical characterization and state of pollution by metallic trace elements of groundwater in Lomé (South Togo): case of the Agoe district Zongo. *Larhyss Journal*, 24: 41-56.
- [31] Koumassi DH. 2017. Hydroclimatic risks and ecosystem vulnerabilities in the Sota watershed at the Couberi outlet. Doctoral thesis. <https://hal.archives-ouvertes.fr/tel-01572602> Submitted on August 7, 2017.
- [32] Laleye GT. 2016. Identification and analysis of the determinants of source water contamination and artesian fodder in the communes of Zagnanado and Zogbodomey in Benin. Doctoral thesis. University of Abomey- Calavi. 266p.
- [33] Mojisola F. 2008. Creation of a marine protected area in Benin (West Africa). Scene report, 20p.
- [34] Rodier J, Legube B, Merlet N. 2009. *Water Analysis*, ed DUNOD: 749-775.
- [35] Alloway BJ, Ayres DC. 1997. *Chemical Principles of Environmental Pollution*. Blackie Academic and Professional, a Chapman and Hall imprint, London, 394 pp.
- [36] Runnels DD, Shepherd TA, Angino, EE. 1992. Metals in water, determination of natural background concentrations in mineralized zones. *Environmental Science and Technology*, 26 (12): 2316-2323.
- [37] Cotran, RS, Kumar V, Robbins SL. 1990. *Ambient Pathology, Structural and Functional Pathology*. Interamericana - McGraw-Hill, Madrid, pp. 499-546.
- [38] Fergusson JE, 1990. *The heavy elements: chemistry, environmental impact and health effects*, 1. Pergamon Press, Oxford, 614 pp.
- [39] Hong S, Candelone JP, Patterson CC, Boutron CF. 1994. Greenland Ice Evidence of Hemispheric Lead Pollution Two Millennia Ago by Greek and Roman Civilizations. *Science*, 265 (September): 1841-1843.
- [40] Candelone, JP, Hong, S, Pellone C, Boutron CF. 1995. Post-industrial revolution changes in large-scale northern hemisphere air pollution by heavy metals, documented in snow and ice of central Greenland. *Journal of Geophysical Research*, 100 (8): 605-616.
- [41] Freyssinet P, Piantone P, Azaroual M, Itard Y, Clozel-Leloup B, Guyonnet D, Baubron JC. 2002. Chemical changes and mass balance of municipal solid waste bottom ash leachate subjected to weathering. *Waste Management*, 22 (2): 159-172.
- [42] Plumlee, GS, Ziegler TL. 2003. The medical geochemistry of dusts, soils and other earth materials. In: BS. Lollar (Ed.), *Environmental geochemistry. Treatise on Geochemistry*. Elsevier-Pergamon, Oxford, p. 264-310.
- [43] Gavilan Garcia I, Gavilan García A, Castro Díaz J. 2004. Organometals. In: A. Fernandez Bremauntz, M. Yarto Ramirez, (Eds.), *Las sustancias toxic persistent*. Instituto Nacional de Ecología, Mexico, p. 1-64.
- [44] Sukandar S, Yasuda K, Tanaka M and Aoyama I. 2006. Metal leaching from medical waste incinerator fly ash: a case study in particle size comparison. *Environmental Pollution*, 144 (3): 726-735.
- [45] Bouziani M. 2000. *Water from shortage to disease*, Edition ibn khaldoun, 247p.
- [46] Biney C, Amuzu AT, Kalamari D, Kaba N, Mbome IL, Naeva H, Ochumba PBO, Osibanjo O, Radegonde V, Saad MAH. 1994. Review of heavy metals in the african aquatic environment. *Ecology and environmental safety*. 28 134-159 (1994).

- [47] Kabir E, Ray S, Kim K, Yoon H, Jeon E, Kim YS, Cho Y, Yun S, and Brown RJC. 2012. Current Status of Trace Metal Pollution in Soils Affected by Industrial Activities. *The Scientific World Journal*. Volume 2012, Article ID 916705, 18 pages. doi: 10.1100/2012/916705.
- [48] Vilagines R. 2003. Water, environment and public health, Introduction to hydrology, 2nd edition, Editions Tec&Doc, PP: 195-198.
- [49] Mahan KI, Foderaro TA, Garza TL, Martinez RM, Maroney GA, Trivisonno MR, and Willging EM. 1987. Microwave Digestion Techniques in the Sequential Extraction of Calcium, Iron, Chromium, Manganese, Lead, and Zinc in Sediments. *Anal. Chem.* 1987, 59, 938-945. <https://doi.org/10.1021/ac00134a003>
- [50] Hurlbut JCS, Klein C. 1982. Dana's Handbook of Mineralogy. Editorial Reverté, Barcelona, 564 pp.
- [51] Smedley PL, Kinniburgh, DG. 2002. Review of the source, behavior and distribution of arsenic in natural waters. *Applied Geochemistry*, 17 (5): 517-568.
- [52] Chung JS, Kalman DA, Moore LE, Kosnett, MJ, Arroyo AP, Beeris M, Guha-Mazumder DN, Hernandez AL, Smith AH. 2002. Familial Correlations of Arsenic Methylation Patterns in Children and Parents Exposed to High Levels of Arsenic in Drinking Water. *Children's Health*, 110 (7): 729-733.
- [53] Chouti W, Marna D, Changotade O, Alapini F, Boukari M. 2010. Study of metallic trace elements contained in the sediments of the Porto-Novo lagoon (South Benin). *Journal Applied Biosciences* 34: 2186-2197.
- [54] Mohiuddin KM, Ogawa Y, Zakir HM, Otomo K, Shikazono N. 2011. Heavy metal contamination in urban river water and sediment in a developing country. *Int. J. About. Sci. Tech.*, 8 (4), 723-736, Autumn 2011 ISSN 1735-1472 © IRSEN, CEERS, IAU.
- [55] Anhichem M, Dellal M, Chfiri R, Yahyaoui A, Benbrahim S. 2017. Study of water and sediment quality in the bay of Dakhla in Morocco. Physico-chemical quality and metal contamination. *Bull. Soc. zool. Fr.*, 2017, 142 (4): 185-202.
- [56] Fouad S, Hajjami K, Cohen N, Chlada M. 2014. Physico-chemical quality and metallic contamination of the waters of Oued Hassar: impacts of wastewater from the locality of Mediouna (Suburban Casablanca, Morocco). *Afrique Science* 10 (1) (2014) 91 - 102 ISSN 1813-548X, <http://www.afriquescience.info>
- [57] Yapi YHA, Dongul BK, Trokourey A, Barima YSS, Essisy, Atheba P. 2014. Evaluation of metal pollution of groundwater and surface water in a gold mining environment in Hiré (Côte d'Ivoire). *Int. J. Biol. Chem. Science*. 8 (3): 1281-1289, June 2014 ISSN 1997-342X (online), ISSN 1991-8631 (print).
- [58] Fahssi A, Yahya HSA., Touzani R, Chafi A. 2016. Spatiotemporal assessment of metal contamination of surface water resources in lower Moulouya. *J. Mater. Around. Science*. 7 (7) (2016) 2404-2423. ISSN: 2028-2508 CODE: JMESCNC.
- [59] Wanga BM, Musibono DE, Mpiana PT, Mafuana L, Kiza NJ, Diana. 2015. Assessment of the physico-chemical quality of the waters of the Kalamu River in Boma, DR Congo. *Congo Sciences Online Journal of ACASTI and CEDESURK ACASTI and CEDESURK Online Journal* ISSN: 2410-4299, an International Journal, Volume 3, Number 1. Pp. 56-57.
- [60] Blinda M, Bellaouchou A, Fekhaoui M, Barcha SE, El Morhit M. 2013. Evaluation of metallic contamination of sediments and surface waters of the northwest coast of Morocco. *Bulletin of the Scientific Institute, Rabat, Life Sciences Section*, 2013, n° 35, 43-49.
- [61] Tanouayi G, Gnandi K, Ahoudi H, Ouro-Sama K. 2015. Metallic contamination of surface water and groundwater in the phosphate mining area of Hahote-Kpogame (South-Togo): case of cadmium, lead, copper and nickel. *Larhyss Journal*, ISSN 1112-3680, n°21, March 2015, pp. 25-40.
- [62] Chaheb A, Khattach D. 2016. Evaluation of the physico-chemical quality of groundwater in the vicinity of the controlled landfill of Berkane (Morocco). *J. Mater. Around. Sci.* 7 (11) (2016) 3973-3983. ISSN: 2028-2508.
- [63] Greichus YA, Greichus A, Ammann BD and Hopcraft J. 1978. Insecticides, polychlorinated biphenyls and metals in African lake ecosystems. 3. Lake Nakuru, Kenya. *Bull. Environ. Contam. Toxicol.*, 19: 454-April 61, 1978; 19 (4): 454-61. doi: 10.1007/BF01685825.
- [64] Kakulu SE, Osibanjo O. 1992. Nigerian River Pollution Studies: Surface Water Trace Metal Levels in the Niger Delta Region. *Int. J. Environ. Stud.*, 41: 287-92.
- [65] Youssao Abdou Karim A. 2011. Study of the distribution of lead residues in the aquatic ecosystems of the Cotonou Channel and Lake Nokoué in Benin. These. Defended on December 1, 2011.
- [66] Onivogui G, Balde S, Bangoura K, Barry MK. 2013. Evaluation of the risks of pollution by heavy metals (Hg, Cd, Pb, Co, Ni, Zn) of the waters and sediments of the Konkouré river estuary (Rep. of Guinea). *Africa SCIENCE* 09 (3) (2013) 36 - 44.
- [67] Traore A, Ake -Assi Y, Ahoussi Kouassi E, Soro N. 2015. Evaluation of the concentration of trace elements (Pb, Cu, Zn, Fe, Cd and Hg) in shrimp (*macrobrachium vollehovenii*) from the Aghien and Potou lagoons (south-eastern Ivory Coast). *Larhyss Journal*, ISSN 1112-3680, n°24, December 2015, pp. 129-142.
- [68] Edward JB, Agunbiade RO, Falade J. 2017. Influence of Land Use Pattern on Ureje Reservoir, Ado-Ekiti, South West Nigeria. *American Journal of Life Sciences* 2017; 5 (3-1): 81-89.
- [69] Kadriua S, Malollari I, Pula-Beqiria L, Aliu M, Sadiku M, Baruti B, Kelmendi M. 2017. Presence of heavy metals in water and sediments of Trepc and Sitnica rivers. *Journal of Environmental Protection and Ecology* 18, No. 1, 10-21.
- [70] Agbandou B, Houessou D, Thoto F, Chabi G. 2018. Ecosystem imbalance of the Lake Nokoué lagoon complex - Porto-Novo lagoon. Action Center for the Environment and Sustainable Development. Abomey- Calavi - Benin. Policy note. 8p.
- [71] Gbamele KS, Konan KS, Kouassi KL, Brou LA, Konan KF, Bini KD. 2020. Evaluation of the Chemical Contamination of Groundwater by Anthropogenic Activities: Case of the Ity-Floleu Zone, Zouan - Hounien Sub-Prefecture, Western Côte d'Ivoire. *European Scientific Journal* February 2020 Edition Vol 16. No 6 ISSN 1857-7881 (Print) e-ISSN 1857-7431.
- [72] Kholtei S, Bouzidi A, Bonini M, Fekhaoui M, Sbair K, Anane R, Creppy EE. 2003. Contamination of groundwater in the Berrechid plain in the Chaouia region, Morocco, by metals present in wastewater: Effect of rainfall. *VECTOR environment • Volume 36 • number 5 • 68-80*.

- [73] Legret M, Colandini V, Raimbault G. 1994. First approach to the effects of reservoir structures on the quality of rainwater and soil. *white coal/W* 112-1994.
- [74] Hebabaze S, Abdelali S, Badri W, Nahli A. 2015. Diagnosis of the quality of rainwater from roofs with a view to their landscape reuse: case of a public education establishment in Casablanca (Morocco). *Larhyss Journal* ISSN 1112-3680, n°24, December 2015, pp 143-160.
- [75] Al -Asadi, MKK. 2018. Assessment of marine mercury pollution from petrochemical hotspots, western Libya. *Mesopot. J. Mar. Sci* 33, 49–56.
- [76] Avocefohoun SK, Youssao Abdou Karim A, Baloun KC, Gbaguidi ANM, Saizonou KMVM., Montcho SP, Hounsou FTM, Alassane Moussa AK, Azokpota E, Dovonon FL, Seby F, Soclo HH, Donard OFX and Sohounhloue CKD. 2022. Physico - chemical quality and metallic contamination of water from a well in the sixth district of Cotonou, southern Benin. *Int. J. Adv. Res.* 10 (10), 374-386. Article DOI: 10.21474/IJAR01/15501.
- [77] Azokpota E, Youssao Abdou Karim A, Avocefohoun SK, Alassane Moussa AK, Adandedjan C, Ahyi V, Alowanou JC, Adoukpe J, Mama D, Sohounhloue D. 2022. Contamination levels of heavy metals (As, Cd, Hg, Pb) in some sources of water for human consumption in the town halls of Agbangnizoun and Za-Kpota, in southern Benin. *International Journal of Chemistry; Flight*. 14, no. 1; 2022 ISSN 1916-9698 E-ISSN 1916-9701 Published by the Canadian Center for Science and Education. <https://doi.org/10.5539/ijc.v14n1p41>
- [78] Brunke EG, Walters C., Mkololo T., Martin L., Labuschagne C., Silwana, B., Slemr, F., Weigelt, A., Ebinghaus, R., Somerset, V. 2016 Mercury in the atmosphere and in rainwater at Cape Point, South Africa. *atmosphere. About.* 125, 24–32. <https://doi.org/10.1016/j.atmosenv.2015.10.059>
- [79] Campbell LM, Hecky RE, Muggide R., Dixon DG, Ramlal PS. 2003. Variation and distribution of total mercury in water, sediments and soil from northern Lake Victoria, East Africa. *Biogeochemistry* 65, 195–211. <https://doi.org/10.1023/A:1026058417584>
- [80] Donkor A., Adimado NK, Apeke A. 2016. Influence of mining-related activities on mercury levels in water, sediments and fish in river basins Ankobra and Tano in southwestern Ghana. *About. System Res.* 5, 2193-2697. <https://doi.org/10.1186/s40068-016-0055-4>
- [81] Donkor AK, Bonzongo JC, Nartey VK, Adotey DK. 2006. Mercury in different environmental compartments of the river basin Pra, Ghana. *Science. Total approx.* 368, 164–176. <https://doi.org/10.1016/j.scitotenv.2005.09.046>
- [82] Gichuki SW, Mason RP. 2013. Mercury and metals in South African precipitation. *atmosphere. About.* 79, 286–298. <https://doi.org/10.1016/j.atmosenv.2013.04.009>
- [83] Ikingura JR, Mutakymiwa MKD and Kahatano JMJ. 1997. Mercury and mining in Africa with special reference to Tanzania. *Water, Air and soil pollution* 97: 223-232, 1997. Academic Publishers.
- [84] Lusilao- Makiese, JG, Tessier, E., Amouroux, D., Tutu, H., Chimuka, L., Weiersbye, I., Cukrowska, EM. 2016. Speciation and dispersion of mercury from an active gold mine in West Wits, South Africa. *About. Monit. Assess.* 188, 1–11. <https://doi.org/10.1007/s10661-015-5059-4>
- [85] Ouedraogo O, Amyot M. 2013. Concentrations of mercury, arsenic and selenium in water and fish from sub-Saharan semi-arid freshwater reservoirs (Burkina Faso). *Science. Total approx.* 444, 243–254. <https://doi.org/10.1016/j.scitotenv.2012.11.095>
- [86] Poste, AE, Muir, DCG, Guildford, SJ, Hecky, RE, 2015. Bioaccumulation and biomagnification of mercury in African lakes: The importance of trophic status. *Science. Total Approx.* 506–507, 126–136. <https://doi.org/10.1016/j.scitotenv.2014.10.094>
- [87] Ugbediye S., Ishaq Eneji S., Sha'Ato R. 2013. Determination of mercury level in *Rana esculenta* (frog), sediments and river water Guma, Benue State in Nigeria. *About. Earth Sci.* 3, 201-207.
- [88] Williams CR, Leaner JJ, Nel JM, Somerset VS. 2010. Mercury Concentrations in Water Resources Potentially Impacted by Coal-Fired Power Plants and Artisanal Gold Mining in Mpumalanga, South Africa. *J. About. Science. To tend to. - Part A Toxic/hazardous substance. About. Eng.* 45, 1363-1373. <https://doi.org/10.1080/10934529.2010.500901>
- [89] Youssao Abdou Karim A, Daouda M, Alassane Moussa AK, Mama D, Youssao Abdou Karim I. 2018. Sources and Distribution of Mercury Residues in Environmental and Food Matrices of the Mekrou River Watershed in Kèrou, Kouandé and Péhunco in Republic of Benin. *American Journal of Applied Chemistry.* 2018; 6 (2): 57-63. <http://www.sciencepublishinggroup.com/j/ajac>. doi: 10.11648/j.ajac.20180602.14. ISSN: 2330-8753 (Print); ISSN: 2330-8745 (Online).
- [90] MIA., (2018). Initial assessment of Minamata Convention on Mercury (MIA). Initial assessment report in Bénin. P. 182.
- [91] Grosbois C., Meybeck M., Lestel L., Lefèvre I., Moatar F. 2012. Severe and contrasting polymetallic contaminations (1900–2009) in the sediments of the Loire (France). *Total Environmental Science*, 435, 290-305.
- [92] INSPQ (National Institute of Public Health of Quebec). 2003. Scientific Panel on Water fact sheet on lead. National Institute of Public Health of Quebec, p. 14.
- [93] Botta A, Bellon L. 2004. Chemical water pollution and human health. Occupational medicine and health service. Laboratory of biogenotoxicology and environmental mutagenesis (EA 1784, IFR PMSE 112), p. 23.
- [94] Ayad W, Kahoul M. 2016. Evaluation of the physico-chemical and bacteriological quality of well water in the El- Harrouch region (Wilaya of Skikda). *J. Mater. Around. Sci.* 7 (4) (2016) 1288-1297 ISSN: 2028-2508 CODE: JMESCNC.