Intelligent Human Systems Integration (IHSI 2024), Vol. 119, 2024, 314–323
https://doi.org/10.54941/ahfe1004495

Statistical Assessment of Physico-Chemical Pollution of Sebou River in Mechraa Bel Ksiri, Morocco

Fariri Khalid[1], Hraira Thami[1], Ettaki Jalal[1], Doumi Khalid[1], Maaroufi Manal[1], Ztit Ghizlane[2], El Kharrim Khadija[1], and Belghyti Driss[1]

[1]Laboratory of Natural Resources and Sustainable Development, University Ibn Tofail, Faculty of Sciences, Kenitra, PB133, Morocco.
[2]Superior Normal School, Rabat, PB5118, Morocco

ABSTRACT

Pollution of groundwater and surfaces is a major problem around the world. In Morocco due to population growth, industrial, agricultural and climate change the country is currently experiencing water stress and is expected to experience a water shortage in 2025 (less than 500 m^3/ inhabitant / year). In addition, according to the WHO, around 30,000 people per day, approximately 10 million per year, die due to insufficient or poor quality water supply and deplorable hygienic conditions (WHO, 1977). The Sebou river is located in the western region of Morocco, which is a very important agricultural area and therefore experiences high pollution. The purpose of this study is to carry out an updated forecast on its pollution by Urban, Agricultural and Industrial activities. To achieve this objective, several series of samples of the Sebou waters and physicochemical analyzes were carried out (pH, Ca++, Na+, Mg++, Cl-, SO_4--, NO_3-,...). To verify the hypothesis of pollution of the Sebou river by domestic and industrial wastewaters and by its tributaries, we compared its physico-chemistry with those of Moroccan standards and of the two main rivers in the region, namely the Beht river and the Ouergha river. The results show that Sebou is very loaded with salts (10581 μs / cm; 11g / L). On the other hand, the waters of Beht are less polluted by nitrates (14.34 mg / L) and sulphates (51.51 mg / L) but more loaded with Potassium (55.87 mg / L) and Magnesium (107.62 mg / L). Finally, the waters of Oued Ouergha are even cleaner than other rivers.

Keywords: River, Sebou, Drinking, Irrigation, Water, Pollution, Mechraa Bel Ksiri, Kenitra, Morocco

INTRODUCTION

Physical, chemical, and biological characteristics characterize water quality, but so does its use. Thus, unfit for human consumption water can be repurposed for irrigation, fish farming, or cooling industrial circuits (Boutin and Dias, 1987; Abouzid and Outair, 1991; Benyakhlef, et al. 2011). For local decision-makers to adopt a fair policy that takes into account the importance of this resource and the difficulty of growing water resources, the sensible

management of water resources in the Kenitra Gharb region has emerged as the primary concern.

The Oued Sebou (Sebou River) and its tributaries provide 34,000km^2 of drainage. It began as Oued Guigou and stretches over 600km, starting in the Middle Atlas.

Its 35km-long estuary empties into the Atlantic Ocean in Mehdia, Kenitra. The guard dam, which is situated directly downstream of Sidi Allal Tazi, stops the rise of marine waters. (ORMVAG, 1994).

Furthermore, a multitude of pollutant discharges from diverse sources occur in the Sebou river. The Sebou watershed is among the most impacted places in Morocco and is a highly significant area from a socioeconomic perspective. The primary reasons for the decline in the quality of Sebou waters are the presence of two of the nation's principal agricultural plains (The Gharb Plain and the Sais Plain), as well as the quantity and variety of industrial facilities and urban wastewater effluents in the basin's major cities (Fez, Meknes, Mechraa Bel Ksiri, Dar Gueddari, and Kenitra), not to mention the careless disposal of household waste.

The aim of this study is to investigate the physic-chemical surface water of the Lower Sebou sub-basin, which is located between Kenitra and Mechraa Bel Ksiri. Monitoring the pH, electrical conductivity (EC), ammonium, sodium, potassium, magnesium, calcium, bicarbonate, chloride, sulphate and nitrates are the methods used to characterize the amounts and concentrations of the organic and mineral loads of Sebou raw water.

MATERIALS AND METHODS

Study Area

The Gharb region, delineated by the pre-Rif hills to the north, the Maâmora plateau to the south, and the Atlantic Ocean to the west (see Figure 1), encompasses a diverse geographical composition. This includes the central alluvial plain of the lower Sebou, the primary Oued (river), continental boundaries, and a coastal zone characterized by dune cordons, flooded depressions, and internal dunes. The Sebou Basin, situated between the Fez-Taza corridor in the east, the Atlantic Ocean in the west, the Rif in the north, and the Middle Atlas and the Meseta in the south, spans an approximate area of 38380 km^2. As the most significant basin in the country, it is home to approximately 5.73 million inhabitants, with a slight majority (51%) residing in rural areas and the remainder (49%) in urban locales. The region's economy, primarily driven by industrial and agricultural sectors, plays a substantial role in bolstering the country's economy (see Figure 2).

The entire basin is characterized by a Mediterranean climate, influenced by oceanic elements, although the climate within the basin progressively assumes a more continental nature. Industrial activity within the Sebou basin is notably advanced, with large-scale units such as the textile sector, cement plants, oil refineries, tanneries, sugar, paper, and oil mills contributing significantly to the basin's economy.

The procedure of water sample extraction is a delicate process that requires meticulous care due to its impact on the interpretation and analytical results. For a sample to be deemed representative, it should ideally be homogeneous and should not alter the physicochemical properties of the water, including dissolved gases and suspended particles (Rodier, 1996).

Sampling equipment necessitates specific attention. The nature of the intended analyses dictates the cleaning procedures for the flasks. Instant sampling is the most commonly employed technique for sample collection. The vials are filled without agitating the water and, in some instances, without exposure to air (ONEP, 1998; Belghyti et al., 2013).

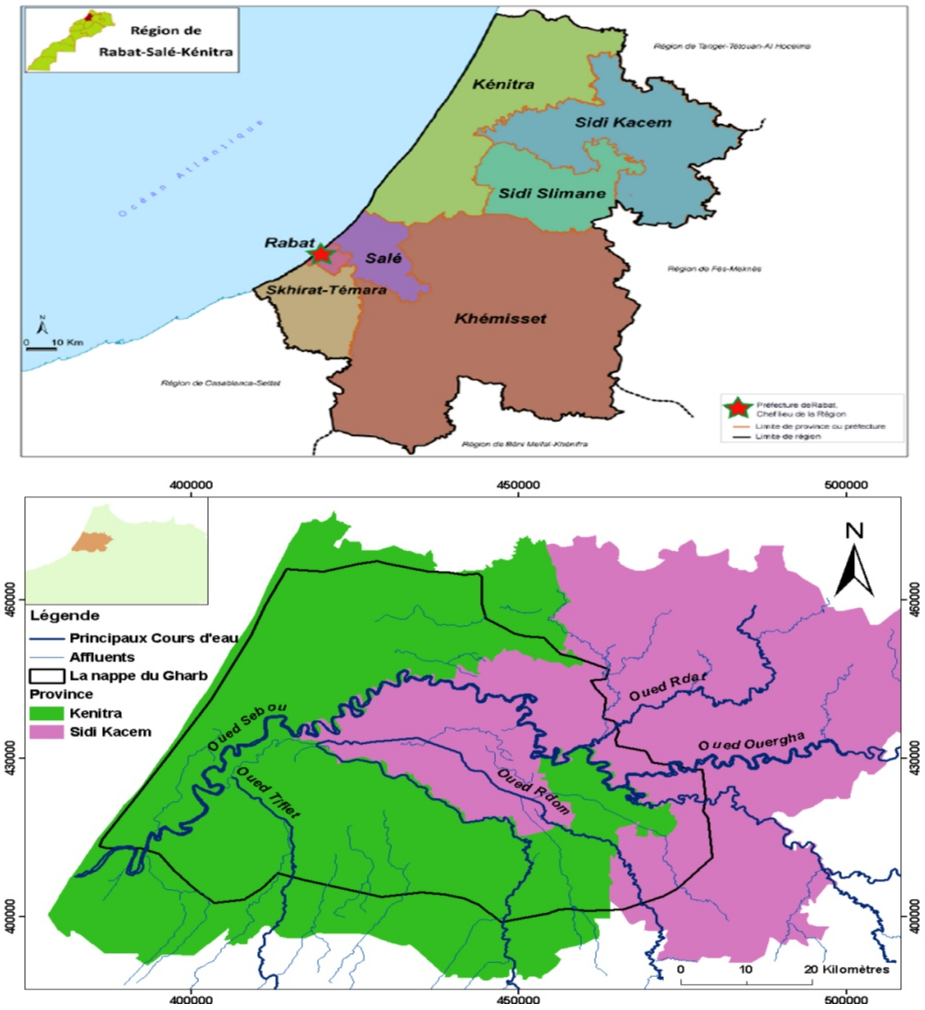

Figure 1: Localization of sebou river and gharb basin.

Figure 2: Sebou river and sampling area.

Study Method

Sampling Waters

Initially, polyethylene bottles with a capacity of 1000 ml were cleansed using distilled water, subsequently filled with water samples from the field. Sampling was conducted in areas with both flowing and non-stagnant water. To minimize contamination and prevent changes in the sample, a total immersion technique was employed, ensuring the bottles were filled to the brim, devoid of air bubbles. The collected water samples were transported to the laboratory in portable coolers, maintaining a low temperature of 4°C for analysis. Moreover, for consistency, samples were gathered from the same station, approximately at the same time and location, throughout the campaigns.

The present study conducted an examination of the following parameters: pH, electrical conductivity (EC), calcium (Ca^{++}), magnesium (Mg^{++}), sodium (Na^{+}), potassium (K^{+}), carbonate (CO_3^{--}), bicarbonate (HCO_3^{-}), chlorides (Cl^{-}), sulphates (SO_4^{--}), ammonium (NH_4^{+}), and nitrate (NO_3^{-}). The instruments utilized for these assays included a C831, a Jenway flame photometer, a NOVASPEC II pharmacy-grade spectrophotometer, and a UV-Visible spectrophotometer (Benkabbour, 2002; Bentouati and Bouzidi, 2011; Martini et al. 2012; El Hammoumi and Belghyti, 2012).

- The determination of carbonates and bicarbonates is achieved by utilizing a 0.02N sulfuric acid solution, with phenophthalein and bromocresol green serving as color indicators.
- The quantification of combined chloride in its chloride state is facilitated by the use of silver nitrate in the presence of a potassium chromate solution.
- The concentrations of calcium and magnesium are ascertained through complexometric titration with EDTA, using Eriochrome black T as an indicator.
- The determination of nitrates and ammonium ions is carried out via distillation, employing magnesium oxide and DEVARDA alloy as catalysts, respectively.
- The measurement of sulfates is conducted through colorimetry, precipitating sulfate ions as barium sulfate in a hydrochloric acid medium using barium chloride. Following the collection of NH_4^{+} and NO_3^{-} ions in a boric acid solution, H_2SO_4 is utilized in the subsequent analysis.

RESULTS AND DISCUSSION

Several physicochemical parameters were assessed to gauge the level of pollution in the raw water of the lower Sebou. This evaluation, conducted during our internship at the Regional Office of Implementation Agricultural Value of Kenitra, serves to enhance the foundational data collected on the Sebou basin and provides a clearer understanding of its pollution levels.

Tables 1 and 2 suggest that the lower Sebou River subbasin is susceptible to various types of pollution. The primary sources of this pollution are natural, predominantly mineral-based (stemming from the dissolution of the natural substrate and Atlantic tides), and anthropogenic, which includes agricultural, industrial, and urban pollutants.

The thermal regime of the Sebou hydrographic network mirrors the Mediterranean's, with lower temperatures in November and higher temperatures in June. The water, after traversing the basin's defining limestone and marl-limestone soils, possesses an alkaline pH that oscillates between 8.1 and 8.78, as indicated in Tables 2, with no significant variations (see Table 3).

Tables 1, 2, and 3 illustrate that mineralization is directly proportional to levels of salinity, chloride, dissolved salt, sodium, and potassium. The primary causes of this mineralization are the leaching of karstic limestone, the presence of kelp-like terrain, and the impact of ocean spray. According to AH (1996), Hilali (2002), and Akhiar (2009), the electrical conductivity (EC), a

measure of salinity, ranges from 628μs/cm to 22761μs/cm (see Table 1). This range significantly exceeds Morocco's standard for irrigation water, which is greater than 2700μs/cm.

Table 1. Cations and other physical-chemical information on the lower Sebou's raw waters.

Stations	Ca^{2}+ mg/L	Mg^{2}+ mg/L	K^{+} mg/L	Na^{+} mg/L	NH_4^{+} mg/L	TH mg/L	CE μS/cm
S1	97,7	89,05	6,45	1241	0,19	6,16	1191
S2	119	46,57	6,25	1271	0,44	4,88	1121
S3	126,5	59,53	2,55	1561	0,05	5,73	1241
S4	166,5	17,77	5,28	1361	0,69	4,8	1161
S5	150,9	44,5	4,30	1821	0,23	5,63	1431
S6	169,3	68,65	9,57	1331	0,19	7,08	1401
S7	148,5	51,37	4,69	1471	0,69	5,86	1491
S8	220,5	111,7	12,49	1841	0,6	10,17	2371
S9	217,7	17,29	3,72	52	0,69	6,17	628
S10	914,5	631,3	5,08	141	1,77	49,17	15821
S11	148,5	26,65	6,64	191	15,35	4,83	11961
S12	314,9	39,37	17,56	391	0,55	9,52	22761
S13	170,9	124,09	9,76	2540	2,67	9,45	2201
S14	1072,9	74,89	15,98	151	1,27	57,95	16701
S15	144,9	94,09	7,42	401	1,28	7,55	1661
S16	175	99,37	2,74	121	1,52	8,48	881

Table 2. Anions and other physical-chemical information on the lower Sebou's raw waters.

Stations	pH	NO_3^{-} mg/L	CL^{-} mg/L	SO_4^{2-} mg/L	HCO_3^{-} mg/L	CO_3^{2-} mg/L
S1	8,63	9,4	214	314,65	233,03	13
S2	8,66	10,43	161,89	159,19	214,73	19
S3	8,38	0,25	202,36	150,26	213,6	5
S4	8,47	17,12	154,79	141,19	275,73	0
S5	8,1	63,37	243,54	181,95	246,45	0
S6	8,13	20,59	202,36	151,63	362,35	0
S7	8,68	86,93	248,6	183,58	241,57	21,5
S8	8,34	188,7	385,54	258,33	323,4	13,3
S9	8,48	827,8	230,5	106,8	75,65	0
S10	8,25	2693	860,28	113,2	123	0
S11	8,5	260,9	269,08	37,63	100,05	0
S12	8,32	886,8	476,42	276,58	84,19	0
SD13	8,78	94,7	461,32	359,28	246,45	49,3
SD14	8,22	162,3	397,8	441,5	178,13	43
SD15	8,74	59,8	304,58	248,6	241,57	19
SD16	8,34	693,7	145,56	54,05	108,59	0

CONCLUSION

There is a paucity of hydraulic and hydrological studies pertaining to Moroccan rivers. The current study proposes a characterization of the physico-chemical properties of surface water in the lower Sebou subbasin of Kenitra. The raw waters of the Sebou were subjected to physico-chemical analysis,

revealing a high concentration of organic and mineral materials. The chemical composition exhibited significant variability, with electrical conductivity (EC) ranging from a minimum of 628μS/cm to a maximum of 2371μS/cm. The pH values averaged between 8,10 and 8.78, indicating a slightly basic nature, yet remaining suitable for irrigation purposes.

In terms of surface water quality, the water was classified as poor quality in 35% of cases and medium grade in 65% of cases. The concentration of ammonium varied between 0.05mg/L and 2.67mg/L. Nitrate (NO_3^-) concentrations spanned from a minimum of 0.25mg/L to a maximum of 886.80mg/L. Furthermore, the concentration of chloride ions (Cl^-) was found to range from 145.56mg/L at its lowest to 476.42mg/L at its highest.

Table 3. Physico-chemical characteristics of the waters of Sebou river.

Stations	T°C	pH	CE μs/cm	COD mg/L	NTU	Cl^- mg/L	Salinity g/L	TH °F	TAC
Sebou 1	13	------	----------	197,3	7,215	-------	4,98	--------	18,8
Sebou 2	16	7,65	2489	112,58	15,595	1140	2,68	73,45	14,51
Sebou 3	18	7,38	12570,71	195,2	6,62	5315	8,53	245,82	11,95
Sebou 4	18,5	7,615	3263,1	181,77	4,71	1430	2,37	88,3	14,83
Sebou 5	22	7,33	10434,17	185,62	7,46	4145	5,26	186,5	18,06
Sebou 6	25,5	7,2	11950	254,55	6,48	3965	8,96	235,75	19,14
Sebou 7	27	7,37	20171,43	363,64	15,38	6900	17,42	324,93	25,55
Sebou 8	27	7,075	1401,11	211,27	12,7	560	10,88	48,33	14,73
Sebou 9	27	7,36	15652,7	102,11	17,76	5760	8,48	218,55	12,29
Sebou10	27	7,46	12898,57	--------	--------	4920	---------	200,57	39
Sebou11	12	------	----------	9,6	3,89	-------	0,93	--------	25
Sebou12	13	8,05	7380	9,6	4,27	2800	0,74	284	15
Sebou13	15	7,92	29600	19,2	4,67	12780	1,75	536	22,5
Sebou14	15	7,89	16900	9,6	2,17	7740	0,58	328	25
Sebou15	20	7,79	17600	9,6	4,08	7040	1,4	304	39
Sebou16	22	7,45	21400	28,8	3,79	6810	1,99	380	30
Sebou17	23	7,95	26300	19,2	7	9940	10,06	490	25
Sebou18	24	7,5	2490	38,4	8,45	1140	5,85	75	15
Sebou19	26	8,03	26800	19,2	8,2	10720	2,11	376	13
Sebou20	25	7,94	24000	--------	--------	9790	-------	334	9
Sebou21	14	------	----------	691,2	15	-------	13,45	--------	10
Sebou22	19	6,55	1150	278,4	66	420	4,6	40	9
Sebou23	19	6,98	2000	576	22,5	890	21,06	60	12
Sebou24	22	7,07	797	604,8	6,1	350	7,27	48	10
Sebou25	24	7,06	2900	499,2	16	1060	11,7	72	20
Sebou26	28	6,93	2500	662,4	16,2	1210	13,33	84	9
Sebou27	31	7,05	5220	940,8	28,3	2130	121,17	125	11
Sebou28	30	4,42	1100	624	26,4	350	18,37	35	----------

The concentrations of sulfate ions (SO_4^{2-}) in the water range from a maximum of 359.28mg/l to a minimum of 37.63mg/l. The bicarbonate ion concentrations adhere to the irrigation standard, with values ranging from a maximum of 362.35mg/l to a minimum of 75.65mg/l. The calcium ion (Ca^{2+}) content varies between 220.5mg/L and 97.7mg/L. The magnesium ion (Mg^{2+}) concentrations comply with the irrigation standard, with a maximum value of 124.09mg/L and a minimum value of 17.29mg/L. Sodium ion (Na^+) concentrations in the water range from 2540mg/L to 52mg/L, while potassium ion (K^+) concentrations in surface waters vary from 17.56mg/L to 2.55mg/L.

This study's findings indicate that despite the high mineral load, the waters of the lower Sebou remain within the Moroccan irrigation standards. However, the waters of the Sebou are heavily polluted. Therefore, it is recommended to properly treat all residential and commercial wastewater to mitigate its adverse effects on the local ecosystem and compensate for the loss of this valuable water resource.

The waters of the Lower Sebou sub-basin contain significant concentrations of nitrates and sulfates, which are introduced into the water stream through runoff and leaching of nitrogenous and phosphorus fertilizers and phytosanitary products due to nearby agricultural activities (Nisbet and Verneaux, 1970; Laferriere et al. 1996; ONEP, 1999). The distribution of physicochemical characteristics upstream and downstream suggests a decrease in salt and chloride levels in the water due to the influx of marine saline waters.

While this study has highlighted the poor quality of the waters in the lower Sebou, it is not comprehensive. Further investigation is needed, including analyses of pesticides and trace heavy metals, to provide decision-makers with the necessary scientific and technological basis (OMS, 1986; MATUHE, 2001; ABH, 2011).

ACKNOWLEDGMENT

The authors acknowledge all people from ORMVAG who have aided in accomplishing the analysis.

REFERENCES

A. B. H. S. (2011): Etude d'actualisation du plan directeur d'aménagement integer des resources en eau du basin hydraulique du Sebou. Note de synthèse, Septembre 2011, Agence du Bassin Hydraulique du Sebou, Fès, Maroc.

Abouzid, H. et Outair, A. (1991): Les Nitrates dans les eaux, 7ème Congrès Mondial des ressources en eau, Rabat, Maroc, 13–18 Mai 1991, Volume 2.

Administration Hydraulique (AH) (1996): Etat de la qualité des ressources en eaux dans le bassin du Sebou, année 1989-1990, Ministère des Travaux Public, de la Formation Professionnelle et de la Formation des Cadres.

Akhiar, S. 2009 : "Caractérisation des eaux souterraines de la ville de Mechraa Bel Ksiri". Mémoire Master Eaux usées. Université Ibn Tofail, Kénitra.

Alemad, A., Nagi, M., Ibeda, A., Nasser, R., Alwathaf, Y., Elrhaouat, O., Elkharrim, K., Babaqi, A., Belghyti, D. (2013): The impact of sana'a solid waste on the quality of groundwater in Yemen, 2nd Intemational Conference on Water and Society, 4 - 6 September 2013, New Forest, UK, Paper DOI: 10, 2495/WS130151.

Belghyti, D., Daifi, H., Alemad, A., Elkharrim, K., Elmarkhi, M., Souidi, Y., Benelharkati, F., Joti, B., Elmoukrifi, Z., Ibeda, A., Azami-Idrissi, Y., Baroud, S., Elkhayyat, F., Elrhaouat, O., Sadeq, S., Taboz, Y., Sbai, H., Naser, R., Chigger, H., Derwich, N., 2013: *Groundwater management for sustainable production of drinking water quality in Maamora, 2nd International Conference on Water and Society, 4 - 6 September 2013,* New Forest, UK, 2013, Vol 178, pp. 242–254, doi:10.2495 / WS130201, 2013.

Benkabbour, B. : ≪ Exploration, évaluation et protection des ressources hydriques en zones côtiers Marocaines : Approche Géophysique, Hydro chimiques, modélisation et S. I. G : Cas de la Maàmora occidentale (Bassin du Rharb-Maàmora) ≫. Thèse de Doctoral National, (2002), Université Ibn Tofail.

Bentouati, L. et Bouzidi, A. : étude de la qualité des eaux souterraines de la wilaya de Sétif, algésaire, (2011). Journal Scienceslip.

Benyakhlef, M., Naji, S., Belghyti, D., Elguamri, Y. et Hassouni, T. : Qualité de l'eau de boisson dans la région du Gharb (Kénitra, Maroc) (2011).

Boutin, C., Dias, N. : ≪Impact de l'épandage des eaux usées de la ville de Marrakech sur la nappe phréatique≫, Bull. Fac. Sci. Marrakech (Sect. Sci. Vie), 3 (1987). pp. 5–25.

Coyne, M. S. and Howell, J. M. : ≪ Agricultural Impacts on Fecal Contamination of Shallow Groundwaters in the Bluegrass Region of Kentucky≫, Soil Science News and Views, 15 (6) (1994), pp. 1–3.

El Bouqdaoui, K., Aachib, M., Blaghen, M., et Kholtei, S. : Modélisation de la pollution par les nitrates de la nappe de Berrechid, au Maroc, (2009).

El Hammoumi, T.et Belghyti D., 2012 : Caractérisation physicochimique des eaux potables Produit Par la station de traitement de Mkansa (Maroc, 2012).

Hilali, M. 2002 : Hydrogéologie et modélisation de l'intrusion marine dans les aquifères côtiers de Martile et de sahel- Maroc". Thèse de Doctorat en Sciences Appliquées. Université. Mohammed V-Agdal, Ecole Mohammedia d'ingénieurs, 158p.

Krira Chakour, A. B. et Fouta, H. : ≪ Intensification de l'agriculture et son impact sur l'environnement. Cas des nitrates dans la nappe phréatique de M'nasra du Ghab≫, Actes 1er Colloq. Sur le Développement agric. Rech. Agron. Au niveau de la région du Ghab, (2001).

Laferriere. M, Minville, J. J., Lavoie J., et Payment, P. : ≪ L'industrie porcine et les risques reliés à la santé humaine ≫, Bull. Information Santé Environnem, Québec, 7 (2) (1996) 1–4.

Matini, L., Moutou, J. M. et Kongo-Mantono, M. S. : Evaluation hydro-chimique des eaux souterraines en milieu urbain au Sud-Ouest de Brazzaville, Congo, (2012).

Matuhe, 2001 : Rapport sur l'Etat de l'Environnement du Maroc (REEM), Ministère de l'Aménagement du Territoire, de l'Eau et de l'Environnement, Département de l'Environnement, Observatoire National de l'Environnement du Maroc (ONEM), Octobre, Ed, 2 (2001) 296.

MPCI, 2005, Impact environnemental de l'usage des eaux usées d'assainissement dans l'irrigation des agricultures, ministère de la planification et de la coopération internationale, juillet 2005. **Nisbet,** M. et Verneaux J., 1970: Composantes chimiques des eaux courantes : discussion et proposition de classes en tant que bases d'interprétation des analyses chimiques, Annal Limnol, 6, 2. **O. N. E. P** 1998: Méthodologie d'analyse de l'eau au laboratoire. Mode opératoire: Contrôle de la pollution des eaux destinées à l'alimentation en eau potable. (1998).

O. N. E. P, Alimentation en eau potable, Menaces de pollution. (1999).

Organisation Mondiale de la Santé (O. M. S.), ≪ Charte d'Ottawa pour la promotion de la santé≫, Copenhagen : Bureau régional de l'Europe, (1986).

ORMVAG, Office Régional de mise en Valeur Agricole Gharb Maroc : Etude pédologique au 1/20 000 de la Troisième Tranche d'Irrigation (TTI) sur une superficie de 100.000 ha. Zone M'nasra, Z1-Z2. Kénitra, Maroc, Rapport inédit, (1994), 180 p.

Rodier, J.1996: ≪ L'analyse de l'eau: eaux naturelles, eaux résiduaires, eau de mer: physico-chimie, bactériologie et biologie ≫, Ed. Dunod, Paris, France, 8 (1996) 1383p.

Saadi, Z, Maaslouhi, A. Zeraouli, M. et Gaudet, J. P : ≪ Analyse et modélisation des variations saisonnières des concentrations en nitrates dans les eaux souterraines de la nappe Mnasra, Maroc ≫, C. R. Acad. Sci., Sér. 2, Sci. Terre Planètes, 329 (8) (1999), pp. 579–586.

Secrétariat d'Etat chargé de l'Environnement, ≪ Etude pour programme d'action visant à minimiser et à contrôler l'impact des engrais et des pesticides sur l'environnement du bassin de Sebou ≫, PPES (Projet de l'environnement du Sebou), Secrétariat d'état chargé de l'environnement, (Maroc), (1999), 43p.

Zeraouli, M. : ≪ Pollution par les nitrates. Premiers résultats de la situation actuelle dans la nappe des Mnasra (décembre 1992-janvier 1993) ≫, Office régional de mise en valeur agricole du Gharb, Département de développement agricole, Service des études de développement agricole, Bureau Agro-Pédologique, Publication interne ORMVAG, septembre, (1993).

Zilliox, L., Schenc, C., Kobus, H. et Huwe, B. : ≪ Pollution par les nitrates: Quels remèdes? Supplément ≫, La Recherche Suppl. les enjeux de l'agriculture en Europe, 227 (1990), pp. 18–21.

Zouhri, L. 2000: "Structure et modélisation hydro dynamique del'aquifère de la Maamora (Maroc)". Thèse, Univ, Lille I, (2000), 218p.