

A coastal Lake's Hydro-chemistry: Sidi Boughaba Case, North Western Morocco.

M. Lachhab¹, D. Belghyti¹, M. Najj¹, Fatimetou Salma M.M.O.S¹, H. Ech-chafay¹, O. Akkaoui¹,
R. Ben Aakame², K. El Kharrim¹

¹: Laboratory of Agro-physiology, Biotechnologies, Environment and Quality, Equipments, wasteaters and Health, University Ibn Tofail, Faculty of Sciences, BP 133, 14000 Kénitra Maroc.

²: National Institute of Hygiene, Laboratory of Hydrobiology-Industrial and Environmental Hygiene, Av. Ibn Battouta Agdal, Rabat, Morocco.

Email: salah-825@hotmail.com

Abstract : In order to determine the factors and the mechanisms which control the chemistry and the salinity of the waters of Sidi Boughaba Lake, the waters of the lake environment and those taken from a well near the lake, we subjected these waters to a hydro-chemical control at a trimestrial sampling rate. The analyzes revealed a basic pH between 8.38 and 9.03, an electrical conductivity in the range of 12.40 to 17.41 mS/cm and high Sodium and Chloride contents up to the respective values of 3698 mg/L and 6625 mg/L for the waters of the lake on the one hand, and a neutral pH and a low mineralization for those of the wells, on the other hand. The results' projection on the Piper Diagram revealed the presence of a hydrochloric-sodium facies for the lacustrine waters and a mixed facies for those of the wells. The comparison between the chloride content with the rest of the main elements and the increasing levels of Sodium and Chlorides mentioned above shows that the hydrochemistry of the lake's water is due to the effect of marine spray, evaporation's cycles, while the Ca²⁺ - Mg²⁺ exchange is due to the water-carbonate interaction, and Na⁺ - Ca²⁺ or Na⁺ - Mg²⁺ exchange is due to the basic exchanges, and the sulphates' reduction. The calculation of saturation indices revealed that Sidi Boughaba Lake waters are under-saturated with evaporite minerals (halite, gypsum and anhydrite) and supersaturated with carbonate minerals (calcite, aragonite and dolomite).

Index Terms: Hydro-chemistry, Kenitra, Marine intrusion, Morocco, Sidi Boughaba Lake.

1 INTRODUCTION:

The lakes of the endorheic basins are frequently affected by salinization, especially in arid zones. Two types of configurations which could lead to salinization of these types of environment have been distinguished. The first one occurs when the water's volume lost by evaporation is greater than the fresh waters volume entering the lake. The other configuration is manifested through the case of salt water supply. These flows may have a natural origin, as in the case of the salinization of the Lake of Tiberias [1],[2]. On the other hand, the salinization of Salton Sea Lake by irrigation water illustrates the example of an anthropic origin of the salinity [3]. Other processes are involved in the phenomenon of both lakes and wetlands' salinization:

- The modification in the incoming flows' composition [4];
- The accumulation of marine aerosols on an exposed continent [5],[6];
- The mixture with residual seawater [7],[8];
- The rise of hydrothermal fluids [9].

In this work, we are trying to determine the origin of the strong mineralization of the Ramsar site "Lake Sidi Boughaba" located in Kénitra.

2 MATERIALS AND METHODS OF STUDY

2.1 Description of the study area:

The lake of Sidi Boughaba is located on the Northwest Atlantic coast of Morocco (N 34 ° 24 ', W 06 ° 67'), with 10 km south of Kénitra and 1 km from the coast (Figure 1). It is bounded to the north by Sebou river estuary, to the south by the Marabout of Sidi Boughaba, to the east by a consolidated dune system and to the west by another motive. It is oriented NNE-SSW and extends over 5.5 km in length and 100-350 m in width [10].

The banks of the lake are covered by dense vegetation which is composed of *Juniperus phoenicea*, *Olea europea*, *Pistacia lentiscus*, *Myrthus communis* and *Populus alba* [10]. The lake has been classified as a Ramsar site since 1980 thanks to the importance of its avifauna, which has attracted the attention of many researchers [11],[12],[13]. Its fauna is also characterized by its diversity and richness [14],[15],[16]. The surface water level of the lake environment depends on the precipitation and groundwater flowing towards the ocean in a north-westerly direction [17]. The aquifer's mineralization is estimated to be about 600 mg/L [18],[19],[20], which becomes more important under the effect of evaporation [21]. The lacustrine waters are characterized by a salinity of about 3 to 27 g/L [22], an alkaline pH, a temperature between 15 and 34 ° C and a high content of dissolved oxygen mostly above saturation [23],[22].

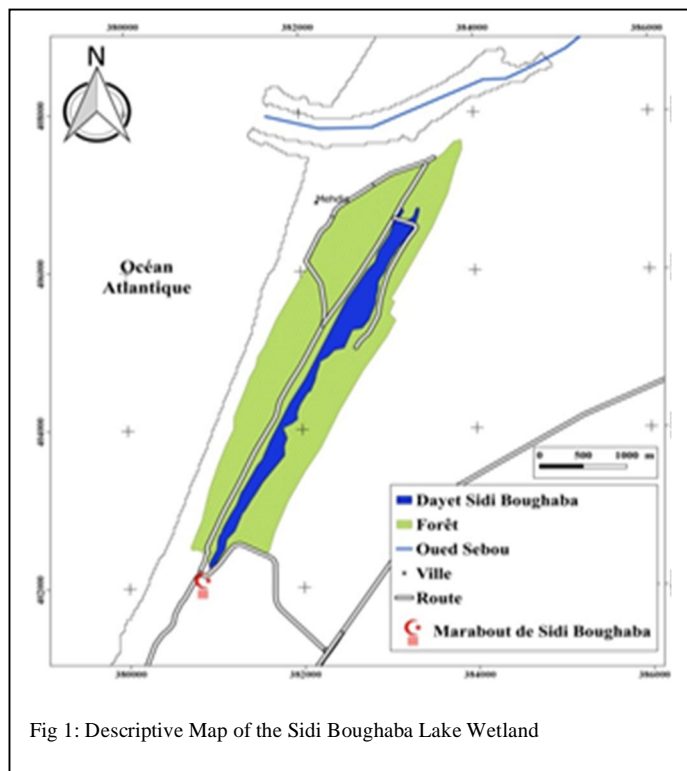


Fig 1: Descriptive Map of the Sidi Boughaba Lake Wetland

2.2 Sampling, preservation and analysis of samples

23 out of 25 lake water samples were taken from 06 stations in this study (S1, S2, S3, S4, S5 and S6) during 4 sampling campaigns, as well as 2 samples of well water (EP) were also taken from a well in the vicinity of the studied site. The temperature, pH, and electrical conductivity were measured "in situ" by the use of a Thermometer incorporated in the 3110SET 2, WTW pH meter, a 3110SET 2, WTW and A Cond Conductimeter Cond 3110SET 1, WTW. The Na, Mg, Ca, Na Cations were measured by VARIAN Atomic Absorption Spectrophotometer and the anions were measured by ion chromatography Dionex ICS 2000 version at the National Institute of Hygiene. The samples were filtered through a 0.45 µm filter, and those for the cation assay were acidified with the nitric acid in order to avoid adsorption and precipitation of the chemical elements and were stored in (+4 ° C). They were analyzed as soon as they arrived in the laboratory [24].

3 RESULTS AND DISCUSSION

3.1 Chemistry of the waters of the lake and those of the underground water table

The lake water is characterized by a temperature ranging from

19.46 to 21.55, the basic pH oscillates between 8.38 and 9.03, the high chloride and sodium contents and an electrical conductivity are between 12.40 and 17.41 mS/cm which can be attributed generally to marine intrusion [25] and major element concentrations with marked variation over the study period, with the following values: Chlorides (5007-6625 mg/L), Sodium (2526-3698mg/L), Calcium (47-163mg/L), Potassium (39-58mg/L), Sulfates (140-1091mg/L), Magnesium (271-485mg/L), Bicarbonates Strong salinity and high levels of chlorides and sodium reflect typical values of those found in seawater [26],[25],[5],[6] as well as their concentration by the

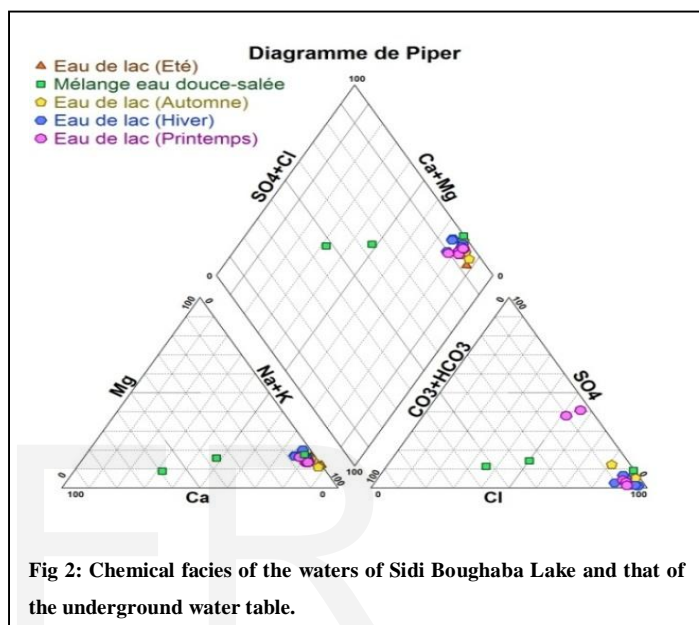


Fig 2: Chemical facies of the waters of Sidi Boughaba Lake and that of the underground water table.

high number of evaporation cycles that the lake has experienced since its generation [27],[6]. The latter dates from about 4570 ± 110 BC [28] or from a marine intrusion [29],[30],[25],[31],[32]. On the other hand, wells' water has a low electrical conductivity of the order of 1.4 mS/cm and low levels of Chlorides (185 mg/L), Sodium (129 mg/L), Bicarbonates (329 mg/L) Sulfates (75 mg/L), Magnesium (22mg/L), Calcium (143mg/L) and Potassium (10mg/L). The low mineralization and the low levels of chlorides and sodium in groundwater are not the result of marine intrusion.

3.2 Hydrochemical Facies

For the interpretation of water chemistry, we used the Piper diagram, which is composed of two triangles representing the cationic and the anionic facies and a lozenge synthesizing the

TABLE 1

THE HYDRO-CHEMICAL PARAMETERS (AVERAGE AND STANDARD DEVIATIONS) OF THE LAKE WATER AND THE UNDERGROUND WATER TABLE.

Echantillon	T (°C)	pH	CE (mS/cm)	Na ⁺ (mg/L)	Ca ²⁺ (mg/L)	Mg ²⁺ (mg/L)	K ⁺ (mg/L)	Cl ⁻ (mg/L)	SO ₄ ²⁻ (mg/L)	HCO ₃ ⁻ (mg/L)
S1 Mex	21,5	8,96	12,51	2623	74	288	39	5117	183	423
σ	5,34	0,27	3,69	981	15	113	14	1648	68	73
S2 Mex	21,3	9,03	12,49	2526	73	271	39	5498	164	410
σ	5,17	0,25	3,61	840	18	84	14	1568	70	72
S3 Mex	21,4	8,97	12,40	2812	72	276	42	5095	140	423
σ	5,21	0,21	3,50	1170	13	87	10	1373	86	63
S4 Mex	21,3	8,38	16,29	3609	47	360	48	6223	1091	1002
σ	5,18	0,63	15,80	4075	35	302	32	6294	1067	715
S5 Mex	21,1	8,44	17,41	3698	163	485	58	6625	687	348
σ	5,11	0,61	11,29	2606	90	309	40	4125	391	90
S6 Mex	19,4	8,55	13,62	2848	157	363	49	5007	751	303
σ	3,45	0,67	9,62	2402	109	290	42	3546	458	43
EP	24,0	7,55	1,40	129	143	22	10	185	75	329
σ	2,19	0,14	0,16	26	57	7	6	35	8	103

σ : Standard deviation

global facies [33]. The lake and wells water analyzes on this diagram shows some superposition and clustering which are due to the low variability of the concentrations from one measurement station to another. Only the point representing the water table significantly deviates from it. It follows that the lacustrine waters are chloride-sodic while that of wells present a mixed facies (Figure 2).

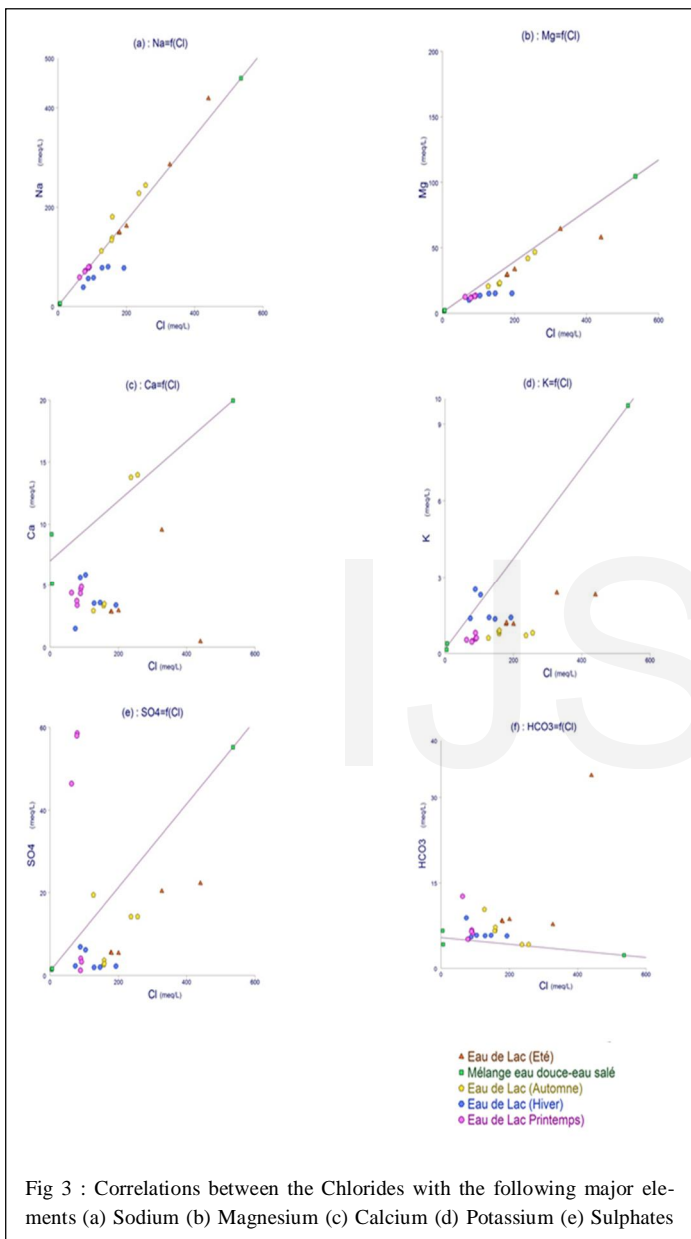


Fig 3 : Correlations between the Chlorides with the following major elements (a) Sodium (b) Magnesium (c) Calcium (d) Potassium (e) Sulphates

3.3 Hydro-chemical results

To better understand the process of mineralization of the lake waters, we have represented the major elements according to the chlorides. The latter is a conserved element which does not participate in rock water interactions. It characterizes the origin of the salinity of the waters and constitutes a tracer of mixture [34],[25].

Figure 3 shows the relation between the chlorides and the major elements (SO₄²⁻, Ca²⁺, Mg²⁺, Na⁺ and K⁺) of the six stations and the well water. The arrangement of the different

points with respect to the freshwater-salt water mixing line may be of great utility in identifying the other phenomena which are appended to the mixing process. The water taken from the various stations generally shows an enrichment of HCO₃⁻ and a depletion of Ca²⁺, Mg²⁺, Na⁺, K⁺ and SO₄²⁻.

The relationship between Na⁺ and Cl⁻ (Fig. 3a) shows that the representative points of the group V with a few representative points of group I and group III are on the mixing line indicating the presence of the freshwater-salt water mixing process without the reactions of ionic exchanges [35],[36]. The representative points of group IV are below the line of the mixture freshwater-salt water indicating sodium depletion [35],[36],[37],[38]. The Na⁺ deficit is explained by the phenomenon of reverse ion exchange between water and aquifer and resulting in Na⁺ adsorption and Ca²⁺ release [35],[36],[38],[39],[25],[32]. Some representative points of group III are above the line indicating sodium enrichment which can be explained by the first type of ion exchange [40],[39].

The correlation diagram between Mg²⁺ and Cl⁻ (Fig.3b) shows that the points are often below the freshwater-salt water mixing line. This could be explained by the depletion of Mg²⁺, by the phenomenon of water - rock interaction as dolomitization [35].

The diagram Ca²⁺ -Cl⁻ (Fig. 3c) shows that virtually all of the points lie below the line of soft-salt mixing except for two points in group III. Calcium depletion can be explained by the precipitation of calcium carbonates, which is due to evaporation and photosynthetic activity, since calcite is the first mineral that is beginning to precipitate [41] and enrichment is explained by cation exchange [40]. The reduction of sulphates facilitates, under anaerobic conditions, the formation of bicarbonates, which precipitates calcium carbonates and removes carbonates from the solution [42].

Figure SO₄²⁻ and Cl⁻ (Fig.3e) shows that the majority of points are below the freshwater-salt water mixing line with the exception of a few points, which could be explained by a reduction in Sulphates [42] and verifying the marine origin of waters [43].

The graph HCO₃⁻ and Cl⁻ (Fig.3f) shows that the majority of points are above the freshwater-salt water mixing line. This enrichment in bicarbonates is due to the reduction of sulphates [42], Bicarbonates, Calcium and Magnesium. They are controlled by the precipitation of calcite which is itself induced by photosynthesis [44].

The relationship between K⁺ and Cl⁻ (Fig. 3d) points out that the majority of points are below the mixing line except for a few points approximating this line showing that the most probable origin is rather marine [35],[25].

3.4 Geo-chemical modulation

To understand the geochemistry of sidi boughaba lake, a simulation using the PHREEQC code [45] was performed. This code makes it possible to calculate the mass balance of the aqueous solution of sidi Boughaba Lake. This simulation made it possible to calculate the saturation indices (SI) and to approach the speciation of the minerals. This made it possible to evaluate the saturation state of the water which controls the

TABLE 2
SATURATION INDICES OF THE VARIOUS MINERALS IN THE LAKE AND IN THE WATER TABLE.

Station	IS Calcite	IS Aragonite	IS Dolomite	IS Gypse	IS Anhydrite
S1 Moy	1,67	7,37	1,52	-7,52	-3,61
σ	0,28	0,15	0,29	0,15	0,77
S2 Moy	1,72	7,41	1,57	-7,55	-3,71
σ	0,20	0,14	0,20	0,14	0,53
S3 Moy	1,67	7,39	1,52	-7,54	-3,61
σ	0,17	0,13	0,17	0,13	0,53
S4 Moy	1,06	7,4	0,91	-7,55	-2,72
σ	0,57	0,31	0,58	0,32	1,62
S5 Moy	1,23	7,22	1,08	-7,37	-2,56
σ	0,47	0,25	0,47	0,25	1,12
S6 Moy	1,39	7,30	1,24	-7,45	-2,75
σ	0,38	0,16	0,38	0,16	0,91
Nappe phréatique	0,67	6,88	0,525	-7,025	-0,32
σ	0,48	0,34	0,49	0,35	0,68

σ : Standard deviation

chemistry and the state of equilibrium with the solid phases [46].

Generally, the water-rock equilibrium is reached when $IS = 0$. If $IS > 0$, water is supersaturated, precipitation of minerals is necessary to achieve equilibrium; if $IS < 0$, water is undersaturated, dissolution of minerals is necessary to achieve equilibrium [47], so these minerals control the chemistry of these waters.

The significant results of all lake water samples and that of the underlying water table (Table 2) show that the lake waters are saturated with calcite, dolomite and aragonite, unsaturated with respect to gypsum and anhydrite.

The calculation of the mineral saturation index in water indicates that only carbonate minerals tend to precipitate mainly as calcite, aragonite and dolomite.

4 Conclusion:

The waters of Sidi Boughaba Lake are characterized by a basic pH, and a strong variation of the mineralization which increases from the center towards the two extremes north and south especially during the summer. The conductivity is generally high oscillating between 12.40 and 17.41 mS/cm. The most heavily loaded areas are the northern and southern ends where the depth of the water table is low.

The projection of the results on the Piper Diagram showed that the lacustrine waters present a chloride-sodium facies, while the well waters present a mixed facies.

The use of correlation diagrams between chlorides and other major elements led us to suggest that high conductivity values and chlorides are probably due to the exposure to marine spray from its neighboring location to the sea and the repetition of a high number of evaporation cycles as well as oxidation-reduction and dissolution-precipitation reactions which modify the hydrochemistry of the waters. The most notable processes are sulfate reduction, Ca-Mg dissolution-precipitation and Na-Ca and Na-Mg basic exchange.

On the other hand, well water is characterized by a neutral pH, a low mineralization expressed by an electrical conductivity of the order of 1407 $\mu\text{S}/\text{cm}$, low chloride and sodium contents. This rejects the hypothesis of Salinization of lacustrine waters by a marine intrusion into the underlying water table supplying the lake.

This study shows that the waters of the lake are undersaturated with evaporite minerals (halite, gypsum and anhydrite) and supersaturated with carbonate minerals (calcite, aragonite and dolomite).

Acknowledgment

The authors wish to thank Mr M. TSOULI FAROUKH for the translation of this article, Mr M. KHAFU, for assistance to the field of informatics and Mr M. CHAKIT and Mr M. HANINE for assistance in the field of sampling.

References

- [1] Y. Kolodny, A. Katz, A. Starinsky, T. Moise, and E. Simon, "Chemical Tracing of Salinity Sources in Lake Kinneret (Sea of Galilee), Israel," *Limnol. Oceanogr.* vol. 44, no.4, pp. 1035-1044, June. 1999.
- [2] A. Nishri, M. Stiller, A. Rimmer, Y. Geifman, and M. Krom, "Lake Kinneret (The Sea of Galilee): The Effects of Diversion of External Salinity Sources and The Probable Chemical Composition of The Internal Salinity Sources," *Chem. Geol.*, vol. 158, no. 1-2, pp. 37-52, June. 1999.
- [3] A. Vengosh, "Salinization and Saline Environments," *Environmental geochemistry*, B. Sherwood Lollar, H.D. Holland and K.T. Turekian, Eds., Treatise in Geochemistry, Elsevier Science, pp. 333-365, 2003.
- [4] B.F. Jones, D.L. Naftz, R.J. Spencer and C.G. Oviatt, "Geochemical Evolution of Great Salt Lake, Utah, USA," *Aquatic Geochemistry*, vol.15, no.1, pp. 95-121, Febr. 2009.
- [5] A.L. Herczeg, S.S. Dogramaci and W.J. Leaney, "Origin of Dissolved Salts in A Large, Semi-arid Groundwater System: Murray Basin, Australia," *Mar. Freshwater Res.*, vol. 52, no.1, pp. 41-52, Jan. 2001.
- [6] D. Craw and S. Beckett, "Water and Sediment Chemistry of Sutton Salt Lake, East Otago, New Zealand," *New Zealand Journal of Marine and Freshwater Research*, vol. 38, no. 2, pp. 315-328, June. 2004.

- [7] N. Waldmann, A. Starinsky and M. Stein, "Primary Carbonates and Ca-Chloride Brines as Monitors of A Paleo-hydrological Regime in The Dead Sea Basin," *Quaternary Science Reviews*, vol. 26, no. 17-18, pp. 2219-2228, Sept. 2007.
- [8] A. Katz and A. Starinsky, "Geochemical History of The Dead Sea," *Aquatic Geochemistry*, vol. 15, no.1, pp. 159-194, Feb. 2009.
- [9] A. Vengosh, A.R. Chivas, A. Starinsky and Y. Kolodny, "Boron Isotope Geochemistry of Nonmarine Brines from The Qaidam Basin (China)," *Chem. Geol.*, vol. 120, no. 1-2, pp. 135-154, Feb. 1995.
- [10] N. Elkhiti, I. Soulié-Marsche, P. Gemayel, R.J. Flower and M. Ramdani, "Recent Environmental Changes at Sidi Bourhaba Lake (Morocco) Inferred from Fossil Charophyte Gyrogonites," *Cryptogamie Algol.*, vol. 25, no. 2, pp. 175-188, Apr. 2004.
- [11] M.A. El Agbani, M. Dakki, M. Thevenot et P.C. Beaubrun, "Statut Actuel au Maroc d'une Espèce Globalement Menacée, la Sarcelle Marbrée (*Mararonetta angustirostris*)," *Bull. Inst. Sci.*, Rabat, no. 20, pp. 163-180, 1996.
- [12] M. Dakki et M.A. El Agbani, "Diversité, Fonctions et Valeurs des Zones Humides du Maroc," *Actes du Séminaire sur les Zones Humides, Administration des Eaux et Forêts et de la Conservation des Sols-MedWet, Kénitra-Maroc*, pp. 12-14, 1997.
- [13] A. Harch-rass, K. EL Kharrim et D. Belghyti, "Etude Ornithologique et Evaluation de l'Importance du Site Ramsar Sidi Boughaba entre 2005 et 2010 (Maroc)," *ScienceLib Editions Mersenne*, vol. 4, no. 120114, pp. 1-22, Janv. 2012.
- [14] M. Ramdani, N. El Khiati and Flower RI, With contributions from M.M. Kraiem, A.A. Fathi, H.H. Birks and S.T. Patrick, "Open Water Zooplankton Communities in North Africari Wetland Lakes: The Cassarina Project," *Aquatic Ecology*, vol. 35, no. 3, pp. 319-333, Apr. 2001.
- [15] M. Ramdani, R.I. Flower, N. El Khiati, H.H. Birks, M.M. Kraiem and A.A. Fathi, "Zooplankton (Cladocera-Ostracoda) Chironomidae and Other Benthic Faunal Remains in Sediment Cores from Nine Wetland Lakes: The Cassarina Project," *Aquatic Ecology*, vol. 35, no. 3, pp. 389-403, Oct. 2001.
- [16] R. El Hamoumi, M. Dakki et M. Thévenot, "Etude Ecologique des Larves d'Anoures du Maroc," *Bulletin de l'Institut Scientifique, Rabat, Section Sciences de la Vie*, no. 29, pp. 27-34, 2007.
- [17] L. Zouhri, C. Gorini, B. Deffontaines and J. Mania, "Relationships Between Hydraulic Conductivity Distribution and Synsedimentary Faults, Rharb-Mamora Basin, Morocco, Hydrogeological, Geostatistical and Modeling Approaches," *Hydrogeol. J.*, vol. 12, no. 5, pp. 591-600, Oct. 2004.
- [18] B. Ben Kabbour and L. Zouhri, "Hydrochemical and Bacteriological Features of The Groundwater: Southern Border of The Rharb Basin (Morocco)," *Hydrological Sciences Journal*, vol. 50, no. 6, pp. 1137-1149, Decem. 2005.
- [19] I. Kherrati, A. Alemad, B. Joti, I. Abdelsalam, M. Ramzi, S. Aboubaker Alzwi, H. Chiguer, K. El kharrim, B. Kherrati et D. Belghyti, "Qualité des Eaux Potables de la Nappe Phréatique Maâmora, Gharb-Kénitra, Maroc," *ScienceLib Editions Mersenne*, vol. 6, no. 141203, pp. 1-17, Decem. 2014.
- [20] D. Belghyti, H. Daifi, A. Alemad, K. Elkharrim, M. Elmarkhi, Y. Souidi, F. Benelharkati, B. Joti, Z. Elmoukrifi, A. Ibeda, Y. Azami-Idrissi, S. Baroud, F. Elkhayyat, O. Elrhaouat, S. Sadeq, Y. Taboz, H. Sbai, R. Naser, H. Chigger et N. Derwich, "Groundwater Management for Sustainable Production of Drinking Water Quality in Maâmora," *WIT Transactions on Ecology and The Environment*, vol. 178, pp. 241-252, 2014.
- [21] L. Zouhri, E. Toto, E. Carlier et T. H. Debieche, "Salinité des Ressources en Eau: Intrusion Marine et Interaction Eaux-Roches (Maroc Occidental)," *Journal des Sciences Hydrologiques*, vol. 55, no. 8, pp. 1337-1347, Novem. 2010.
- [22] M. Lachhab, K. El Kharrim, A. EL Abidi, R. Ben Akkame et D. Belghyti, "Etude Physico-chimique des Eaux du Lac Sidi Boughaba - Site Ramsar - Kénitra Maroc," *ScienceLib Editions Mersenne*, vol. 5, no. 131216, pp. 1-13, Decem. 2013.
- [23] A. Harch-Rass, K. El Kharrim et D. Belghyti, "Analyses Physico-chimiques des Eaux du Site Ramsar Sidi Boughaba (Maroc)," *ScienceLib Editions Mersenne*, vol. 4, no. 120607, Juin. 2012.
- [24] J. Rodier, "L'Analyse de l'Eau : Eaux Naturelles, Eaux Résiduelles et Eaux de Mer," 7ème Ed., Dunod, pp. 3-10, 2009.
- [25] Fadili A., K. Mehdi, J. Riss, S. Najib, A. Makan and K. Boutayab, "Evaluation of Groundwater Mineralization Processes and Seawater Intrusion Extension in The Coastal Aquifer of Oualidia, Morocco: Hydrochemical and Geophysical Approach," *Arabian Journal of Geosciences*, vol. 8, no. 10, pp. 8567-8582, Oct. 2015.
- [26] M.F. Ben Hamouda, J. Tarhouni, C. Leduc and K. Zouari, "Understanding The Origin of Salinization of The Plio-quaternary Eastern Coastal Aquifer of Cap Bon (Tunisia) Using Geochemical and Isotope Investigations," *Environ Earth Sci*, vol. 63, no. 5, pp. 889-901, July. 2011.
- [27] A. Taheri Tizro and K. S. Voudouris, "Groundwater Quality in The Semi-arid Region of The Chahardouly Basin, West Iran," *Hydrol. Processes*, vol. 22, no. 16, pp. 3066-3078, July. 2008.
- [28] M. Reille, "Analyse Pollinique du Lac de Sidi Bou Rhaba, Littoral Atlantique (Maroc)," *Ecologia Mediterranea*, no. 4, pp. 61-65, 1979.
- [29] M. Batchi, J. Al Karkouri, M. El Maaqli, et I. Fenijiro, "Cartographie de la Vulnérabilité à l'Intrusion Marine de l'Aquifère Côtier de Mnsra (Littoral du Gharb, Maroc-Nord-Occidental)," *Marine Scor Journal*, vol. 1, pp. 54-69, 2014.
- [30] A. A. Shahsavari, K. Khodaei, F. Asadian, M. Nakhaei, A. Sardar, A. Moradi, R. Hatefi and S.M. Zamanzadeh, "Determination of Origin and Distribution of Saline Water in The Aquifer of Kharg Island, Iran," *Arab J Geosci.*, vol. 8, no. 5, pp. 3129-3137, May. 2015.
- [31] S. Najib, A. Fadili, K. Mehdi et J. Riss, "Etude de l'Evolution de l'Intrusion Marine dans l'Aquifère de la Chaouia Côtère," *J-SAWIS*, vol. 2015, no. 1, pp. 5-12, Decem. 2015.
- [32] S. Najib, A. Fadili, K. Mehdi, J. Riss, A. Makan, H. Guessir, "Salinization Process and Coastal Groundwater Quality in Chaouia, Morocco," *Journal of African Earth Sciences*, vol. 115, pp. 17-31, Mar. 2016.
- [33] R. Simler, "Logiciel d'Hydrochimie Multilingue en Distribution Libre, Version 2," *Laboratoire d'Hydrogéologie, Université d'Avignon, Avignon*, juin. 2004.
- [34] A. Saou, M. Maza and J.L. Seidel, "Hydrogeochemical Processes Associated With Double Salinisation of Water in an Algerian Aquifer, Carbonated and Evaporitic," *Pol. J. Environ. Stud.*, vol. 21, no. 4, pp. 1013-1024, 2012.
- [35] L. Kouzana, A. Ben Mammou, N. Gaaloul, "Intrusion Marine et Salinisation des Eaux d'une Nappe Côtère (Korba, Cap-Bon. Tunisie)," *Geo-Eco-Trop*, vol. 31, no. 1-2, pp. 57-70, 2007.
- [36] L. Kouzana, A. Ben Mammou et M. Sfar Felfoul, "Seawater Intrusion and Associated Processes: Case of The Korba Aquifer (Cap-Bon, Tunisia)," *C. R. Geosci.*, vol. 341, no. 1, pp. 21-35, January. 2009.
- [37] C. Fehdi, A. Rouabhia, F. Baali, A. Boudoukha, "The Hydrogeochemical Characterization of Morsott-El Aouinet Aquifer, Northeastern Algeria," *Environ Geol*, vol. 58, no. 7, pp. 1611-1620, Oct. 2009.
- [38] C. Fehdi, A. Boudoukha, A. Rouabhia et E. Salameh, "Caractérisation Hydrogéochimique des Eaux Souterraines du Complexe Aquifère Morsott-Laouinet, Région Nord de Tébessa, Sud-Est algérien," *Afrique Science*, vol. 5, no. 2, pp. 217-231, Mai. 2009.
- [39] I. Farid, K. Zouari, A. Kallali, "Origine de la Salinité des Eaux du Bassin Chougafiya (Tunisie)," *Water. Sci. J.*, vol. 25, no. 3, pp. 255-274, 2012.
- [40] K. Dindane, L. Bouchaou, Y. Hsissou et S. Boutaleb, "Caractérisation Chimique et Origine des Eaux de la Nappe Libre du Souss Amont (Bassin du Souss-Massa, Maroc)," *Africa Geoscience Review*, vol. 14, no. 3, pp. 329-335, 2007.
- [41] L.A. Hardie and H.P. Eugster, "The Evolution of Closed Basin Brines," *Mineralogical Society of America Special Publication*, vol. 3, pp. 273-290, Feb. 1970.
- [42] A. Vengosh et E. Rosenthal, "Saline Groundwater in Israel: its Bearing on The Water Crisis in The Country," *Journal of Hydrology (Amsterdam)*, vol. 156, no. 1-4, pp. 389-430, Apr. 1994.
- [43] R. Trabelsi, M. Zairi, H. Smida et H. Ben Dhia, "Salinisation des Nappes

Côtières : Cas de la Nappe Nord du Sahel de Sfax, Tunisie." C. R. Acad. Sci. Paris, vol. 337, no. 5, pp. 515-524, Apr. 2005.

- [44] Ph. Négrel, J. Barbier et E. Petelet-Giraud,"Caractérisation Géochimique et Isotopique des Relations Eaux de Surface-Eaux Souterraines de la Zone Humide de la Loire," Rapport BRGM/RP50668-FR, Jan. 2001.
- [45] D.L. Parkhurst, C.A.J. Appelo,"User's Guide to Phreeqc Version 2: A Computer Program for Speciation, Batch-reaction, One Dimensional Transport and Inverse Geochemical Calculations,"USGS Water-Resources Investigations Report 99-4259, Denver, Colorado, USGS, 1999.
- [46] N. Brinis, A. Boudoukha, L. Djabri et J. Mania,"La Salinité Des Eaux Souterraines de la Zone Est de la Plaine d'El Outaya. Région de Biskra, Algérie," Bul. Serv.Géol. Algérie, vol. 20, no. 1, pp. 49-61, 2009.
- [47] S.M. Yidana, D. Ophori, B. A. Banoeng-Yakubo,"A Multivariate Statistical Analysis of Surface Water Chemistry Data-The Ankobra Basin, Ghana," J. Environ. Manage, vol. 86, no. 1, pp. 80-87, Jan. 2008.

IJSER