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# Study of Trace Metals in Surface Sediments of the Dam Reservoir Sidi Chahed (Meknes, Morocco)

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**--------------------------------------------------------ABSTRACT--------------------------------------------------------**
*Twenty surficial sediment samples, distributed in space and time in Sidi Chahed dam (NE Meknes) were collected using an Eckman grab sampler. The analysis focused on the physico-chemical characteristics and heavy metal content (Fe, Mn, As, Cu, Zn, Pb, Cr and Cd) by ICP-AES after digestion of the fraction less than 200 microns. The elements As, Pb, Cd and Cr contents are high compared to watershed natural geochemical levels. Runoff, erosion of agricultural land and domestic sewage spills are likely sources of contamination. The elements As, Pb, Cd and Cr contents are high compared to watershed natural geochemical levels. Runoff, erosion of agricultural land and sewage spills are likely sources of contamination.*

***KEYWORDS*** *: heavy metals, Meknes, pollution, Sediments, Sidi Chahed dam.*

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## I. INTRODUCTION

Water resources are major concerns of countries in arid or semi-arid climate, because they are absolutely essential to the development of all human, economic and social activities elements.Morocco is a country that is linked its socio-economic development of its water resources, the groundwater exploration and construction of dams. Morocco is a country that has linked its socio-economic development of its water resources, by prospecting underground water and building dams.However, in recent decades, these resources seem threatened by industrial, agricultural and urban development which is responsible for metal pollution and over-exploitation. It is also threatened by over-exploitation. Given the magnitude of these, several studies have been conducted in aquatic ecosystems ([1], [2], [3], [4], [5], [6], [7], [8], [9], [10] and [11]).This work focuses on the evaluation and the origin of the metallic contamination in superficial sediments (0-5 cm) of the Sidi Chahed dam.

## II. GEOGRAPHICAL LOCATION AND FRAMEWORK

Sidi Chahed dam is built on Oued Mikkes, about 30 km NW northwest of Fez city and 30 km NE of Meknes city, on the main road n° 4 connecting Fez and Sidi Kacem “Fig. 1” and “Fig. 2”. It was built on soft formations of Miocene and Triassic in the transition zone between the Furrow South Rif and Prérif. Its construction was mainly intended to power the city of Meknes drinking water and irrigation [12]. The main objective of its construction is the drinking and irrigation water supply of Meknes city ([12]. However, since its commissioning in February 1997, the water quality of the reservoir was found unfit for consumption due to its relatively high salinity [13].

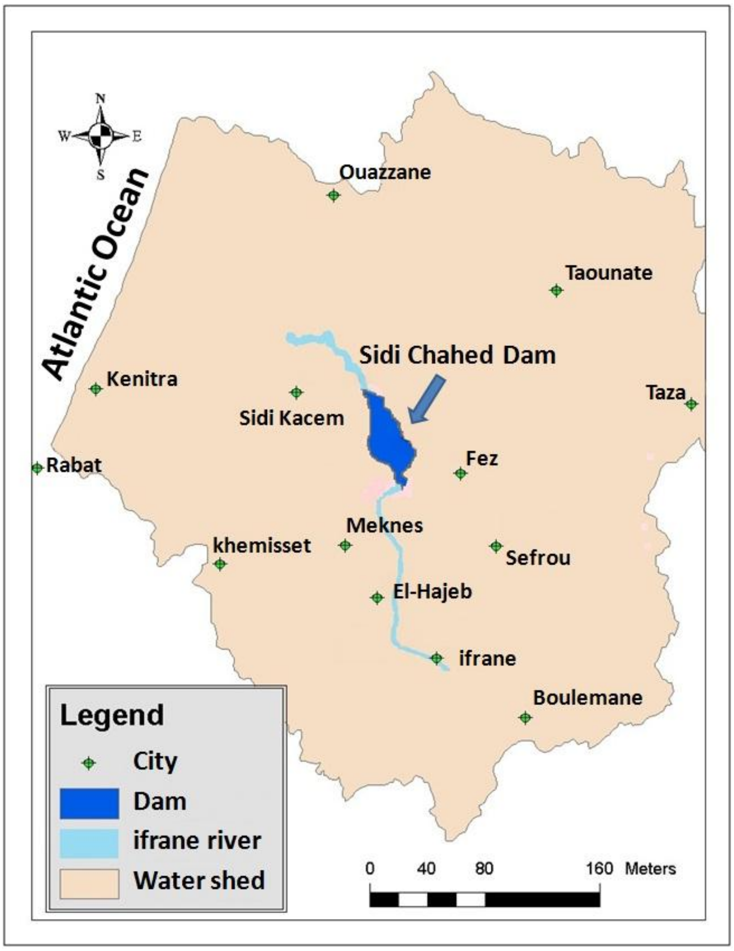


**Figure 1:** Situation of the study area in the Sebou watershed.

## III. MATERIALS AND METHODS

The choice of work on the sediment resides in the fact that it is a conducive environment to the accumulation that could highlight the presence of various pollutants of the aquatic environment and the history of their evolution in time and space.The sediments were collected at the water - sediment interface using a shack and using a bucket-type Eckman for taking surficial sediments of 0-5 cm. The 22 stations were selected to cover the entire retainer “Fig. 2”. The location of sampling stations was carried out using a portable GPS Magellan eXplorist 100.To make comparison, we chose four other reference stations at the watershed scale at sites away from human activity [14]. The samples were taken under very favorable conditions. They were transported in plastic bags and packed in 4°C until laboratory [15], [16] and [17]). Then, they were stirred until getting a homogenous mixture, dried in an oven for 48 hours at 80°C and sieved in water to extract the fraction less than 200 µm.The dosage of eight metallic trace: iron (Fe), zinc (Zn), manganese (Mn), copper (Cu), arsenic (As), cadmium (Cd), lead (Pb) and chromium (Cr) was performed by ICP-AES method. An amount of 1 g of sediment (<200 µm) is mineralized at 120 °C for 4 hours in the regal water (aqua regia) presence (a mixture of 1 volume of concentrated nitric acid with 3 volumes of hydrochloric acid). The mineral deposit is taken by successive rinsing with ultra - pure water, then filtered through a membrane of 0.45 µm and filled to a volume of 50 ml ([2] and [18]).

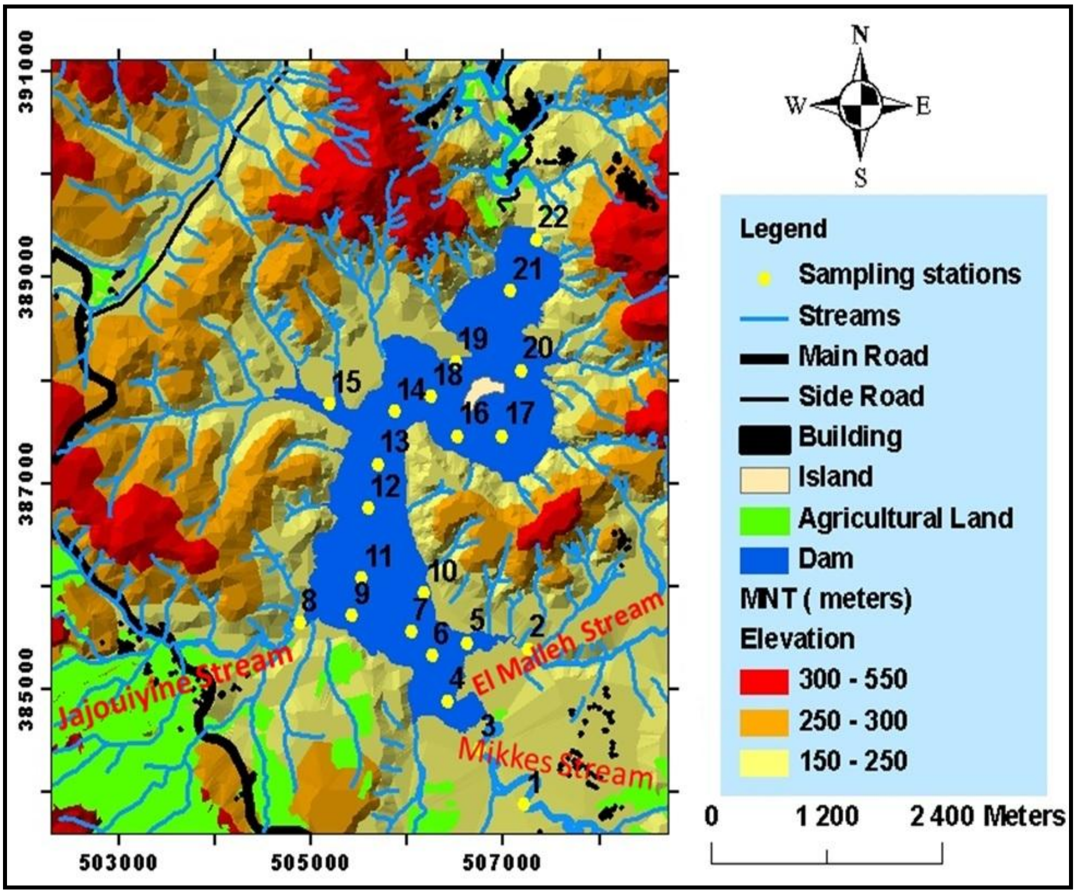


**Figure 2:** Digital elevation model (DEM) of the study and position of sampling stations in the dam Sidi Chahed area.

## IV. RESULTS

The iron "Fig. 3", "Table 1" and" table 2" and manganese "Fig. 4", "Table 1" and "table 2", the most abundant metals in the sediments studied, undergo irregular fluctuations from upstream to downstream with values which oscillate respectively between 5 and 61.54 mg / g and between 148.2 and 314.8 mg / g. Were lower than those of reference stations chosen in the watershed and whose levels vary between 51.1 and 74.5 mg / g for iron and between 234.7 and 313 mg / g for manganese. They therefore would reflect natural levels.

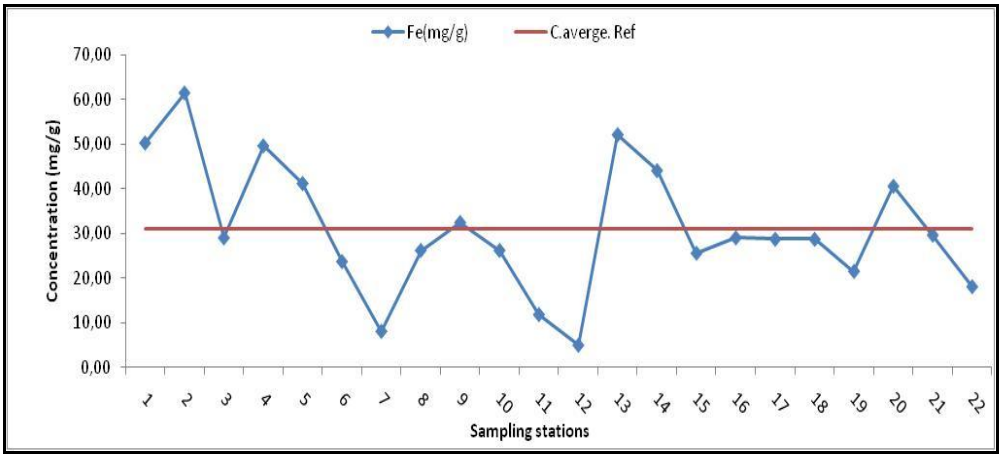


**Figure 3:** Spatial variation in levels of iron.

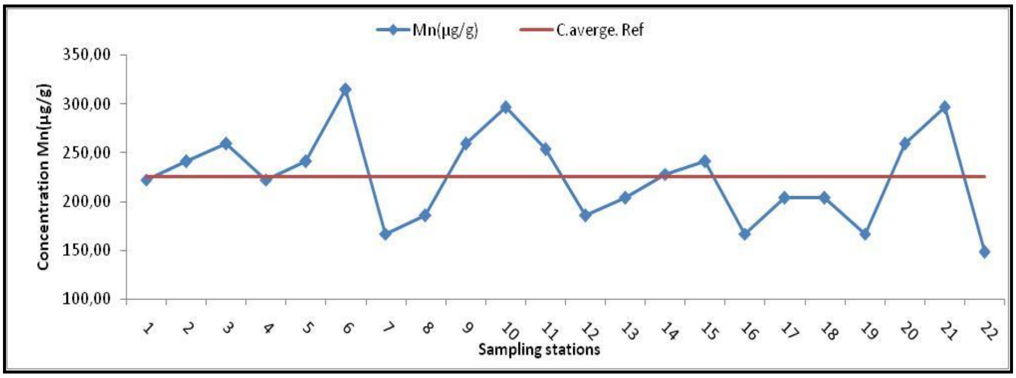


**Figure 4:** Spatial variation in levels of manganese.

The zinc levels "Fig. 5", "Table1" and" table 2" and copper "Fig. 6", "Table 1" and " table 2" respectively oscillate between 10,7 and 60 µg / g and between 2.9 and 22.9 µg/ g. They stay generally lower than the geochemical background given by the reference stations in the watershed and therefore reflect natural levels.For other metals, the levels vary between 8.6 and 19.1 µg / g for lead "Fig. 7", "Table 1" and "table 2" between 1.27 and 3.68 µg / g for cadmium "Fig. 8", "Table 1" and "table 2" between 4.59 and 10.07 µg / g for arsenic "Fig. 9", "Table 1 and 2") and between 19.9 and 79.1 µg / g for chromium "Fig. 10", "Table 1" and" table 2". These levels are generally higher than those of reference stations that vary between 10.6 and 12.6 µg / g for lead, 1.28 and 1.62 µg / g for cadmium, 3.9 and 4.9 µg / g for arsenic and between 36.8 and 49.4 µg / g for chromium. They therefore reflect a metallic contamination of generalized sediment at the scale of the all of Sidi Chahed dam. This metallic contamination is probably due to the intensive agricultural activity in the watershed without excluding domestic and industrial discharges.

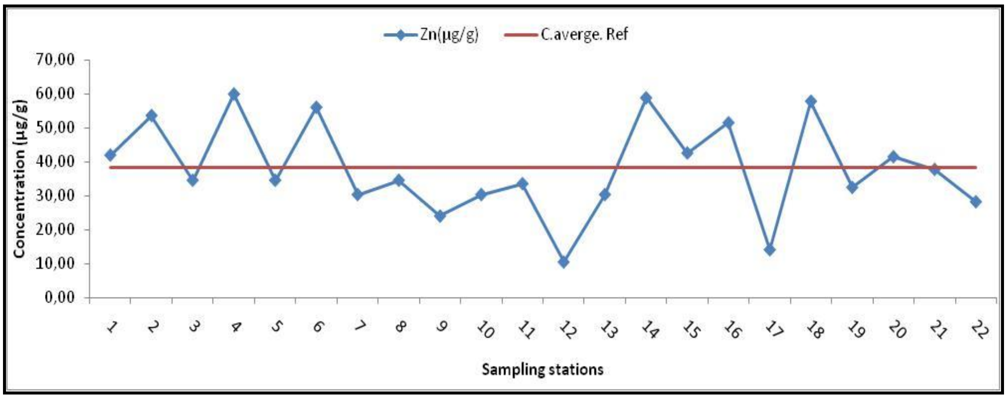


**Figure 5:** Spatial variation in levels of zinc.

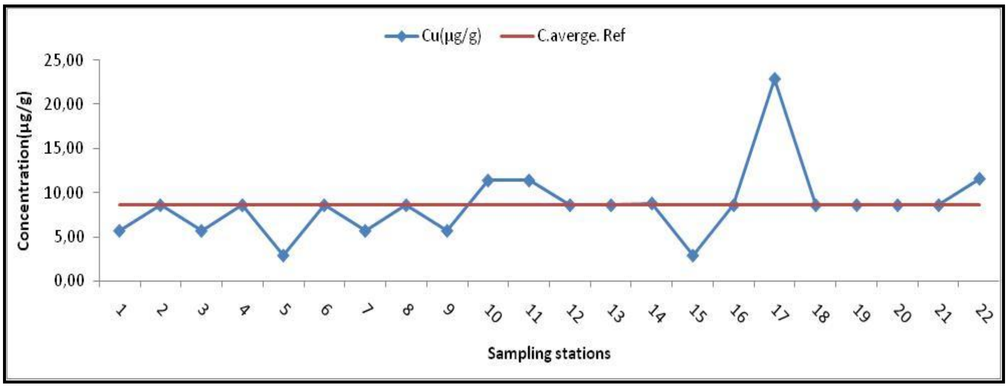


**Figure 6:** Spatial variation in levels of copper.

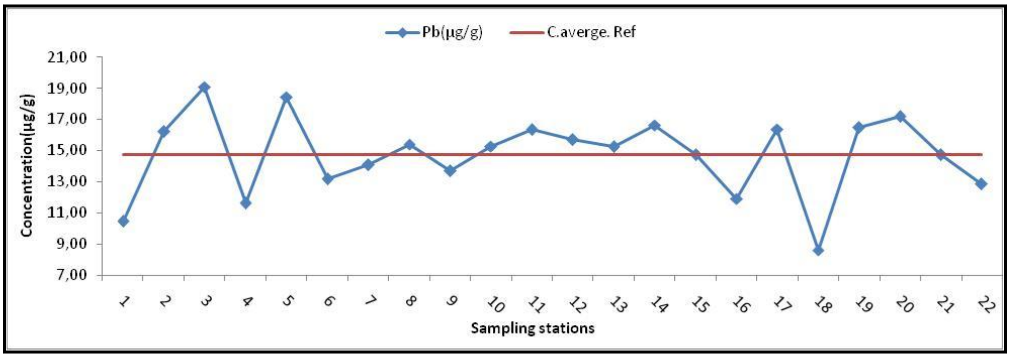


**Figure 7:** Spatial variation in levels of lead.

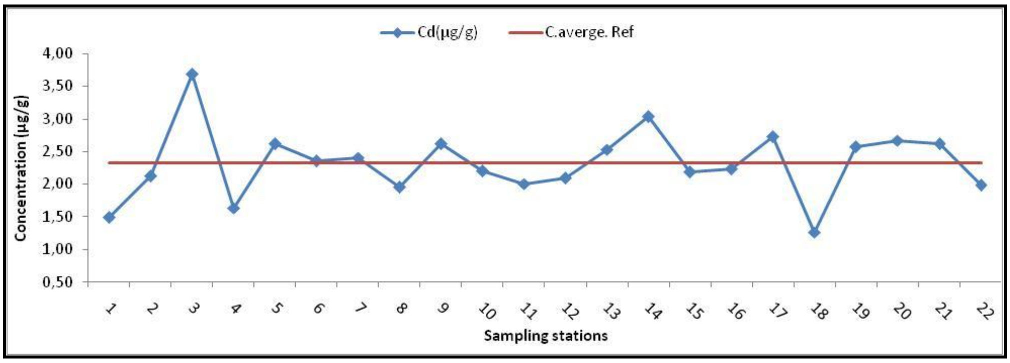


**Figure 8:** Spatial variation in levels of cadmium.

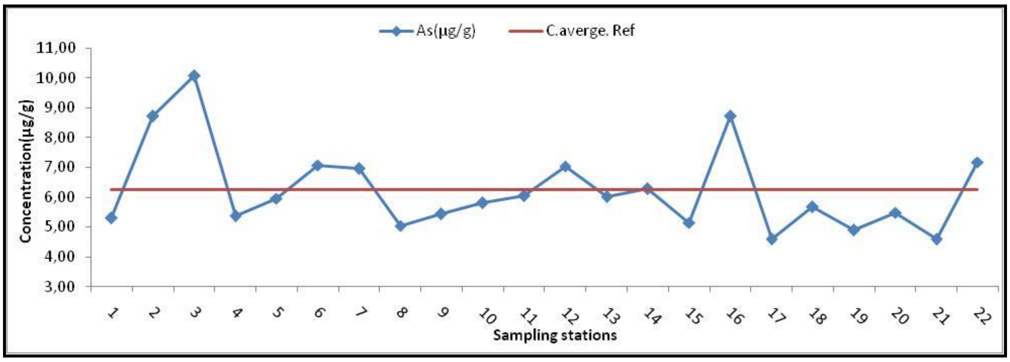


**Figure 9:** Spatial variation in levels of arsenic.

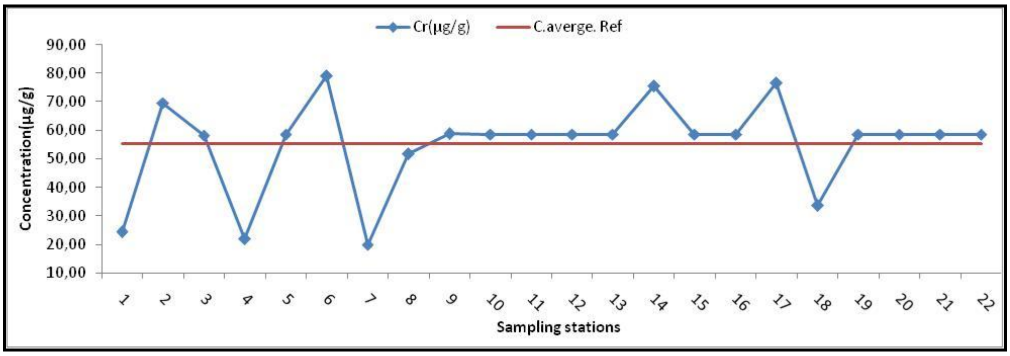


**Figure 10:** Spatial variation in levels of chrome.

## V. DISCUSSION

To estimate the environmental status of Sidi Chahed dam sediments, levels of metallic traces in sediments are evaluated compared with other moroccan aquatic systems and with pollution norms "Table 1" and "table 2".Thus, the iron levels in sediments studied "Table 1" and "table 2" are comparable to those of Talsint river (19 to 89.4 mg / g) [19], but remain higher than those of El Kansra dam (10.7 to 28.4 mg / g) ([2]), Fouarat lake (5.5 to 15.2 mg / g) [6] and Boufekrane wadi (13.7 to 19.3 mg / g) [1]. This iron fertilization would be related to the geological context of the area and probably comes from the alteration of triassic red clays outcropping on the surface of the dam watershaed and also the iron is used as a trace element in agriculture.The manganese levels recorded in this study are similar "Table 1" and "table 2" to those found in the sediments Fouarat lake (257-477 µg / g) [6] and Talsint wadi (230-590 µg / g) [19], but relatively lower than those of El Kansra bbdam [2] and Boufekrane wadi downstream of Meknes city [1]. These levels, relatively high, probably originate from leaching into the edge of the dam and the regional geological context.The concentrations of zinc and copper in sediments of Sidi Chahed dam "Table 1 and 2" are more or less similar to the Boufekrane river downstream of Meknes city [1], but remain lower than those of Sebou river sediments [20], the El Kansera dam [2], Talsint river [19] and Fouarat lake [6].

Table 1. Average levels of trace metals sediment dam Sidi Chahed compared to other Moroccan aquatic systems.

| Element | Sidi Chahed dam | Reference stations | El Kansra dam [2] | Fouarat lake [6] | Talsint river [19] | Boufekrane river [1] |
|---|---|---|---|---|---|---|
| Fer (mg/g) | 31.10 | 61.58 | 10.7 à 28.4 | 5.5 à 15.2 | 19 à 89.4 | 13.7 à 19.3 |
| Mn (µg/g) | 225.58 | 265.73 | 152 à 1000 | 257 à 477 | 230 à 590 | 671 |
| Zn (µg/g) | 38.27 | 49.17 | 22 à 220 | 219 à 477 | 344 | 57 |
| Cu (µg/g) | 8.60 | 16.19 | 10.3 à 48.5 | 45.5 | 44 | 15 |
| Pb (µg/g) | 14.74 | 11.79 | 4 à 48 | 18 à 125 | 58.4 à 109.23 | 48 |
| Cd (µg/g) | 2.32 | 1.44 | 0.60 à 1.30 | 0.05 à 0.81 | 0.26 à 0.42 | 0.8 à 1.6 |
| As (µg/g) | 6.25 | 4.37 | - | - | - | - |
| Cr (µg/g) | 55.18 | 42.40 | 26 à 151.5 | 73.9 | 33.3 | 335.2 |

Moreover, lead values obtained in this study "Table 1" and "table 2" are comparable to natural levels in the sediments at the international scale (19 µg / g) [21]. However, they remain well below 200 µg / g recorded in the sediments of Sebou river [20], 125 µg / g in Fouarat Lake [6], 109 µg / g in Talsint river [19], 48 µg / g recorded in the sediments of Boufekrane river [1] and El Kansra dam [2]. Levels, more or less similars to those of the reference stations, reflect the absence of contamination by Pb.Cadmium concentrations in the analyzed different samples are relatively high "Table 1" and "table 2". In fact, they are higher than those recorded in the Fouarat Lake sediments (from 0.05 to 0.81 µg /g [6], the Boufekrane river downstream of Meknes city (0.8 to 1.6 µg / g) [1], the Sebou river (0.005 to 0.550 µg / g) [20], Talsint river (0.26 to 0.42 µg / g) [19] and El Kansra dam (0.6 to 1.3 µg / g) [2]. The burden of this element would be attributed to leaching from agricultural land heavily amended by fertilizers (micronutrients / trace element), to atmospherical depositions and / or urban wastes [6].The values of arsenic found in Sidi Chahed dam sediments (4.59 to 10.07 µg/g) are higher than the average levels of these elements in soils (1 to 2µg / g, as geochemical background [22] and global averages in the rivers sediments (5 µg/g) [23] "Table 1" and "table2", but comparable to those of St. Francis Lake in Quebec (3 7µg / g) [24].Concerning the chromium, levels recorded in the present study (Table 1 and 2) are comparable to those of Talsint river sediments [19] and Fouarat Lake [6], but lower than those of El Kansra dam sediments [2] and Boufekrane river [1].

Table 2. Sediment heavy metal levels of Sidi Chahed dam compared to reference stations and to Moroccan pollution standards ([25], [26] and [23]).

| | | Mn (µg/g) | Zn (µg/g) | Cu (µg/g) | Pb (µg/g) | Fe (mg/g) | Cd (µg/g) | As (µg/g) | Cr (µg/g) |
|---|---|---|---|---|---|---|---|---|---|
| Stations in the dam | Min | 148.20 | 10.70 | 2.90 | 8.61 | 5.00 | 1.27 | 4.59 | 19.90 |
| | Avg | 225.58 | 38.27 | 8.60 | 14.74 | 31.10 | 2.32 | 6.25 | 55.18 |
| | Max | 314.80 | 60.00 | 22.90 | 19.09 | 61.54 | 3.68 | 10.07 | 79.09 |
| | Stdev | 45.74 | 13.74 | 3.95 | 2.54 | 14.54 | 0.53 | 1.43 | 16.28 |
| Reference stations | Min | 234.66 | 38.75 | 13.40 | 10.57 | 51.11 | 1.28 | 3.90 | 36.80 |
| | Avg | 265.73 | 49.17 | 16.19 | 11.79 | 61.58 | 1.44 | 4.37 | 42.40 |
| | Max | 313.08 | 60.31 | 23.11 | 12.62 | 74.52 | 1.62 | 4.89 | 49.40 |
| | STDEV | 37.48 | 11.88 | 4.64 | 0.90 | 9.66 | 0.15 | 0.42 | 5.70 |
| Moroccan pollution standards | | 400 [25] | 88 [25] | 26 [25] | 22 [25] 34.5– 66.7 [26] | 3.12-6.68 [26] | 0.6 [25] | 5 µg/g global average sediment rivers [23] | 45 [25] |
| Nature of pollution | | No pollution | | | | Pollution : agricultural. domestic. rich mafic geological context (alteration of Triassic red clays). | | | |

The comparison of the results with respect to reference stations taken in the watershed and to Moroccan pollution norms shows that there is virtually no contamination of Sidi Chahed dam sediments by Mn, Cu, Pb and Zn "Table 2". Thus, the presence of these four metallic elements in studied sediments is probably naturally related to the geological nature of the soil exposed in the region.For cons, the contents of metallic traces Fe, Cd, As and Cr and are superior to Moroccan norms and to the reference stations levels (Table 2). Therefore, they would reflect a rather anthropogenic contamination in conjunction with farming, but without excluding the industrial and domestic activity.

## VI. STATISTICAL ANALYSIS

In order to view, to analyze existing correlations between the different variables through their structurings and their guidances, and to identify the main factors responsible for the quality of the environment through the sediments surveyed, the data set was treated statistically by the Principal Component Analysis (PCA). This technique is used to determine a system of axes of hierarchical references while reducing the number of dimensions of space in which the points are projected observations. Much information is explained by the first three principal axes "Table 3". The contributions of different parameters in the formation of the first three factorial axes F1, F2 and F3 are respectively 29.59%, 22.53% and 14.44%, for a total of 66.56% of the information explained. As a result, the maximum of the total inertia is accumulated by the planes formed by the factorial axes F1 and F1 × F2 × F3 (F2XF3).

Table 3. Eigen values and percentage contribution of the first three principal components.

| Axis | Eigen values | Cumulative Eigen values | % Total Variance | % Cumul |
|---|---|---|---|---|
| F1 | 2.37 | 2.37 | 29.59 | 29.59 |
| F2 | 1.80 | 4.17 | 22.53 | 52.12 |
| F3 | 1.15 | 5.32 | 14.44 | 66.56 |

Linear correlations vary on average almost half in the positive direction and half in the negative direction "Table 4". However, the most significant correlations are positive and are recorded between the Pb and Cd with a correlation coefficient of 0.78 between the Fe and Zn with the average correlation coefficient of 0.5. The other parameters vary in the same direction or in the opposite direction but with very low correlation coefficients. This result is confirmed by the two circles on the correlation plane F1 * F1 * F2 and F3 "Fig. 10" and "Fig. 11".

Table 4. Correlations matrix.

| | Fe | Mn | Zn | Cu | Pb | Cd | As | Cr |
|---|---|---|---|---|---|---|---|---|
| Fe | 1 | | | | | | | |
| Mn | 0.22 | 1 | | | | | | |
| Zn | 0.50 | 0.22 | 1 | | | | | |
| Cu | -0.13 | -0.12 | -0.30 | 1 | | | | |
| Pb | -0.03 | 0.21 | -0.39 | 0.04 | 1 | | | |
| Cd | -0.01 | 0.25 | -0.25 | 0.01 | 0.78 | 1 | | |
| As | -0.01 | -0.07 | 0.16 | -0.19 | 0.16 | 0.30 | 1 | |
| Cr | -0.25 | -0.03 | -0.38 | 0.12 | 0.30 | 0.26 | 0.11 | 1 |

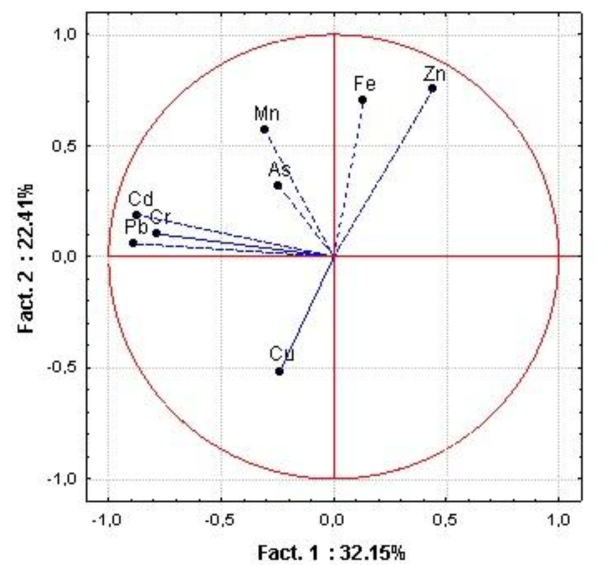


Figure 11. Circle of correlations in terms F1xF2.

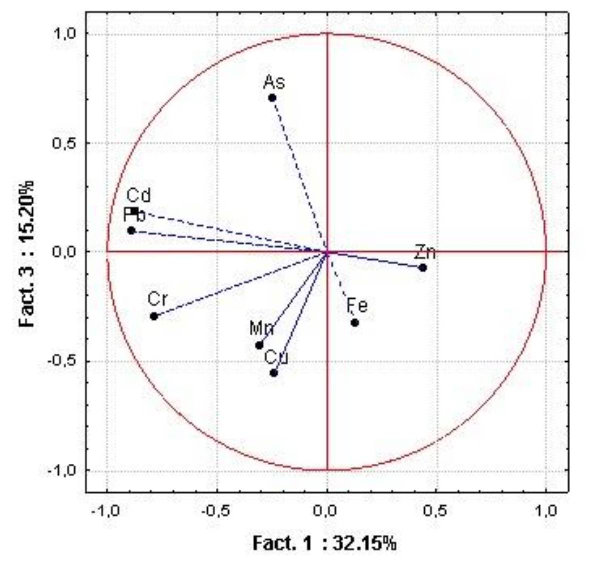


Figure 12. Circle of correlations on the map F1xF3.

The observation of the planes formed by the axes (F1xF2) and (F1xF3) “Fig. 13” and “Fig. 14” shows the presence of three groups:- F1 axis shows a contrast between heavily contaminated with heavy metals Cr. Pb and Cd occupying the part negative “Table 5”, “Fig. 11” of the axis and Zn in heavily contaminated occupying the positive portion of the axis sediment “Table 5” and “Fig. 12”. - The axis F2 indicates a conflict between the Cu-rich sediments occupying the positive part of the axis and the rich sediment Fe and Mn occupying the negative part of this axis.- F3 axis has a sediment contamination Ace which varies according to a gradient of increasing the negative portion to the positive portion of the shaft.This distribution shows a metal contamination of natural sediments in relation to the geology of the area and anthropogenic metal contamination in relation to agricultural practices, industrial and domestic in the region. However, this typology is of no relation to the geographical distribution of different sampling stations.

Table 5. Correlations between the factors and variables (weight factor).

| | Axe F1 | Axe F2 | Axe F3 |
|---|---|---|---|
| Fe | -0.40 | -0.58 | 0.27 |
| Mn | 0.03 | -0.60 | 0.50 |
| Zn | -0.70 | -0.50 | -0.10 |
| Cu | 0.24 | 0.47 | 0.43 |
| Pb | 0.80 | -0.39 | 0.14 |
| Cd | 0.75 | -0.51 | 0.03 |
| As | 0.19 | -0.40 | -0.75 |
| Cr | 0.62 | 0.15 | -0.14 |

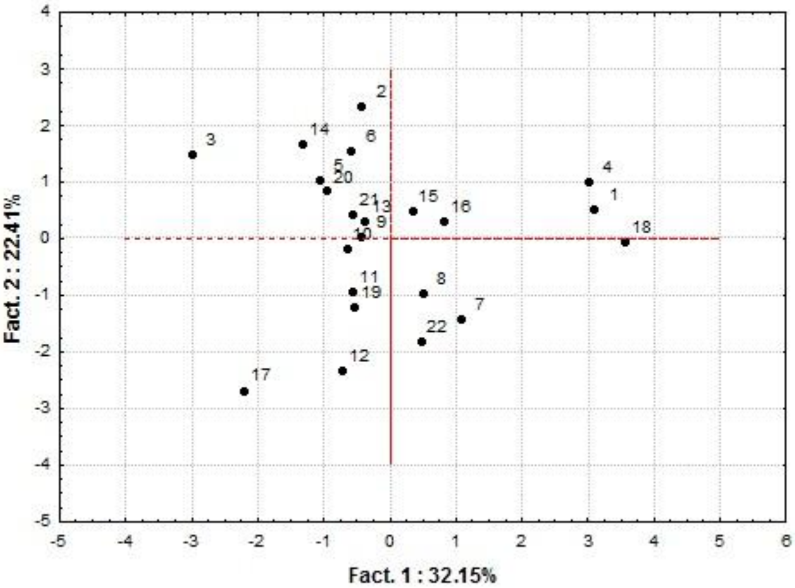


Figure 13. Projection of individuals on Factorial F1xF2 plans.

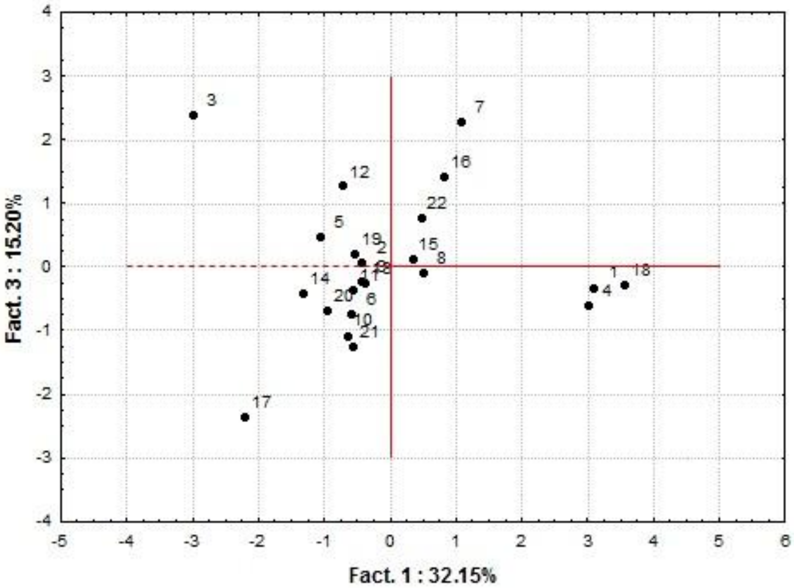


Figure 14. Projection of individuals on Factorial F1xF3 plans.

## VII. CONCLUSION

The results show that there is virtually no contamination of Sidi Chahed dam sediments by Mn, Cu, Pb and Zn. The levels recorded are lower than those of reference stations taken in the watershed and those of moroccan pollution norms. Therefore, these four metallic trace elements have a rather natural origin due to the geological nature of the soil exposed in the region.For cons, the levels of Fe, Cd, As and Cr are higher than those of the reference stations and those of moroccan pollution norms. Therefore, they would reflect well, a contamination probably in conjunction with farming, but without (any time to exclude the activity of industrial and domestic activity) excluding the industrial and domestic activity.Statistical analysis by PCA has identified a typology of the different stations of sediments by their degree of metal pollution and also to highlight the sources of natural or anthropogenic contamination.This study contributed to the quantification of metallic pollution accumulated in sediments and to determine its origin. This pollution is largely natural and slightly accentuated by the anthropogenic contribution. These results should enable policy makers to intervene for the preservation of the aquatic ecosystem and could serve as a reference in future studies.

# REFERENCES


[1] M. Saadallah, *Contribution à l étude de la pollution métallique des sédiments des cours d'eaux Marocains. Cas de l'oued Boufekrane*. Thèse de 3ème cycle, Université Moulay Ismail, Faculté des Sciences de Meknès, 1991, 241p.

[2] A. Abdalloui, *Le phosphore et les métaux lourds contenus dans les sédiments. Leur influence sur les phénomènes d'eutrophisation et de pollution*, Editions Universitaires Européennes, 2013, 341p.

[3] A. Serghini, A. El abidi, L. Idrissi, L. Mouhir, M. Fekhaoui And E. Zaid, Evaluation de la contamination métallique des sédiments de complexe zone humides de la ville de Mohammadia (Maroc), *Bulletin de l'institut scientifique, science de la vie*, Rabat, 23, 2001, 77-81.

[4] M. Khamar, *Etude de la charge en métaux lourds dans les eaux, sédiments, les sols et les productions agricoles irrigués par les eaux usées de la ville de Fès*, Thèse de Doctorat, Université Moulay Ismail, Facultés des Sciences, Meknès, 2002, 213p.

[5] W. Chouti, D. Mama, O. Changotade, F. Alapini and M. Boukari, Étude des éléments traces métalliques contenus dans les sédiments de la lagune de Porto-Novo (Sud Bénin), *Journal of Applied Biosciences*. 34, 2010, 2186 – 2197.

[6] H. Ben Bouih, H. Nassali, M. Leblans and A. Srhiri, Contamination en métaux traces des sédiments du lac Fouarat (Maroc), *Afrique Sciences*, 1, 2005, 109-125.

[7] D. Abrid, A. El Hmaidi, A. Abdallaoui, O. Fassi Fihri, A. Essahlaoui, Pollution impact on Boufekrane river water's (Meknes – Morocco) : Physico-chemical and bacteriological study, *Phys. Chem. News*, 58, 2011, 98-104.

[8] Abrid, D., El Hmaidi A., Abdallaoui A. et Essahlaoui A., Apport du système d'information géographique à l'évaluation de la contamination métallique contenue dans les sédiments de la retenue du barrage Sidi Chahed (Meknès, Maroc). *International Conference of GIS-Users, Taza GIS-days, Fès, Proceeding Book*, 2012a, 396-398.

[9] Abrid D., EL Hmaidi A., Abdallaoui A. et Essahlaoui A., 2012b. Etude de la contamination métallique des sédiments de la retenue du barrage Sidi Chahed (NE de Meknès, Maroc). Journal of Hydrocarbons Mines and Environmental Research, 3, 2, 55-60.

[10] D. Abrid, A. EL Hmaidi, A. Abdallaoui, and A. Essahlaoui, Variation Spatiale des Concentrations en Éléments Traces Métalliques dans les Sédiments de la Retenue du Barrage Sidi Chahed (Meknès. Maroc), *European Journal of Scientific Research*, 106, 4, 2013, 503-511.

[11] EL Hmaidi A., Abrid D., Abdallaoui A. Essahlaoui A. and El Ouali A., Caractérisation sédimentologique et physico-chimique des sédiments de carottes de la retenue du barrage Sidi Chahed, NE de Meknès, Maroc, *Journal of Hydrocarbons Mines and Environmental Research*, 3, 2, 2012, 91-96.

[12] ABHS (Agence du Bassin Hydraulique du Sebou), Inventaire des redevables d'eau d'irrigation et d'alimentation en eau potable et industrielle (AEPI) à partir des nappes de la plaine de Fès-Meknès, *Rapport interne, Marché 6/2003 ABHS/F*, 2003.

[13] O. El Fatni, L Gourari, D. Ouarhache, M.Chaffai, H .El Arabi, K. Boumir and A El Khanchoufi, Problème de salinité de la retenue du barrage Sidi Chahed : Etat des lieux et perspectives. *3ème Journées Internationale des Géosciences de l'Environnement*, El Jadida, 2005.

[14] D. Boust, J.M .Jouanneau and C. Latouche, Méthodologie d'interprétation des teneurs totales en métaux traces contenus dans les sédiments estuariens et littoraux, *Bull. Inst. Géol. Bassin d'Aquitaine*, 30, 1981, 72-78.

[15] G. Rofes, Etude des sédiments, méthodes de prélèvements et d'analyses pratiquées au laboratoire de sédimentologie, *Étude n°47, Ministère de l'agriculture, GTGREF*, 1980, 50p.

[16] G. Aubert, Méthodes d'analyses des sols. *Centre National de Documentation Pédagogique, Marseille*, 1978, 189p.

[17] J. Rodier, B. Legube, N. Merlet and Coll, *L'analyse de l'eau,* 9ème Edition, Dunod, Poitier, 2009, 1400p.

[18] M. Fekhaoui, L. Bennasser, and M. Bouachrine, Utilisation d'un nouvel indice d'évaluation de la contamination métallique des sédiments: cas du bas Sebou (Maroc), *Bulletin de l'institut scientifique*, Rabat, 20, 1996, 143-150.

[19] H. Taouil, S. Ebn Ahmed, N Hajjaji, A. Srhiri, Contribution à l'évaluation de la pollution métallique des sédiments de l'Oued Talsint. Bassin versant de Guir (Maroc Oriental). *Science Lib.*, Editions Mersenne, 3, 2011, N° 111109.

[20] M. Fekhaoui, *Recherche hydrobiologique sur le moyen Sebou soumis aux rejets de la ville de Fès, Suivi d'une Macro-pollution et évolution de son incidence sur les composantes physiques, chimiques et biologiques de l'écosystème*, Thèse de Doctorat d'état es Sciences biologiques, Univ. Med V, Faculté des Sciences, Rabat, 1990, 214p.

[21] Bowen, H.J.M., Environmental chemistry of the elements, *Academic Press*, New York, 1979, 49-62.

[22] M.C. Dicotor, P. Barange, L. Chéry., K. Michel, J. Barbie, B. Closel, S. Touzé, Synthese des travaux R&D (1999-2004) en France sur la thématique Arsenic, *Rapport final BRGM/RP-53252-FR.*, 2004, 127p.

[23] J.M. Martin, M. Whitfield, The significance of the river input of chemical elements to the ocean, In: Smedley P.L. & Kinniburgh D.G. (eds.), A review of the source, behaviour and distribution of arsenic in natural waters, *Appl. Geochem.*, 17, 1983, 517-568.

[24] B. Pinel-Alloul, G. L. Methot Lapierre, A. Willsie, Macroinvertebrate community as a biological indicator of ecological and toxicological factors in lake Saint-François (Quebec), *Environment pollution*, 91, 1, 1996, 65-87.

[25] H. Nassali, H. Ben Bouih and A. Sghiri, Effect of wast water on the degradation of water quality in the cases of Fouarat lake in Morocco, *Proceeding of International Symposium on Environmental Pollution Control and Waste Management*, Tunis, 2002, 3-14.

[26] A. Kaimoussi, *Etude de la variabilité de l'accumulation des métaux lourds dans les différents compartiments (sédiments, mollusques et algues) du littoral de la région d'El Jadida*, Thèse 3ème Cycle, Univ. Chouaib Doukkali, Faculté des Sciences, El Jadida, 1996, 147p.