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Final Project report

Implementation partnership agreement N. 4500115241

between

The United Educational, Scientific and Cultural Organization

and

University Ca' Foscari Venezia

Cooperation on the study of the Nador Lagoon (Morocco)

After Amendment N.1 signed on February 3, 2012

Index

Introduction

The importance of coastal aquifer to sustain ecosystems functionality and human needs is widely recognized. In particular, urban and coastal areas in arid and semi-arid climates mainly rely on groundwater resources. The continuous groundwater withdrawal often causes an alteration of the natural quality of the aquifers, with severe effects on ecosystems and human health. In addition, the rapid growth of urban population occurring in coastal areas exerts a strong pressure on the environment, since the increase in industrial and agricultural activities is accompanied by the release of by-products and wastes in the natural system. For this reason it is of paramount importance, on the one hand to identify and discriminate pollution sources and on the other to define adequate criteria to support correct water management practices.

In the framework of the Strategic Partnership for Mediterranean Sea Large Marine Ecosystem, UNESCO-IHP sub-component (Management of Coastal Aquifer and Groundwater), the present work stressed the role of groundwater in sustaining coastal lagoons and wetlands, including their habitats and ecosystems, in both the general case of the Mediterranean shores, and the specific case study of the Bou-Areg plain (Nador, Morocco).

During three sampling campaigns (Nov 09, Jun 10 and Nov 10) groundwater from private wells in the Bou-Areg aquifer (Morocco, **Figure 1 and 2**), surface waters of river (*oued* Selouane) and irrigation channel, spring and lagoon water samples have been collected in order to identify the main hydrogeochemical characteristic of the studied area, to evaluate the effects of human activities and the seasonality effects.

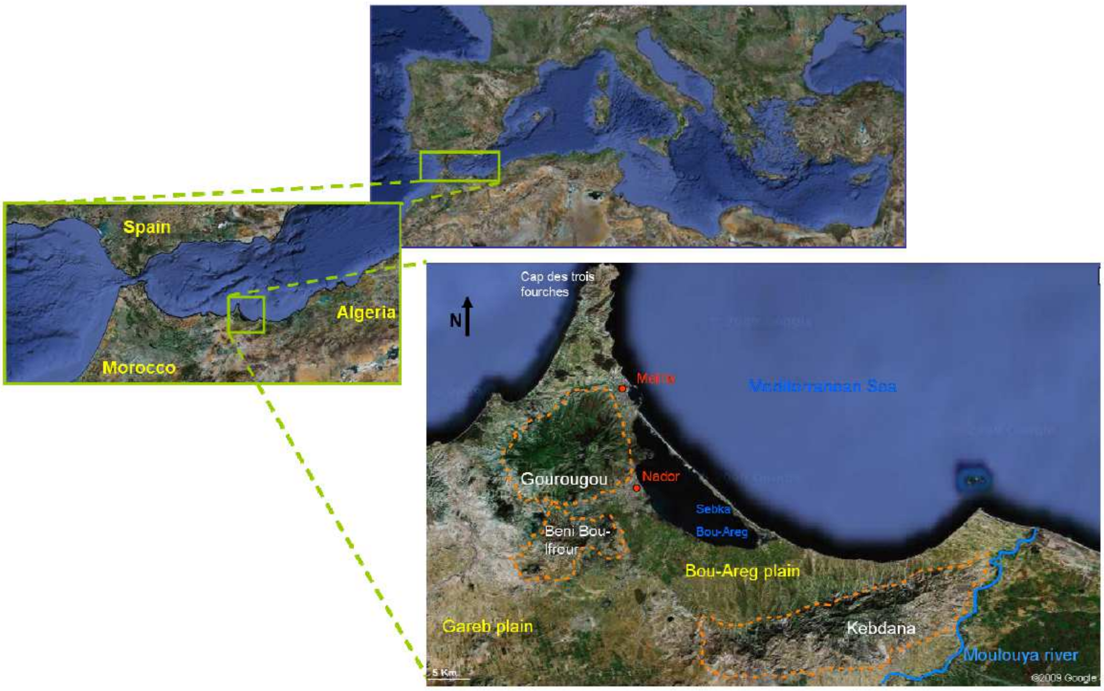

Figure 1. Location of the lagoon of Nador (coordinates 35° 9'14.48"N, 2°51'4.19"O) and the Bou-Areg plain (Modif. Google Earth).

Figure 2. Details of Bou-Areg plain and the lagoon of Nador (Photos Re V.).

Based on the research outlines agreed with UNESCO-IHP, the main steps of the investigation can be summarized as:

i. Assessment of the natural groundwater quality, as baseline criteria are fundamental references to quantitatively and qualitatively gauge whether anomalous concentrations are natural or anthropogenic contamination is occurring.

ii. Evaluation and quantification of deviations from the natural conditions: i.e. evaluation of pollution sources and trends, and identification of occurrence of saline water encroachment in the aquifer.

iii. Assessment and quantification of aquifer/lagoon interactions, evaluation of groundwater quality discharging in the lagoon, and identification of the possible occurrence of Submarine Groundwater Discharge.

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Methods

Major and trace element geochemistry was applied to groundwater samples collected in different period of the year, and analysis of some environmental isotopes was performed in order to investigate the sources of pollution affecting groundwater quality.

Conservative tracers, which remain unchanged in content over short timescale, or for which a change in composition indicates a new input source of groundwater (e.g. Cl, Br, $\delta^{18}O$, $\delta\ ^{2}H$), were used to track contributions from the atmosphere, land surface and soils to the groundwater. Reactive tracers, on the other hand, include cations deriving from weathering and other reactions along flow lines (e.g. B, Li, Sr, Si) and isotopes like $\delta^{13}C$. Those tracers were applied to study water-rock interaction processes.

As literature accounts for an increase of nitrogen concentration in groundwater, mainly associated to human activities, it appeared fundamental to discriminate the contribution of different loads in drainage waters. The basis for the identification of NO_3^- is the use of natural abundance of $^{15}N_{\_NO3}$. The $\delta^{18}O$ composition of nitrate added more information allowing for a clear distinction between synthetic and natural fertilizers. Moreover, the analysis of nitrogen isotope pattern was used to highlight the occurrence of contamination by septic effluents apart from agricultural sources. In addition, the use of ^{13}C in DIC (Dissolved Inorganic Carbon) was analyzed to trace carbon sources in groundwater.

A total of 94 water samples were collected during three surveys between November 2009 and November 2010 (Figure 3). Samplings were carried out in fall and spring over two years, in order to have information about the seasonal effect and possible local recharge in the area.

The results of each campaign have been reported to UNESCO-IHP after each campaign, as summarized in Table 1 and 2.

Based on UNESCO-IHP request to deepen the isotopic investigation on the studied area a fourth campaign was performed in June 2011 (Figure 3.D) and was object of the amendment N.1 signed in February 2011.

In agreement with the results of the previous campaigns, the PhD thesis of Dr. Viviana Re (http://dspace.unive.it/handle/10579/1059?mode=full) and UNESCO-IHP request, the work plan of the last campaign was designed in order to achieve the following **objectives**:

- deepen the analysis on human induced pollution
- support evidences of strong seasonal variations and high vulnerability to human pressures of the studied area;
- maintain the consolidated monitoring network and improve the description of freshwater loads to the aquifer;
- extend the scientific outcomes to support the implementation of IWRM in the area;

The field work of the campaign involved collection of water samples from wells (32), Oued Selouane (3), artificial irrigation channel (1) and Nador Lagoon (2), as indicated in figure 3.C.

According to the amendment, the following analysis were performed on selected samples

- $\delta^{15}N$ and $\delta^{18}O$ of dissolved nitrates on 6 samples
- $\delta^{18}O$ and δD on 15 samples
- $\delta^{11}B$ on 6 samples
- General chemistry analysis on 15 samples, not included in the amendment was co-financed by Ca' Foscari University (Dept. of Molecular Sciences and Nanisystem) as fundamental for the choice of the samples on which performing the isotopic analysis.

In situ measurement data were presented in the June 2011 Report.

The new analytical results are shown in the ANNEX 1

Results will be studied to support the theories proposed based on previous results and to better discriminate pollution sources and water origin.

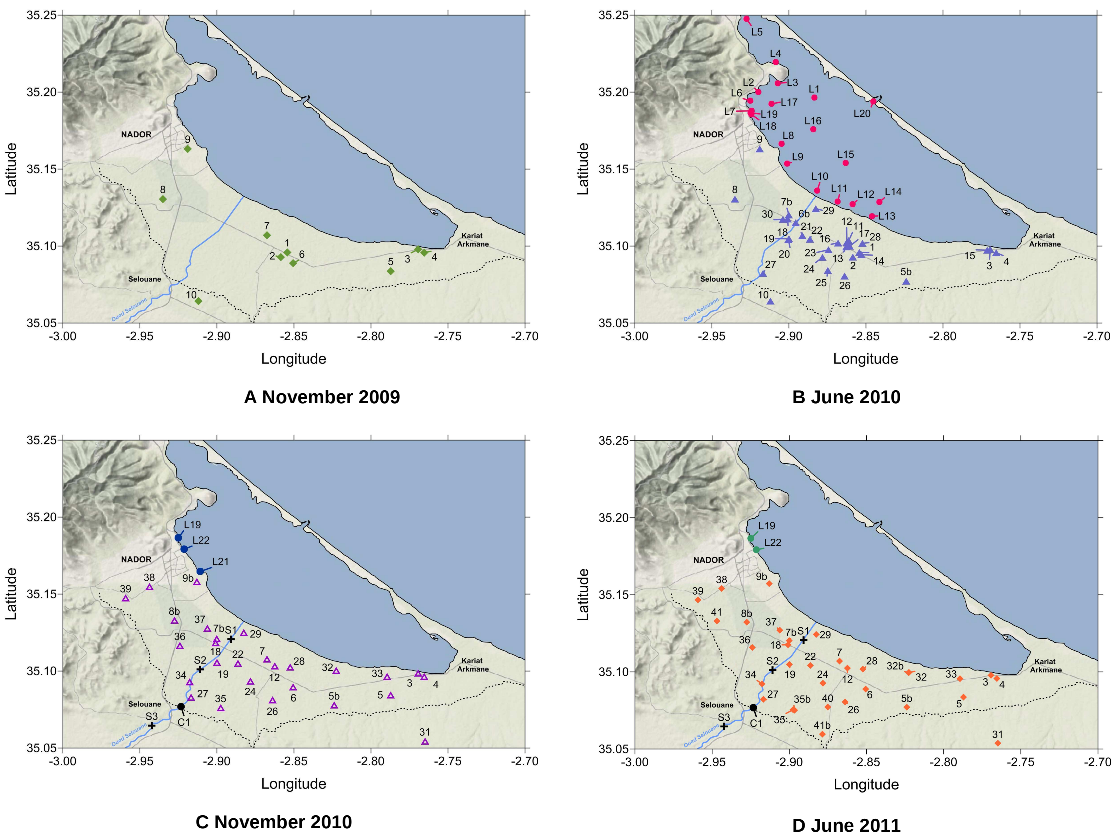

Figure 3. Location of the sampling points of wells. (A) November 2009, (B) June 2010, (C) November 2010. Dotted line represent the irrigation channel, as well as the limit of the coastal plain.

MISSION NAME	Date	Participants	Activity
Preliminary mission	14 November-6 December 2009	**Dr. Viviana Re** (University of Venice. Italy) **Prof. Najib ElHamouti** (Faculté pluridisciplinaire of Nador. Morocco) **Mr. Rachid Bouchnan,** (Faculté pluridisciplinaire of Nador. Morocco)	Networking Collection of groundwater sampling and definition of the future plans
Spring Mission	30 May-12 June 2010	**Dr. Viviana Re** (University of Venice. Italy) **Prof. Najib El Hamouti** (Faculté pluridisciplinaire of Nador. Morocco) **Mr. Rachid Bouchnan,** (Faculté pluridisciplinaire of Nador. Morocco)	Collection of groundwater samples , lagoon water samples and spring water samples
Fall mission	23- 30 November2010	**Dr. Viviana Re** (University of Venice. Italy) **Prof. El Amrani Namira** (University of Settat. Morocco) **Dr. Tomas Lovato** (University of Venice. Italy)	Collection of groundwater samples , lagoon water samples, spring water samples, river water samples and irrigation channel water samples.
Spring Mission 2	19- 26 June 2011	**Dr. Viviana Re** (University of Venice. Italy) **Dr. Tomas Lovato** (CMCC. Italy) **Prof. Elisa Sacchi** (University of Pavia, Italy)	Collection of groundwater samples , lagoon water samples, spring water samples, river water samples and irrigation channel water samples.

Table 1. Summary of the mission and associated activities performed in the framework of the implementation agreement.

Deliverables	File Name
Preliminary mission (Report: February 26, 2010)	00_NADOR_preliminary report_FEB2010.pdf
Spring Mission (Report: June26, 2010)	01_Report_Spring_Mission_2010_Nador_UNIVE.pdf
Fall mission (Report: December 20,2010)	02_Report_Fall_Mission_2010_NADOR-1.pdf
Final Report (Report: September 28,2011)	03_Final Report_signed.pdf
Spring Mission 2 (Report: February 27, 2012)	Report June 2011 Mission Nador.pdf

Table 2. Summary of the deliverables presented to UNESCO-IHP

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Results

The results obtained in the framework of the implementation agreement have been the object of a PhD thesis, several conferences presentations and will be soon published in international peer reviewed journals.

PhD thesis
V. Re (2011). Groundwater pollution in urban coastal areas: hydrogeochemical based approach for managing transition areas. The case of Nador (Morocco). University Ca' Foscari Venice. PhD Programme in Analysis and Governance of Sustainable Development Ca' Foscari University of Venice, IUAV University in Venice, and School for Advanced Studies in Venice Foundation 23rd cycle A.A. 2007/2008- A.A. 2009/2010 Tutor: Prof. G.M: Zuppi Co-Tutors: Dr. A. Aureli and Dr. A. Merla Dissertation held in Venice (Italy) on March, 25th 2011
Conference Presentations
Carrubba S., Martin-Bordes J.L. Re V. (2011). Vulnerability of coastal aquifers and groundwater quality: Ghar El Melh (Tunisia) and Bou-Areg (Morocco). Tenth conference on the Mediterranean Coastal Environment, MEDCOAST 11. Rhodes (Greece) 25-29 October 2011.
Re V. and Zuppi G.M. (2010). Groundwater salinization and climate change in arid zones. Hydrogeochemical study of the Bou Areg plain (North Morocco). International Workshop: Methods for the study of long-term groundwater dynamics. Tozeur, Tunisia, November 1-5, 2010
Re V., El Hamouti N., Bouchnan R., Zuppi G.M. (2010). Water quality in the Bou Areg plain and the Lagoon of Nador (Morocco): The land use connection and groundwater pollution. International Associations of hydrogeologists, XXXVIII IAH Congress Groundwater Quality and Sustainability. Krakow, September 12-17, 2010.
Re V. and Zuppi G.M. (2010). Submarine Groundwater Discharge and surface Water Quality on the Nador lagoon (Morocco): The land use connection and groundwater pollution. 2nd International conference Integrated water resources Management and challenges of the sustainable development. Agadir March 24, 25 & 26, 2010.
Poster Presentations
Re V., Sacchi E., El Amrani N., Martin-Bordes J.L., Aureli A., Zuppi G.M. (2011). Groundwater in urban coastal areas: hydrogeochemical based approach for managing the Bou-Areg aquifer (North Morocco). World Water Week, Stockholm, 21-28 August 2011.
Re V., Allais E., El Hamouti N., Bouchnan R., Sacchi E., Rizzo F., Zuppi G.M (2011). Natural tracers and isotope techniques to definer groundwater recharge and salinization in the Bou Areg coastal aquifer (North Morocco). International Symposium on Isotopes in Hydrology, Marine Ecosystems, and Climate Change Studies. Monaco, 27 March–1 April 2011.

Conclusions and future perspectives

Coastal aquifers often represent an important source of renewable freshwater exploited to sustain human activities worldwide. Those areas are also among the most inhabited zones, especially in arid and semi-arid regions, hence greatly exposed to all the negative externalities associated to human activities (e.g. excessive abstraction and contaminant loads). Preserving natural groundwater quality is of paramount importance, especially in zones where renewable resources are unevenly distributed, or scarce, and average rainfall is low, as in the case of southern rim countries in the Mediterranean Basin.

These issues were addressed in the framework of the implementation agreement and the associated amendment, by applying hydrogeochemical tools to support groundwater management practices. The understanding of the hydrogeochemical characteristics of the Bou-Areg coastal aquifer and its interactions with the lagoon is aimed to serve as a basis for future local management practices in the region of Nador.
As mitigation and remediation policies addressed to the reduction of salt concentrations in the aquifers have to be based on a robust knowledge on the mineralization causes, the priorities of the investigation were to identify salinity origin and clearly assess pollution sources.

The research also highlighted the importance of including aquifer systems in coastal zones management plans, due to their fundamental role in controlling environmental processes. On the other hand, due to their high vulnerability, special attention should be paid in preserving them from human impacts or in improving their characteristics, if the natural quality has been already altered.
As a part of the UNESCO-IHP sub component of the Strategic Partnership for the Mediterranean Large Marine Ecosystem, the overall objective of the research activity were to translate scientific findings into objective criteria for developing sustainable coastal zone management policies in coastal district of Nador and, on a broader perspective, to serve as example along the Southern Mediterranean shore.

Geochemical analysis was applied to describe the main processes occurring in the Bou-Areg coastal plain and its interactions with the lagoon of Nador.
Results allow for the identification of two different kinds of groundwater:

- deeper freshwater, with relatively good quality, mainly found in the south-eastern part of the aquifer, and
- groundwater located in the central part of the aquifer, mostly affected by agricultural pollution (Figure 4).

Hydrochemical results confirm that the general high salinity of the Bou-Areg aquifer is due to the coexistence of water-rock interaction processes, as dissolution of evaporative rocks and carbonates, and agricultural return flow. The latter also represents one of the causes of the general increase in nitrate concentrations. Results also show that the aquifer layer fairly recovers its quality during the non-irrigation season.

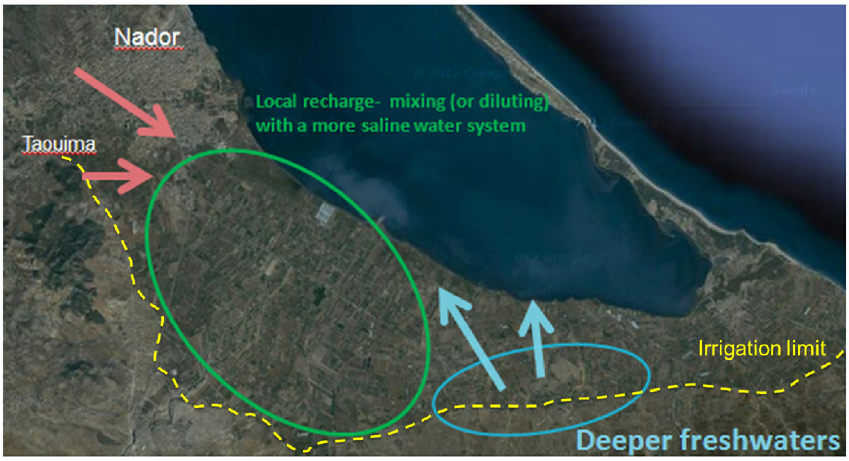

Figure 4. Schematic representation of mixing processes in the Bou-Areg coastal plain Re, 2011).

Results show that in most of the wells nitrate concentration exceeds WHO drinking limits (e.g.50 mg/L; Figure 5). To discriminate among different pollution sources, fundamental step to preserve the system to further contamination and reduce possible impacts on human health, the isotopic composition of dissolved nitrates was studied, allowing to identify the following anthropogenic drivers:

- manure and septic effluents, especially in the urban areas and in the central part of the plain where houses are not adequately equipped with sanitation systems,
- synthetic fertilizers in the agricultural zone.

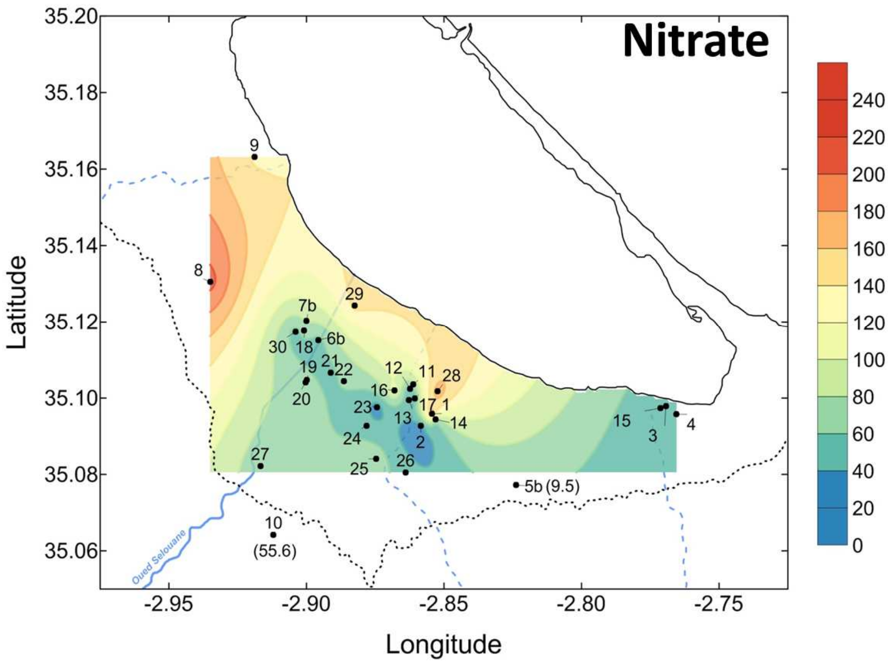

Figure 5. Spatial distribution of Nitrate (NO3-) from June 2010 campaign (Re, 2011).

The sum of the abovementioned pressures and the effects of agricultural return flows are acting in a synergic way and contemporaneously affecting the aquifer quality. Adequate policies should indeed focus on both urban and agricultural pollution in the region, in order to prevent the natural system from further contamination and protect human wellbeing in the Nador district. Consequently, the non-drinkability and non-adequateness of groundwater for irrigational practices should be better highlighted at local level also to reduce the potential risks for human health.

As a major threat of the system, the agricultural return flow has significantly modified the chemistry of the system and it is a prime example of the human induced changes over coastal environments.

Management plans for the preservation of the aquifer and the reduction of anthropogenic impacts on the lagoon should promote the reduction of groundwater use for agricultural practices and the consequent increase in the use of the waters distributed by the irrigation channel. Vulnerability mapping would be a useful tool to support decision processes and management plans in the region.

The hydrogeochemical investigation allowed to consider the saline water intrusion from the lagoon in the shallow aquifer to be negligible, while discharge of polluted groundwater into the lagoon has been found to partially alter its quality. As many springs are present in the lagoon shore, further studies should be extended also to the evaluation and quantification of Submarine Groundwater Discharge (SGD) in order to better assess the impact of the aquifer to the lagoon. In fact, the decline of direct pollution loads into aquifer will produce an improvement in the quality of the general environment, which is a relevant prerequisite considering the future development planned for the area, foreseeing the construction of tourism facilities and recreational sites.

All the scientific findings of this work enclose important management implications for the future development of groundwater resources in the Bou-Areg plain. A management priority should be represented by the reduction of groundwater extraction and synthetic fertilizers employment for farming practices, since the agricultural return flow was shown to have severe impacts on the general quality of the system. A strategic alternative is instead represented by the alternate exploitation of the water distributed through the artificial channel with the treated (and purified from bacteria) one coming from the STEP (wastewater treatment plant). The latter solution would allow employing irrigation water characterized by a controlled nutrients concentration and composition, with the consequent decrease of synthetic components discharge into the system. Obviously, this option will involve the periodic control of the water quality across the plain to avoid the possible drawbacks (e.g. the increase of dissolved nitrates concentration). Besides the remediation actions at the regional level (catchment), the complex pressures exerted by different pollution sources (punctual and diffused) highlight the need to enforce adequate groundwater protection trough specific, local actions at the single well level. To this regard communication plans should promote the awareness of households and farmers, as well as, the public participation within the management process.

Future investigations should engage a direct confrontation with wells holders and local farmers associations to better address the study (ensure possibility of seasonality studies given the permission to include the selected wells in the sampling network), and to retrieve reliable information about the amount and nature of fertilizers and other substances spread on the soil or poured into the wells.

Venice, June 26, 2012

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Bou Areg Aquifer

Station	Class	Depth	EC	T	pH	Eh	HCO3-	CO3--	Cl-	NO3-	SO4--	Na+	K+	Ca++	Mg++	NO2	NH4	Li	Br	F	PO4	d18O	d2H	d15N	d18O NO3
#	-	m	mS/cm	℃	-	mV																			
3	EW	5,23	8,05	23,50	7,5	203																			
4	HDW	4,68	10,35	21,60	7,6	193	407,6	0,0	3143,5	34,0	1024,8	1930,0	33,1	215,4	225,6	< 0,005	0,44	< 0,005	7,28	0,96	< 0,01	-5,12	-34,27		
5	HDW	30,17	3,84	23,30	8,0	184																			
6	HDW	12,80	5,50	20,60	7,5	168																			
7	HDW	4,10	5,65	21,10	7,1	190																			
5b	HDW	28,10	1,72	21,50	7,7	200	310,0	6,5	162,3	9,2	390,7	313,0	16,0	38,0	31,9	< 0,005	0,09	< 0,005	0,47	0,64	< 0,01	-5,60	-37,94		
7b	HDW	3,50	8,77	21,30	7,4	187	414,9	0,0	2579,9	90,8	658,2	1410,0	78,7	257,5	243,2	< 0,005	0,33	< 0,005	4,95	0,31	< 0,01	-5,00	-33,06		
8b	HDW	3,55	5,75	29,90	7,6	190																			
9b	HDW	1,95	5,55	22,90	7,6	187																			
12	HDW	5,20	4,90	21	7,2	130	546,7	3,8	876,9	30,2	1141,9	706,0	48,6	173,1	189,1	< 0,005	0,20	0,20	1,73	1,03	< 0,01	-5,00	-34,38		
18	HDW	3,90	6,76	21	7,5	182																			
19	EW	5,56	6,88	22	7,6	243	405,2	0,0	1890,0	60,5	605,4	1193,0	54,7	120,2	144,0	< 0,005	0,37	< 0,005	4,26	< 0,005	< 0,01	-5,15	-34,04		
22	EW	3,68	5,43	22	7,8	196																			
24	HDW	8,74	4,54	22	7,6	201																			
26	HDW	16,90	2,59	22	7,6	208	524,8	0,0	371,2	36,7	366,5	488,0	17,6	43,9	44,9	0,32	0,20	0,20	0,59	1,25	< 0,01	-5,17	-35,72		
27	HDW	7,20	8,21	23	7,0	213																			
28	HDW	5,28	5,00	21	7,8	158																			
29	HDW	2,55	7,11	30	7,3	230																			
31	Epump	156,00	6,66	22	7,3	184	289,2	0,0	2076,5	17,8	391,6	1280,0	20,8	155,5	115,8	< 0,005	< 0,005	< 0,005	5,30	0,57	< 0,01	-4,88	-29,57		
32	HDW	6,28	9,37	22	8,1	220																			
33	EW	13,28	6,15	23	8,0	142																			
34	HDW	3,65	7,94	22	7,4	210																			
35	HDW	7,00	5,98	22	7,3	206																			
36	HDW	8,50	5,20	23	7,7	190																			
37	HDW	2,10	8,59	22	7,2	203																			
38	HDW	5,84	3,48	24	7,3	221																			
39	EW	9,55	4,60	23	7,4	220																			
40	EW	12,80	3,26	22	7,6	224	371,0	9,6	433,7	27,6	399,7	533,0	9,1	75,1	63,8	0,25	< 0,005	< 0,005	1,32	0,68	< 0,01	-5,38	-34,99	5,90	10,90
41	HDW	16,60	2,65	23	7,4	735	300,2	0,0	612,7	16,1	551,6	451,0	23,1	163,3	83,5	< 0,005	< 0,005	< 0,005	1,26	0,81	< 0,01	-5,77	-38,13	6,90	5,57
41b	Epump	11,50	1,85	22	7,6	191	185,5	0,0	317,8	15,0	316,3	212,0	6,3	99,4	60,6	< 0,005	0,08	< 0,005	< 0,005	0,46	< 0,01	-5,47	-36,61	6,05	12,02
32b	HDW	6,30	11,9	22	7,4	118	358,8	0,0	4215,5	34,5	695,7	1826,0	38,1	360,9	374,6	< 0,005	0,37	< 0,005	8,32	< 0,005	< 0,01	-6,21	-41,39		
35b	HDW	8,37	7,68	22	7,2	212																			

Sufrace water

Station	Class		EC	T	pH	Eh	HCO3-	CO3--	Cl-	NO3-	SO4--	Na+	K+	Ca++	Mg++	NO2	NH4	Li	Br	F	PO4	d18O	d2H	d15N	d18O NO3
#	-	m	mS/cm	℃	-	mV																			
S1	River	-	10,26	26	8,3	183	307,5	0,0	3141,7	29,7	795,7	1744,0	23,0	313,6	239,8	< 0,005	0,50	< 0,005	3,91	< 0,005	< 0,01	-5,21	-33,29	14,67	11,55
S2	River	-	10,28	29	8,3	193	302,7	0,7	3297,4	34,6	903,0	1748,0	22,3	342,5	237,6	< 0,005	0,51	< 0,005	5,02	< 0,005	< 0,01	-5,06	-33,50	14,63	11,74
S3	River	-	10,53	27	7,8	121	292,9	0,0	3402,4	30,8	903,9	1800,0	16,9	326,1	243,2	< 0,005	0,38	< 0,005	4,72	< 0,005	< 0,01	-5,11	-33,67	15,02	8,74
C1	Channel	-	1,30	28	8,2	202	142,5	0,0	146,4	1,3	376,6	96,6	4,3	145,5	44,7	0,19	0,03	< 0,005	< 0,01	0,21	< 0,01	-5,81	-37,76	7,42	16,15

Lagon water

Station	Class		EC	T	pH	Eh
#	-	m	mS/cm	℃	-	mV
L19	Lagoon	0	13	25	7	233
L22	Lagoon	0	55	29	8	174