ISSN 2229-5518

Heavy Metal in Agricultural Soils in The Sahel Region of Doukkala (Morocco)

H. Mohcine, N.Saber and K. Moustarhfer
Laboratory of geology of old chain, Department of Geology, Faculty of Sciences Ben M'Sik, University Hassan II of Casablanca, Morocco.

Abstract—In order to assess the environmental quality of agricultural soils in the region of Sahel of Doukkala, the concentrations of Cd, As, Pb and Zn were determined for a representative sampling point network. The indices relatively related to this assessment (indice of geo-accumulation, contamination factor and pollution load index) were calculated. The results showed high concentrations of cadmium ranging from 3.45 to 4.75 mg/kg. The contamination factor calculated could unveil a high contamination of these soils by cadmium (Cf =12.2 on average) and a moderate contamination by arsenic (Cf = 2.14). This is probably due to the massive and uncontrolled use of agricultural inputs and pesticides practiced in conjunction with highly developed market gardening in the region.

Index Terms— Environmental quality, Heavy metal, Market gardening, Sahel region, Morocco.

1. Introduction

The contamination of agricultural soils caused by the accumulation of heavy metals stemming from farming practices remains an important environmental concern because of their toxicity and persistent. However, before approaching the metallic trace elements (heavy metals) in terms of risks, it should be noted that they are naturally present in soils at low concentrations [1, 2, 3] and that they play an essential role in animal and plant development [4]. However, exceeding a certain threshold, heavy metals become toxic. This double feature gives them a characteristic of being both indicators of environmental risk and indicators of deficiency risk material for intensive productions.

Heavy metals stemming from agricultural inputs were subject to several research works [5, 6, 7 and 8], which demonstrated that these farming practices are considered as a major source of soil contamination.

This risk of contamination associated with heavy metals contained in agricultural inputs depends not only on their mobility, but also on their interaction with soil properties. According to [9, 10], the physicochemical properties of soil influence the status and the dynamics of heavy metals. However, among the factors that control their mobilities and availabilities for plants, the pH appears as a parameter of primary importance [11, 12, and 13]. Nevertheless [14], showed that the nature of the organic matter, clays and oxides in the soil, condition the availability of heavy metals. Thus, sandy soils, therefore, enable a transfer of heavy metals to very high plants than very heavy soils, which led to determine soil characteristics on one hand, and evaluate the behavior of heavy metals in soils on other hand, in order to predict the risks of intensive use of agricultural inputs to the environment.

Therefore, the objectives of this study is the determination of the cadmium concentrations (Cd), arsenic (As), lead (Pb) and zinc (Zn) in soils of the Sahel region of Doukkala and the assessment of the environmental quality of these soils in terms of metal contamination and this by calculating the index of geo-accumulation, the contamination factor and the pollution load index.

- *Corresponding authors: H.MOHCINE and N.SABER*
- *E-mail: hajarmohcine@gmail.com, najib_saber@yahoo.fr*

2. MATERIEL AND METHODS

2.1. Presentation of the study area

Located at the edge of the Atlantic coast, the Sahel region of Doukkala is located between 32°18' and 33°28' of latitude and between 7°58' and 9°3' of longitude. It extends over a length of 80 km of coastline and a width of 15 to 25 km.

As the whole coastal region, it has a climate of southern Atlantic type, characterized by a humid and temperate winter extending from October to May and a hot and dry summer extending from April to November. Annual rainfalls generally are below 400 mm and the moderate temperatures are influenced by the circulation of maritime trade winds. The hottest monthly average temperature oscillates around 27°C and occurs in July and August, from November to February the maximum temperature is below 20°C and the minimum temperature is below 15°C. It can be noted in this environment, a high relative humidity rate is around 76% on average; this humidity is favored by the proximity of the ocean [15].

Geologically, the region is part of the domain of the coastal Moroccan Meseta, it is characterized by the secondary deposits on Precambrian and primary grounds structured by the hercynian orogeny. The Sahel area has two distinct geological entities, the Precambrian and Paleozoic basement and the cover formed by secondary, tertiary and quaternary grounds [16].

2.2. Sampling and analytical techniques

The soil sample collection compaign was conducted in 35 well-distributed points on the Sahel region (Fig.1). An auger was used for sample collection and following a horizon of 0-20 cm.

The samples taken from the field are firstly dried in the open air for 4 to 5 days, crushed then sieved to 2 mm.

The physicochemical analyses were carried out at the Faculty of Sciences Ben M'sik (Geology Department), they are about the pH which was conducted by the method of [17], electrical conductivity (EC) was determined according [18] method, the organic matter (OM) was assayed by the method of [19] and Bernard method described by [120] was opted for determining the calcium carbonate ($CaCO_3$). The determination of the texture was carried out by the pipette method of Robinson at AVI-Rabat (Agronomy and Veterinary Institute).

Analyses of heavy metals (Cd, As, Pb and Zn) were carried out through the extraction of soil with HNO_3. The fractions of the metal elements contained in the extracted solutions were then read by ICP-AES (Inducatively coupled Plasma Atomic Emission Spectrometry) at CNRST (The National Center of Scientific and Technical Research) in Rabat.

Statistical analysis using XLSTAT 2015 software was used to identify the existing correlations between the different parameters studied.

ISSN 2229-5518

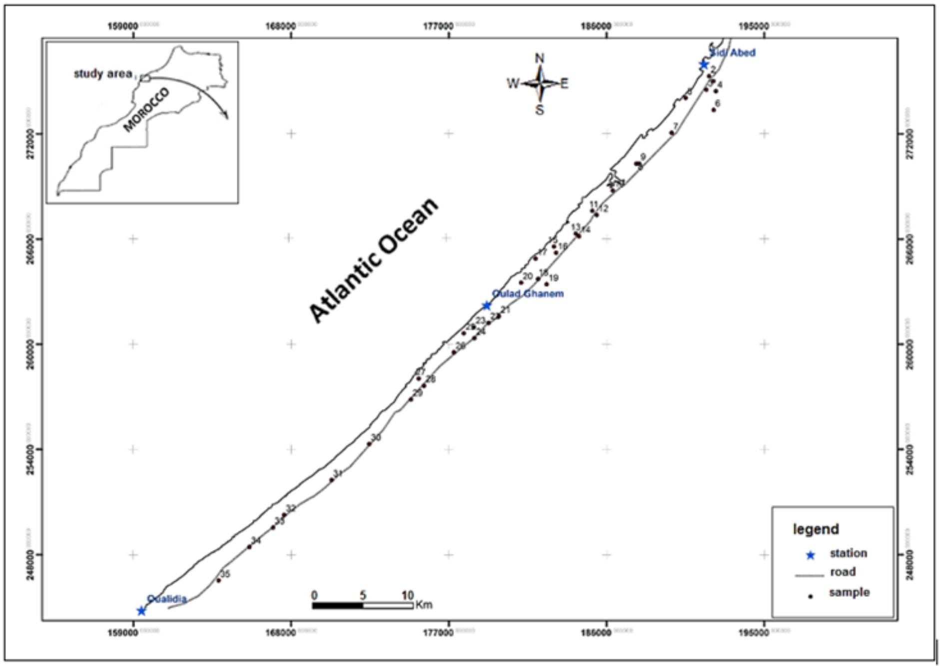

Fig.1. Location of the sampling points

3. Results and Discussions

3.1. Physicochemical analyses

The physicochemical characteristics of soils in the study area are reported in the table 1. The pH recorded indicates an alkaline environment with values ranging from 7.88 to 8.83; this is probably related to the presence of carbonates. The electrical conductivity is generally low and appears to be comparable to those values observed in the surrounding soils [21]. Note that these low values can be attributed to the sandy nature of the soil. The carbonate contents (CaCO3) are important and reflect the nature of the environment that relies directly on carbonate formation. The contents of organic matter of the soil show that the soils studied are considered to be rich in organic matter. The textural analysis by the pipette of Robinson presents high sand contents compared to the other two fractions. The percentage of sand records a maximum value which is of the order of 91.99%, while clays present very low contents which do not exceed 4.40%. The silt fraction records contents ranging from 4.75 to 5.55%.

Table 1: Physicochemical properties of soils of the Sahel region

	pH	OM (%)	EC (ms/cm)	CaCO3 %	C (%)	TSi (%)	TSa (%)
Minimum	7,88	1,46	0,14	25,52	3,24	4,75	90,04
Maximum	8,83	4,94	1,08	37,38	4,40	5,55	91,99
Average	8,28	2,97	0,46	32,18	4,01	5,23	90,75

C: clay TSi: total silt TSa: Total sand

3.2. Heavy metal rates in soil

The table 2 summarizes the descriptive statistics, including median, maximum, minimum, average and standard deviation (SD) of four heavy metals studied in the Sahel region. These results were compared with reference values [22] and

WHO (World Health Organisation) (Table 3). Along the study area, the concentrations obtained ranging from 5.12 and 32.52 mg/kg for As, 6.33 and 24.21 mg/kg for Pb, from 8.80 to 82.50 mg/kg for Zn. It appears that the total contents not exceeding the maximum values set by the WHO in the soil, which are of 40 ppm for As, 100 ppm for Pb and 300 ppm for Zn [23]. By contrast, around 95% of samples present concentration of arsenic which exceed the limit of ordinary soil [22]. However the rate of cadmium identified in samples collected ranging from 3.45 to 4.75, these contents are very high and represent more double of the limit value which is 2 mg/kg recommended by the WHO. Note that for Cd, Zn and Pb, the averages are very close to medians; which show that on the scale of the study area there is a low dispersion of concentrations.

TABLE 2: DESCRIPTIVE STATISTICS OF THE HEAVY METAL CONTENTS IN THE SAHEL REGION

	Minimum	Average	Maximum	Median	Standard deviation
Cd	3,45	4,23	4,75	4,27	0,3
As	5,12	13,83	32,52	11,11	7,91
Pb	6,34	14,8	24,22	15,06	4,58
Zn	8,8	37,94	82,5	37,31	19,27

TABLE 3: TOTAL CONCENTRATIONS (MG/KG) OF HEAVY METALS IN THE SOILS STUDIED COMPARED WITH REFERENCE VALUES. AVERAGE VALUES, 1: [22]; 2: WHO

Element	Reference values		Present study
	1	2	
As	6	40	13,83
Cd	0,35	2	4,23
Pb	35	100	14,8
Zn	90	300	37,94

3.3. Correlation Analysis

Based on several previous works [12, 13, 14, 24, 25, 26 and 27] that indicate a close linkage between heavy metals and different soil parameters, a correlation matrix was calculated for the following elements: OM, pH, CaCO3, Cd, As, Pb and Zn (table 4). Arsenic is slightly significantly correlated with CaCO3 (0.412) and OM (0.35), this correlation reveals the affinity of this element to carbonate minerals, [28] reported that the carbonates precipitate in soils as accumulation horizon, causing the co-precipitation of ETM (heavy metals) associated. In this work, the correlation coefficients of Pearson which we calculated and more precisely of the pH, do not match the results of the work mentioned before, which suggest a strong correlation between the pH and the heavy metals.

TABLE 4: CORRELATION MATRIX

Variables	As	Cd	Pb	Zn	pH water	OM%	CaCO3%
As	1						
Cd	-0,037	1					
Pb	-0,085	0,006	1				
Zn	0,279	-0,211	0,107	1			
pH water	0,074	-0,079	-0,176	-0,150	1		
OM%	0,357	0,024	-0,207	0,037	0,036	1	
CaCO3%	0,412	0,233	0,193	0,263	-0,227	0,003	1

ISSN 2229-5518

3.4. Evaluation of the soil contamination level

To study the contamination degree of heavy metals in the area, three parameters were determined: the index of geo-accumulation (I-geo), the contamination factor (Cf) or the enrichment ratio (ER) and the pollution load index (PLI). Thus, three stations were selected and this by going from North to South. It is about: Sidi Abed station, Oulad Ghanem station and Oualidia station (Fig.1).

The results presented in figure 2 (a,b,c,d) show that the concentrations of metals measured ranging from one station to another. Their evolutions are present as follows:

a) the zinc contents found in the three stations show various concentrations, with a maximum value which is of the order of 50.64mg/kg recorded in the Oualidia station. While in Sidi Abed station content recorded does not exceed 21,74mg/kg. Basically these measures show a significant increase by going from Sidi Abed to Oualidia, but do not exceed the ordinary soil contents (90mg/kg), and the limit threshold recommended by the WHO.

b) The concentrations of Arsenic are generally comparable and show a slight increase from one station to another, going from 9.78 mg/kg at Sidi Abed station to 17,47mg/kg at Oualidia station.

c) The concentrations of cadmium do not show any significant difference between the three stations.

d) Pb showed a decreasing gradient from Sidi Abed (15,35mg/kg) to Oulad Ghanem (14.58 mg/kg) then increasing from Oulad Ghanem to Oualidia (15.13 mg/kg). Basically, Lead is considered as an element with low mobility, being mainly associated with clays and organic matter, it is not mobile unless it makes soluble organic complexes and/or the soil has exceeded its absorption capacity for Pb [29, 30, 31]. Cadmium by its turn recorded similar concentrations in the three stations, with a slight decreasing gradient towards Oualidia station.

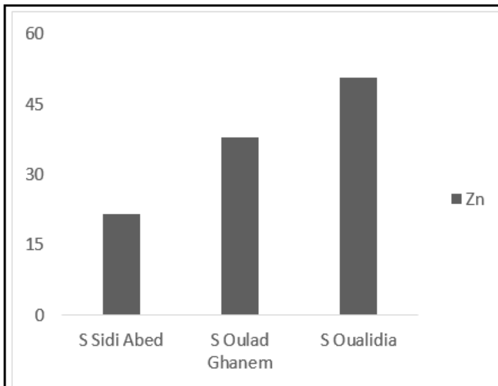

Fig.2 (a). Evolution of Zn concentration in mg/kg depending on the stations

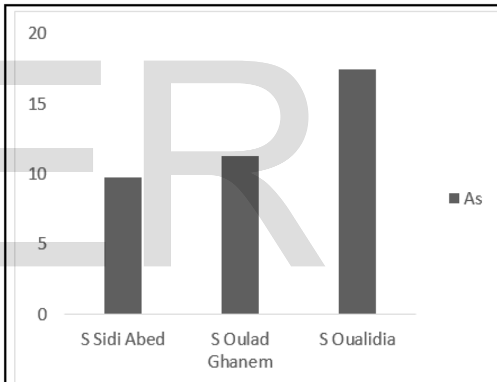

Fig.2 (b). Evolution of Arsenic concentration in mg/kg depending on the stations

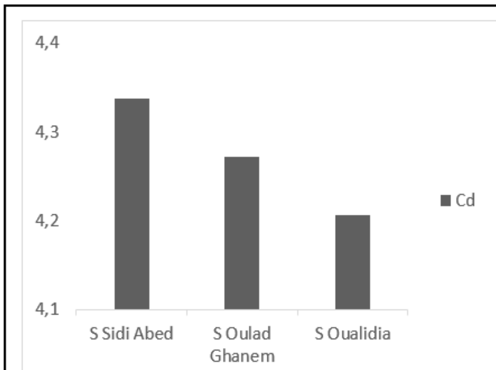

Fig.2 (c). Evolution of Cd concentration in mg/kg depending on the stations

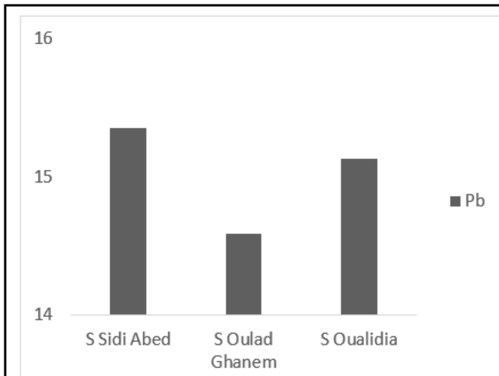

Fig.2 (d). Evolution of Pb concentration in mg/kg depending on the stations

ISSN 2229-5518

If we compare our results with those found by [32] and [33] in the sediments of the two lagoons: Sidi Moussa and Oualidia, we clearly notice that the contents obtained of cadmium in the two lagoons are well below to those recorded in the soils of the area studied (table 5). The Pb concentrations in the soils of the Sahel are above the concentrations recorded in the sediments of the lagoon of Oualidia.

This has underlined that the heavy metal levels recorded in the soils of the Sahel of Doukkala region are due to the massive and not mastered use of agricultural and pesticides inputs. In fact, the intensive cropping practices that the area knows to improve its fertility potential contribute in a drastic way in increase of the heavy metals rates in soil. In fact, previous studies [5] which were carried out on different types of fertilizers have shown extreme Cadmium contents up to 6.3 mg/kg. [7] also reported that fertilizers based phosphate contain high concentrations of heavy metals. [34] mentioned that the fertilizer coming from a phosphate rock contain 11, 25, 32 and 10 mg/kg of As, Cd, Cu and Pb respectively. Furthermore, the proximity of the chemical complex of phosphates processing of Jorf Lasfar can probably contribute in the increase of these elements. Several authors emphasize the importance of industrial effluents of these complexes in the contamination of several sites along the coastline with Cd and other metals by-products of phosphate processing [35, 36, and 37].

TABLE 5: COMPARISON OF HEAVY METAL CONCENTRATIONS (PRESENT STUDY, LAGOON OF SIDI MOUSSA AND OUALIDIA)

Element	lagoon of Sidi Moussa [33]	lagoon of Oualidia [32]	Present study
As	31,87	-	13,83
Cd	2,05	0,58	4,23
Pb	17,38	6,8	14,8
Zn	102	104	37,94

3.5. The index of geo-accumulation (Igeo)

The evaluation of soils pollution related to heavy metal was calculated by using the Index of geo-accumulation (I-geo) which was originally defined by [38]. It is obtained by comparing current concentrations at pre-industrial levels and can be calculated by the following equation:

$$Igeo = \log 2 \, [Ci / (1.5CB)]$$

Which Ci is the concentration measured of the metal i and CB is the concentration of geochemical background of the metal i (mg/kg). The factor 1.5 is introduced to reduce to minimum the effect of possible variations in background values that can be attributed in lithogenic variations in soils. The scale of this index includes seven classes (0-6) ranging from unpolluted to heavily polluted (Table 7). according to the scale of Muller, the results calculated of geo-accumulation index values (Table 6) show that for the cadmium, the soil quality is considered as moderately polluted (1≤Igeo<2) for all stations, while for As, soils were recorded as unpolluted to moderately polluted (0≤Igeo<1). By contrast, Pb and Zn indicate unpolluted soil (Igeo<0) and that is in all stations (except Sidi Abed station where the Zn indicates that the situation is unpolluted to moderately polluted).

Based on the average values of Igeo, soils are enriched in metals in the following order: Cd> As> Pb> Zn.

TABLE 6: VALUES OF SOILS GEO-ACCUMULATION INDEX OF THE SAHEL REGION

Stations	Igeo			
	AS	Cd	Pb	Zn
Sidi Abed S	0,33	1,22	-0,23	0,09
Oulad Ghanem S	0,39	1,21	-0,25	-0,25
Oualidia S	0,58	1,20	-0,23	-0,12
Average	0,44	1,21	-0,24	-0,09

S: Station

TABLE 7: CLASSES OF GEO-ACCUMULATION INDEX (I GEO)

Igeo value	classes	Pollution level
I geo≤0	0	unpolluted
0≤Igeo <1	1	unpolluted to moderatly polluted
1≤Igeo <2	2	moderately polluted
2≤Igeo <3	3	moderately polluted to heavily polluted
3≤Igeo <4	4	heavily polluted
4≤Igeo <5	5	heavily polluted to extremely polluted
Igeo >6	6	extremely polluted

3.6. The contamination factor (Cf)

In the present study, the contamination factor (Cf) and the contamination degree (Cd) were used to determine the status of soils contamination. The contamination factor is calculated through the equation: CFi (contamination factor) = concentration of the metal i / geochemical background of the metal i, while the contamination degree is defined as the sum of all contamination factors. The Cf and Cd of this study are presented in table 8. From this table the maximum contamination factor is recorded at the Oualidia station, where the contamination degree is of the order of 15.92. In fact the three stations show a very high contamination, (Cf> 6) (table 9), for cadmium, a moderate contamination (1≤ Cf <3) for arsenic and a low contamination (Cf <1) for zinc and lead. Based on the average values of Cf, our soils are enriched with heavy metals in the following order: Cd> As> Zn> Pb.

TABLE 8: VALUES OF THE CONTAMINATION FACTOR AND THE PLI FOR THE SOILS OF THE SAHEL REGION

Stations	Contamination factor				Contamination degree	PLI
	As	Cd	Zn	Pb		
Sidi Abed S	1,63	12,39	0,43	0,24	14,7	1,2
Oulad Ghanem S	1,87	12,2	0,41	0,42	14,92	1,4
Oualidia S	2,91	12,02	0,43	0,56	15,92	1,7
Average	2,14	12,2	0,43	0,4	15,18	-

TABLE 9: FACTOR AND LEVEL OF CONTAMINATION [39]

Contamination factor	Contamination level
Cf < 1	Low contamination
1≤ Cf < 3	Moderate contamination
3≤ Cf < 6	Considerable contamination
Cf>6	Very high contamination

3.7. Pollution load Index (PLI)

Pollution load index (PLI) was evaluated following the method proposed by [40]. This parameter is based on the values of concentration factors (Cf) of each metal in the soil, it can be calculated as the n-the root of the product of concentration factors n. The pollution load index (PLI) higher than 1 symbolizes pollution.

$$PLI = \sqrt[n]{Cfi} \times Cfi \ldots . \times Cfn$$

The results obtained show that the PLI does not record significant fluctuations from one station to another, but it presents a slight increase ranging from Sidi Abed (PLI = 1.2) to Oualidia (PLI = 1.7) (table 8). However the values of PLI are relatively high in Oualidia could be due to an increase in agricultural activities as long as this area is known by the presence of a modern and intensive agriculture.

4. Conclusion

This present study enabled the identification and evaluation of the level of heavy metal contamination in the Sahel region. The index of geo-accumulation (I-geo), the contamination factor (Cf) and the pollution load index (PLI) were used for this evaluation. The results obtained in this work show that the concentrations measured of As, Zn and Pb not exceeding the maximum values set by the WHO, against the cadmium values represent the double of the limit value (2 mg/kg) .

Following the index geo-accumulation (I-geo), soils are considered moderately polluted for cadmium, unpolluted to moderately polluted for arsenic and unpolluted for Zn and Pb. The contamination factor (Cf) has shown us a very high contamination for cadmium, moderate contamination for arsenic and a low contamination for Zn and Pb. the pollution load index (PLI) enabled to identify pollution at the three stations (PLI = 1.4 on average). From these evaluation criteria, we can say that cadmium is responsible for a significant contamination and this, in the three stations.

Reference

1. Alloway, B.J. et Ayres, D.C., Chemical Principles of Environmental Pollution. Blackie Academic and Professional, an imprint of Chapman and Hall. In : Salvarredy, M. (2008). - Contamination en métaux lourds des eaux de surface et des sédiments du Val de Milluni (Andes Boliviennes) par des déchets miniers : Approches géochimique, minéralogique et hydrochimique. These de doctorat, Univ. Toulouse, (1997) 379 p.
2. Baize, D., Le Courrier de l'Environnement de l'INRA. Total concentrations of trace metals in soils (France). Références and interprétation stratégies. 39 (1997) 39-54 p.
3. Callender, E., Heavy Metals in the Environment-Historical Trends, US Geological Survey, Westerly, RI, USA. (2003) 67-100 p.
4. Colinet G., Metallic trace elements in soils. Contributive study of driving factors of their spatial distribution I the Belgian Loamy region (these de doctorat in French). Gembloux, Belgium. Faculté universitaire des sciences agronomiques 88 tabl, 176 (2003) 415p.
5. Raven, K.P., Leoppert, RH., Heavy metals in the environment, Trace element composition of fertilizers and soil Amendment. J.Enviro.Qual. Volume 26 (1997) 551-557 pp.
6. Mermut, A.R., Join, J.C., Song, L., kerrich, R., kozak, L., Jana. S., Trace element concentrations of select soils and fertilizers in Saskatchewan, Canada. Environ. Qual. Volume 25 (1996) 845-853 pp.
7. Brigden, K., Stringer, R., & Santillo, D., Heavy metal and radionuclide contamination of fertilizer products and phosphogypsum waste produced by the Lebanese Chemical Company, Tech. Rep.13/2002, Greenpeace Research Laboratories, (2002).
8. Pereira, B., Sonnet, P., La contamination diffuse des sols par les éléments traces métalliques en région Wallone, université catholique de Louvain, Faculté d'ingénieur agronomique, biologique et environnentale (2007).
9. Pédro, G., Delmas A.B., Les principes géochimiques de la distribution des éléments traces dans les sols, J. Ann. Agron. 21(5) (1970) 483-518 pp.
10. Florence, T.M., Batley, G.E., Chemical speciation in natural waters, A review. Critical Reviews. Analy. Chem. 9(3) (1980) 219-296 pp.
11. Barrow, N.J., Testing a mechanistic model VI. Molecular modelling of the effects of pH on phosphate and on zinc retention by soils. J. Sail Sei. 37 (1986) 311-318 pp.
12. McLaughlin MJ, Zarcinas, B.A., Stevens, D.P., Cook, N., Soil testing for heavy metals Communication in Soil Sciences and Plant Analysis. (2000) 1661-1700 pp.
13. Alkorta, I., Hernandez-Alica, J., Becerril, J.M., Amezaga, I., Albizu, I., Garbisu, G., Recent finding on the phytoremediation of soils contaminated with environmentally toxic heavy metals and metalloids such as Zinc, cadmium, lead and arsenic, Reviews in Environmental Science and Bio/Technology 3 (2004) 71-90 pp.
14. Bargagli R.. Trace elements in terrestrial plants. An ecophysiological approach to biomonitoring and biorecovery. Springer. (1998) 324 pp.
15. ORMVAD., Rapport relatif à l'agro-climatologie dans le périmètre des Doukkala. Campagne agricole 2009-2010 (2010).
16. Fadili, M., Etude hydrogéologique et géophysique de l'extension de l'intrusion marine dans le Sahel de l'Oualidia (Maroc) : analyse statistique, hydrochimie et prospection électrique. Thèse de Doctorat Es-science, Univ. Chouaib Doukkali, (2014) 15 pp.
17. Mc lead, e.o., pH and lime requirements. In : Page, A.L. et al. (Eds.), Methods of Soil Analysis, Part 2, second ed., Agronomy, vol. 9 Soil Society of America, Madison, WI, (1982) 199–244.
18. Rhoades, J.D. Corwin, D.L., Monitoring soil salinity. J. Soil and Water Cons., 39(3) (1984) 173-175.
19. Walkley, A., Black, I.A., An examination of the Degtjareff method for determining organic carbon in soils: Effect of variations in digestion conditions and of inorganic soil constituents. Soil Sci. 63 (1934) 251-263 pp.
20. Chamley, H., Guide des techniques du laboratoire de Géologie Marine de Luminy, (1966) 198 pp.
21. Moustarhfer, K., Saber, N., Mohcine, H., Rafik, F.,

Zaakour, F., Matech, F.Z., qualité agronomique des terrains Agricoles de la région de jorf lasfar (Doukkala, Maroc), European Scientific Journal August 2015 edition vol.11, No.24 (2015) 53-69 pp.
22. Bowen, H.J.M., Environmental chemistry of elements. Academic Press, (1979) 333 pp.
23. Godin, P., Source de contamination et enjeu. Séminaire "Eléments traces et pollution des sols", 4-5 Mai 1982, Paris, (1982) 3-12 pp.
24. Christensen, T.H., Cadmium soil sorption at low concentrations: 1. Effect of time, cadmium load, pH and calcium. Water, Air, Sail, Pollut., 21 (1984) 105-114 pp.
25. Harter, R.D., Effect of soil pH on adsorption of lead, coppel', zinc, and nickel. Sail Sei. Soc. Am. J., 47 (1983) 47-51 pp.
26. Peakall, D., Burger, J., Méthodologies for assessing exposure to metals: speciation, bioavailability of metals, and ecological host factors. Ecotoxicology and Environmental Safety, 56 (2003) 110-121pp.
27. Peijnenburg,W.J.G.M., Jager.T. Monitoring approaches to assess bioaccessibility and bioavailability or metakmatrix issues. Ecotoxicology and Environmental Safety (56) (2003) 63-77.
28. McBride, B., Chemisorption of Cd2+ on calcite surfaces. Soil Sci. Soc. Am. J. 44 (1980) 26- 28 pp.
29. Morlot, M., Aspects analytiques du plomb dans l'environnement, Ed Lavoisier TEC&DOC (1996).
30. Raskin, I., Ensley, B.D., Phytoremediation of toxic metals; using plants to clean up the environment". John Wiley and Sons, New York (2000).
31. Kabata-Pendias, Trace Elements in Soil & Plants. CRC Press, Boca Raton, USA (2000).
32. Idardar, Z., Moukrim, A., Chiffoleau, J.F., Ait alla, A., Auger, D., Rozuel, E., Evaluation de la contamination métallique dans deux lagunes marocaines: Khnifiss et Oualidia. Rev. Mar. Sci. Agron. Vét. 2 (2013) 58-67pp.
33. Joulami, L., Daief, z., Elmalki, S., El hamoumi, r., variation spatio-temporelle des caractéristiques physicochimiques et la qualité des eaux et des sédiments d'une lagune ; Côtière marocaine (sidi moussa-El Jadida). ScienceLib Editions Mersenne: Volume 5, N° 130702, ISSN, 2111-470 (2013).
34. He, Z. L., Yang, X. E., Stoffella, P. J., Trace elements in agroecosystems and impacts on the environment. J. Trace. Elem. Med. Biol., 19(2-3) (2005) 125-140 pp.
35. Banaoui, A., Chiffoleau, J.F., Moukrim, A., Burgeot, T., Kaaya, A., Auger, D., Rozuel, E., Trace metal distribution in the mussel Perna perna along the Moroccan coast. Mar. Pollut. Bull. 48 (2004) 378-402.
36. Cheggour, M., Chafik, A., Langston, W.J., Burt, G.R., Benbrahim, S., Texier, H., Metals in sediments and the edible cockle Cerastoderma edule from two moroccan atlantic lagoons: Moulay Bousselham and Sidi Moussa. Environ. Pollut. 115 (2001) 149-160.
37. Maanan, M., Biomonitoring of heavy metals using Mytilus galloprovincialis in Safi Coastal waters, Morocco. Environ. Toxicol. 22 (2007) 525-531 pp.
38. Muller, G., "Heavy metals in the sediment of the Rhine-Changes seity," Umsch. Wiss. Tech.79 (1979) 778-783 pp.
39. Hakanson, L., "An ecological risk index for aquatic pollution control a sedimentological approaches, "Water Research, 14, (1980) 975-1001 pp.
40. Tomlinson, D.L., Wilson, J.G., Harris, C.R., Jeffrey, D.W., Problems in the assessments of heavy metal levels in estuaries and formation of a pollution index. Helgol Meeresunters, 33 (1980) 566-575 pp.